February 2022

Costing Climate Change Impacts to Public Infrastructure

Assessing the financial impacts of extreme rainfall, extreme heat, and freeze-thaw cycles on public buildings in Ontario

Paper Submitted to the 2022 ICEAA Conference

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Abstract

Climate change is significantly impacting public infrastructure, yet governments lack reliable analytics to incorporate these costs into budgetary decision making. This paper presents a new methodology for incorporating the impacts of three climate hazards into long term public infrastructure cost projections and outlines some key results for public buildings in Ontario. This approach provides a basis upon which to gauge the size of the budgetary impact these climate hazards will cause over time, and a new evidence base with which to compare costs under different adaptation strategies.

Background

In August 2021, the Intergovernmental Panel on Climate Change (IPCC) released its sixth comprehensive scientific assessment, reiterating that "it is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred."[1] Climate change is leading to increasingly costly and disruptive impacts on many aspects of society, with the risks to physical infrastructure considered one of the most likely and consequential.[2]

To ensure safety and reliability, public infrastructure is designed, built, and maintained to withstand a specific range of climate conditions typically based on historic climatic loads. However, many of these climate parameters are changing. As public assets are typically designed to last between 50 and 100 years, public infrastructure faces significant risk from the impacts of climate change that are expected to reduce their lifespan and effectiveness.[3]

Ontario's provincial and municipal governments manage a combined portfolio of public buildings valued at $254 billion.[4] This portfolio includes schools, hospitals, water facilities and administrative buildings, and is among the largest asset portfolios of any physical asset manager in Canada.

Keeping assets in a state of good repair helps to maximize the benefits of public infrastructure in the most cost-effective manner over time. It is also clear that climate change will impact public infrastructure in many ways that will carry significant budgetary consequences for asset managers. To date in Canada, both the federal and Ontario provincial climate plans have set emission targets and acknowledged the importance of funding infrastructure resilience,[5] but neither government has fully assessed the climate risks to public infrastructure or developed comprehensive adaptation plans to address them.[6]

Many assessments of climate impacts to public infrastructure focus on specific assets or conduct case studies examining the resilience of individual assets or asset components.[7] Outside of government, the insurance industry evaluates the costs of natural disasters to privately insured infrastructure, often for singular events.[8] However, there has not yet been a comprehensive assessment of how climate change could add to public infrastructure costs in Ontario. As such, public infrastructure managers don't have reliable analytics to incorporate climate change considerations into budgetary decision making.

In recognition of this knowledge gap, a Member of Provincial Parliament asked the Financial Accountability Office of Ontario (FAO) to analyze the long-term costs that climate change impacts could impose on Ontario's

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[1] Intergovernmental Panel on Climate Change, 2021.

[2] Council of Canadian Academies, 2019, Warren, F. and Lulham, N., editors, 2021, page 12.

[3] Cannon, A.J., Jeong, D.I., Zhang, X., and Zwiers, F.W., 2020.

[4] This is the current replacement value in 2020 dollars. All cost estimates are in 2020 undiscounted real dollars unless otherwise stated.

[5] Climate change adaptation plans and actions, Government of Canada. Government of Ontario, 2018.

[6] Office of the Auditor General of Canada, 2018.

[7] See: The PIEVC protocol.

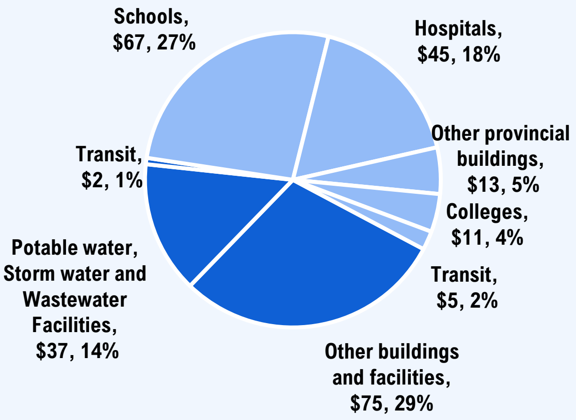
[8] For example, see Insurance Bureau of Canada and The Institute for Catastrophic Loss Reduction.

provincial and municipal infrastructure, and the potential budgetary implications for the Province of Ontario. The FAO is an independent office of the Legislative Assembly of Ontario that provides analysis on the state of the province's finances, trends in the provincial economy and related matters.[9] In response to this request, the FAO launched its Costing Climate Change Impacts to Public Infrastructure project (CIPI) in 2019.

CIPI Project Scope

Figure 1

Ontario's portfolio of public buildings has a Current Replacement Value of $254 billion



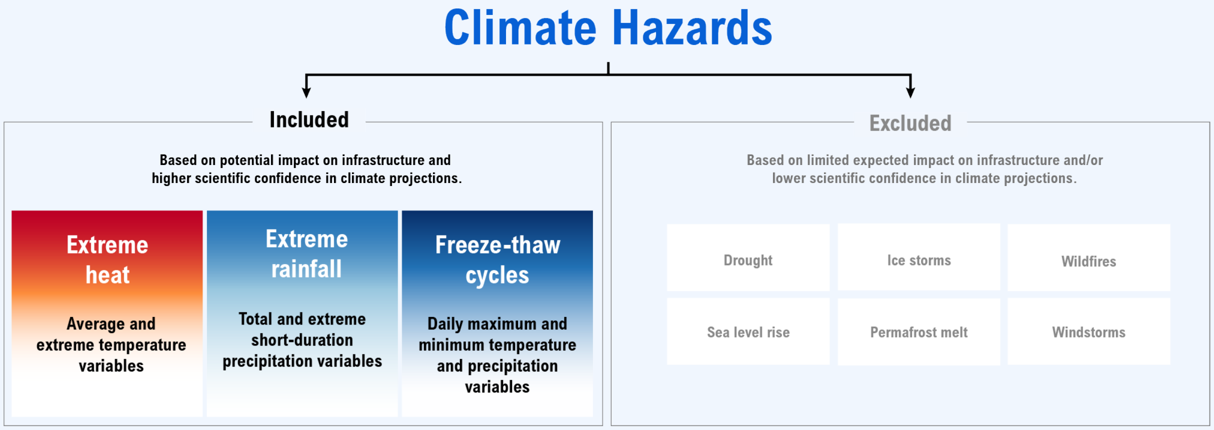
Source: FAO. Note: CRV estimates are in real 2020 billion dollars. Percentage values refer to a sector's share of total CRV.

The purpose of the CIPI project is to estimate the long-term budgetary costs that these climate hazards could impose on the province and municipalities through increased infrastructure costs. In this paper, the FAO focused on costing the impacts of these three hazards on Ontario's combined $254 billion portfolio of public buildings and facilities. This analysis focuses only on the current suite of existing public buildings and does not account for any future growth in this portfolio.[10]

While public infrastructure faces many climate hazards, this project focuses on those that are likely to have the largest budgetary impact and can be projected by climate scientists with a reasonable degree of confidence. These hazards include extreme rainfall, extreme heat and freeze-thaw cycles.[11]

Figure 2

Scope of climate hazards included in CIPI



Source: FAO.

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[9] The office is similar in nature to the US Congressional Budget Office or Canada's Parliamentary Budget Office.

[10] In the future, the FAO will examine the impacts of these climate hazards on transportation and water infrastructure.

[11] See: Financial Accountability Office of Ontario, 2021b for details and rationale on the selection of climate hazards.

Incorporating climate impacts into infrastructure cost projections

Provincial and municipal asset managers (AMs) are tasked with keeping their portfolios of public infrastructure in a state of good repair and are often asked to produce cost projections of doing so. To date in Ontario, these cost projections do not explicitly account for any climate change impacts.

To begin addressing this problem, the FAO produced <u>three</u> different long-term cost projections of maintaining Ontario's portfolio of public buildings and facilities in a state of good repair (SOGR) from now until 2100. A long-term horizon was selected as many public buildings have very long service lives, some over 100 years.

1) The <u>first</u> projection assumed that the climate was stable.[12] This provides a baseline cost of maintaining the current suite of public buildings in a SOGR in the absence of climate considerations.
2) The <u>second</u> type of projection incorporates the impacts of these climate hazards and assumes that AMs do not undertake any adaptation measures to address them. Instead, AMs allow their assets to suffer accelerated infrastructure deterioration and simply pay the higher repair costs and increased operating expenses that result. This asset management strategy is called the "damage cost" strategy.

Comparing long-term infrastructure costs in the baseline and damage cost strategy allows AMs to assess the additional infrastructure costs that these three climate hazards could have over time, and which hazards are the largest contributors.

Since the impacts of climate change over the next 80 years will depend on the future path of global emissions, the FAO also produced multiple "damage cost" scenarios to reflect the possibility of high, medium, and low global emissions futures. These three damage cost scenarios can be compared to each other to assess how the future path of global emissions would impact infrastructure costs in the absence of adaptative action.

However, public buildings can be adapted to withstand the impacts of these climate hazards. Adapting public infrastructure to specific climate hazards could take many forms.[13] In this study, "adaptation costs" are defined as the cost of actions that would prevent the impacts of these three climate hazards and avoid accelerated asset deterioration and additional O&M expenses despite the change in climate variables.

3) The <u>third</u> type projection also incorporates the impacts of these climate hazards but assumes that AMs undertake adaptive measures to address them. These projections include the additional costs of adaptation, and once adapted, assets avoid accelerated deterioration and increased operating expenses associated with these climate hazards.

Various broad adaptation strategies are possible. For example, public buildings could be adapted at the first available opportunity (a "proactive" strategy) or at the end of their service life as part of a full redesign/rebuild (a "reactive" strategy). The FAO projected the life cycle costs of two adaptation strategies, which can be compared with each other or with the damage cost strategy.

Accounting for the impacts of these climate hazards and comparing the projected cost outcomes of strategies to deal with them can assist AMs in determining the most cost-effective course of action for their portfolio over the life cycle of their assets.

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[12] In this report, a "stable climate" means that all climate indicators for extreme rainfall, extreme heat and freeze-thaw cycles remain unchanged from their 1975-2005 average levels over the projection to 2100.

[13] In some cases, it might involve updating infrastructure design parameters to a higher standard. In others, it might mean upgrading certain asset components to accommodate changing climatic conditions. Adaptation could also mean that infrastructure is redesigned or replaced with other options, such as the use of green infrastructure including planting trees, enhancing wetlands or installing green roofs instead of relying on stormwater pipes or ditches to accommodate higher rainfall intensities.

Key Messages

Climate change will have a significant impact on the cost of maintaining public buildings in the absence of adaptive action

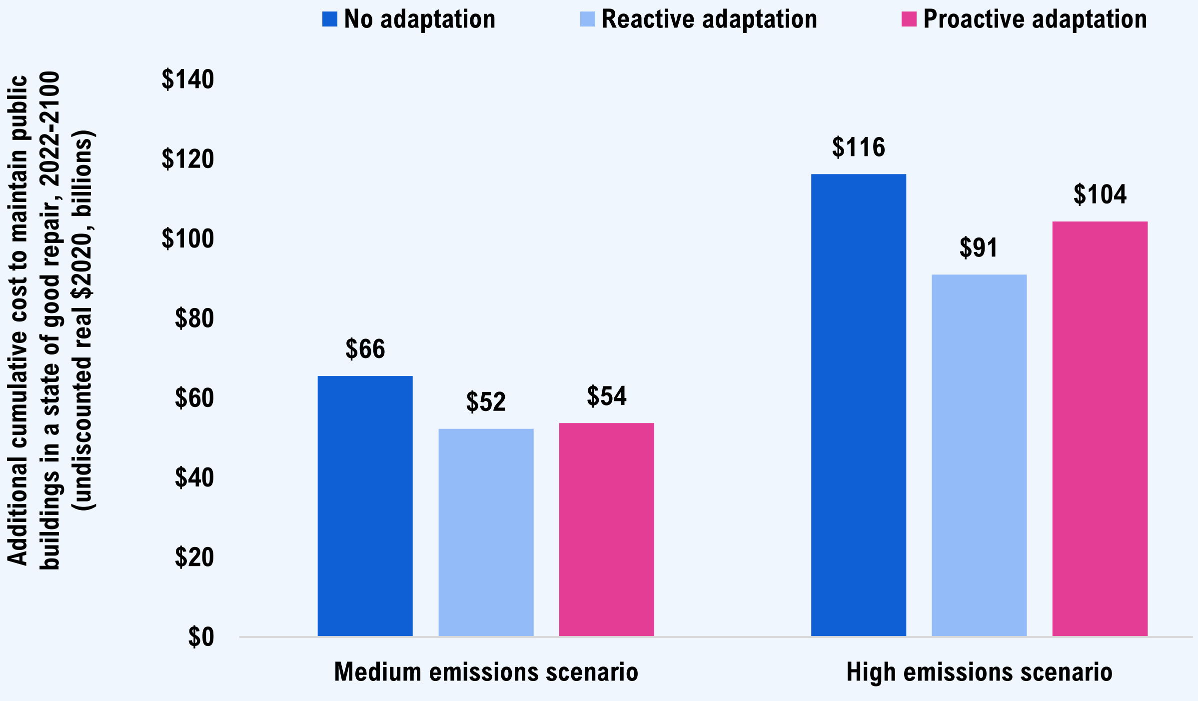
Keeping assets in a state of good repair helps to maximize the benefits of public infrastructure in the most cost-effective manner over time. This requires annual O&M spending, as well as intermittent capital spending either to rehabilitate part(s) of an asset or to fully renew it at the end of its service life. Changing climate hazards will materially add to these costs in the absence of adaptation. These impacts should be considered as part of broader life cycle cost projections.

Implementing broad adaptation strategies will save AMs money in the long term

Long term infrastructure costs can be lowered by adapting public buildings to avoid the impacts of these climate hazards. In the FAO's study of public buildings in Ontario, adaptation strategies resulted in lower total infrastructure costs to government over the long term than the *no adaptation* (damage cost) strategy.[14]

Figure 3

The long-term cumulative costs of maintaining Ontario's public buildings are modestly lower when adaptation actions are taken



Source: FAO. Note: The costs presented in this chart are in addition to the baseline costs over the same period.

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[14] On a discounted basis, the *reactive adaptation* strategy remains the lowest cost strategy at discount rates below 4.5 to 5.5 per cent depending on the emissions scenario. See: Financial Accountability Office of Ontario, 2021c, appendix D for details.

The extent of global climate change in the future will influence the severity of climate hazards and the costs they impose on public infrastructure budgets

Over the long term, the extent of global climate change will influence the severity of these climate hazards and their impacts to public buildings. Additional infrastructure costs in a medium emissions scenario[15] are lower than those in a high emissions scenario.[16] But the future trajectory of global emissions remains uncertain, resulting in a range of possible changes to these climate hazards farther in the future. This raises the difficult question of how projected changes in key climate hazards should be accounted for when public buildings are designed, built or retrofitted.

The comparative benefits of adaptation would be more significant if societal costs were incorporated

This study only includes a narrow range of financial costs directly related to maintaining public buildings and facilities in a state of good repair. As public infrastructure provides vital services, including transportation, health and flood protection, any service interruption can have significant social and economic consequences. The societal costs associated with planned or unplanned service disruptions were beyond the scope of this report but would be significant in the absence of adaptation (i.e. in the damage cost strategy). The comparative benefits of adaptation would be more significant if these societal costs were incorporated.

This portfolio-level analysis could be refined to analyze specific assets

The project also does not assess the climate resiliency of specific assets, but instead approaches the issue at an asset class level. As such, the portfolio level costing results in this report are not intended to inform asset-specific management decisions. Determining the most cost-effective strategy for an individual asset would require comparing the costs of different asset management strategies over its service life, for a broader range of climate hazards and societal costs, and with the asset's specific circumstances taken into consideration.

While the concept of quantifying these impacts and estimating their financial liabilities for asset owners is relatively new, this methodology could support capital funding decisions by governments, and could be refined to examine the climate change cost implications for specific assets.

A new methodology for costing climate impacts to public infrastructure

The baseline cost projection

Infrastructure assets require ongoing capital and operating spending. Capital spending for existing infrastructure includes money spent on repairing assets through either rehabilitation[17] or renewal,[18] and occurs less frequently

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[15] A scenario where global emissions peak in the 2040s, then decline thereafter. The global mean temperature is projected to increase by 2.3°C (median estimate, with a range of 1.7 to 3.2°C) by 2100 relative to 1850-1900. This corresponds to the Intergovernmental Panel on Climate Change's (IPCC) RCP4.5 scenario in its Fifth Assessment Synthesis Report.

[16] A scenario that assumes global emissions continue to grow for most of the century. Global mean temperatures are projected to increase by 4.2°C (median estimate with a range of 3.2 to 5.4°C) relative to 1850-1900. This corresponds to the IPCC's RCP8.5 scenario in AR5. Cumulative global emissions from 2005 to 2020 most closely match the high emissions scenario. Not shown in the chart are the results for the low emissions scenario, which assumes that global emissions peak in the early 2020s and decline to zero by the 2080s, and that by the end of the century, global mean temperatures are held to a 1.6°C (0.8 to 2.4°C) increase by 2100 relative to 1850-1900.

[17] Rehabilitation is the repair of all or part of an asset, extending its life beyond that of the original asset, without adding to its capacity, functionality, or performance. Rehabilitation is different from maintenance, which is the routine activities performed on an asset that maximize service life and minimize service disruptions. Assets are rehabilitated to a state of good repair (the repair target) and not to a new condition.

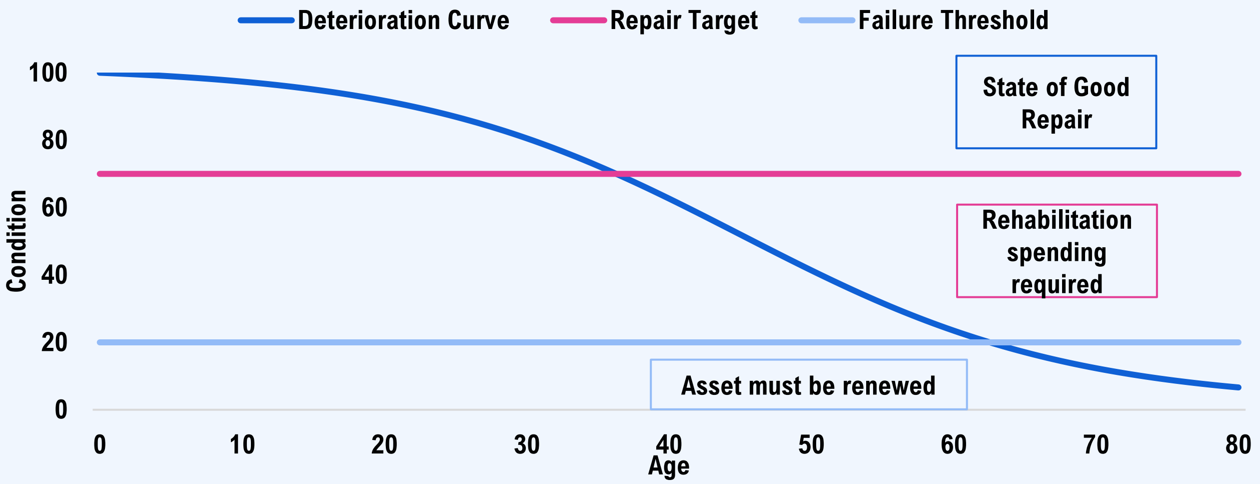
[18] Renewal is the replacement of an existing asset, resulting in a new or as-new asset with an equivalent capacity, functionality, and performance as the original asset. Renewal is different from rehabilitation, as renewal rebuilds the entire asset.

than operating costs, which take place annually and include operations and maintenance (O&M) expenses. Both costs are necessary to maintain infrastructure in a state of good repair, helping to ensure assets are delivering their intended services in a condition that is considered acceptable from both an engineering and a cost-management perspective.

To project the required capital and operating expenses to maintain Ontario's public buildings in a SOGR to 2100 (in the absence of climate change considerations), the FAO used an infrastructure deterioration model[19] in combination with provincial and municipal infrastructure datasets.[20]

Figure 4

Infrastructure deterioration modelling framework



Source: FAO.

The model consists of asset deterioration curves for major public infrastructure asset classes that were developed by the Ontario Ministry of Infrastructure and capital portfolio ministries. These curves describe how the physical condition of infrastructure (represented by a condition index)[21] declines over time and are specific to each asset class. This approach is standard practice in asset management and often forms the basis for maintenance and rehabilitation decision-making.

The model determines annual capital and operating expenses by plotting individual assets on the curve based on their age or condition. Assets deteriorate as they age and move down their respective deterioration curves. As they do, the model evaluates each asset annually against certain performance standards.[22] These performance standards determine what, if any, type of capital spending is required and include:

- Repair targets are the condition which, at or above, an asset is in a SOGR and does not require any current capital spending.

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[19] The FAO model is based on techniques developed by the Ontario Ministry of Infrastructure.

[20] Asset data for provincial infrastructure were gathered from engineering-based asset-level assessments and high-level asset information provided by various ministries of the Ontario government. Asset data for municipal infrastructure were gathered from municipal asset datasets, asset management plans (AMPs), Canada's Core Infrastructure Survey (CCPI) 2018, the Financial Information Return 2018, and the Ministry of Infrastructure Municipal Asset Inventory. For a description of provincial and municipal infrastructure data as well as data sources, see the appendices of Financial Accountability Office of Ontario, 2020, and Financial Accountability Office of Ontario, 2021a.

[21] The condition of buildings is measured by a "facilities condition index", measured as the cost to bring the building into new condition as a share of its replacement value.

[22] These performance standards were largely provided to the FAO by the Ontario Ministry of Infrastructure.

- Failure thresholds are defined as the condition at which assets are beyond rehabilitation and should be replaced.
- Design Service Life (DSL) is the number of years an asset was designed to operate. However, assets typically exceed their design life. The FAO defines an asset's Useful Service Life (USL) as twice its DSL, which assets achieve if rehabilitated in a timely manner.

The model determines these capital and operating expenses based on the individual characteristics of each particular asset. A new asset in very good condition requires less capital spending over the coming decades compared to an older asset in a poor state of repair. Similarly, one asset-type may have higher performance standards than another. Operating expenses also vary based on asset-type. Using these performance standards, the model evaluates the capital and operating expenses required to maintain the portfolio in a SOGR annually.

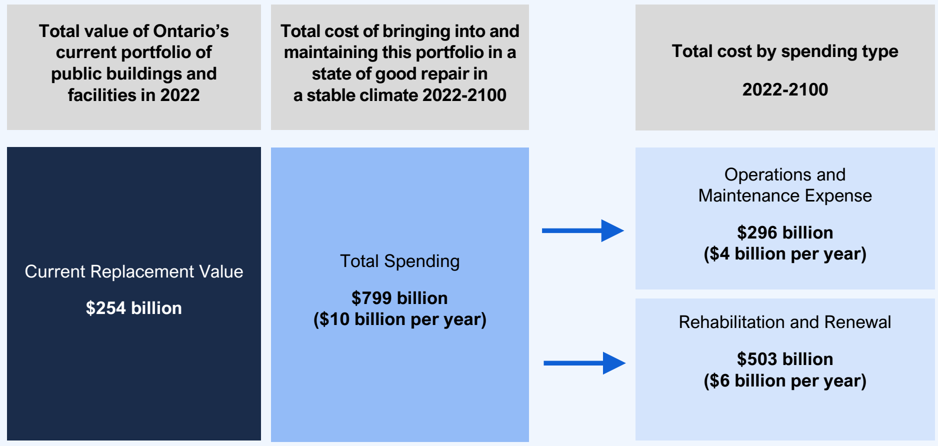
While the model replicates decisions made by asset managers within this simple framework, it was designed principally as a financial model to estimate the costs of infrastructure and is not intended to replicate or predict specific engineering interventions that asset managers make.[23]

Projecting the costs required to bring and maintain public infrastructure into a state of good repair over the long term, and in the absence of climate change considerations, forms the base case against which scenarios that include the impact of climate hazards are compared. In this way, the costs associated with climate change are distinguished from the costs associated with addressing the current and future infrastructure backlog.[24]

Using this methodology, the FAO estimates that the cost of maintaining Ontario's $254 billion portfolio of public buildings and facilities in a state of good repair would be around $10.1 billion[25] per year on average, totalling about **$799 billion** over the rest of the 21st century (2022-2100).[26] These projected "baseline costs" are what would have occurred in a stable climate.

Figure 5

The cumulative cost of maintaining Ontario's public buildings and facilities in a state of good repair to 2100 in a stable climate



Note: All values presented in real 2020 dollars.

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[23] The model's financial estimates are sensitive to the data and methodology used. For example, asset managers may have different views on what is considered a "state of good repair" for a particular asset class. This makes assumptions necessary while recognizing that the definitions are subject to debate.

[24] The infrastructure backlog is defined as the total costs required to bring the entire portfolio of assets into a state of good repair according to Provincially and municipally defined standards.

[25] All cost estimates are in 2020 undiscounted real dollars unless otherwise stated.

[26] Numbers may not add due to rounding.

Including climate hazards in the infrastructure deterioration model

To ensure safety and reliability, infrastructure is designed, built and maintained to withstand a specific range of climate conditions typically based on historic climatic loads.[27] However, extreme rainfall and extreme heat are projected to increase in the future, while freeze-thaw cycles are projected to decrease.

Extreme rainfall can often exceed the capacity of infrastructure drainage systems and lead to flooding, water infiltration or increased erosion of infrastructure components.[28] Extreme rainfall events can impact buildings as acute hazards that occur rarely (for example the 100-year rainfall event).[29] Extreme rainfall can also cause chronic impacts, such as ongoing moisture or water infiltration. This hazard includes the impacts of pluvial flooding (i.e., overwhelmed drainage systems) but not the impacts of fluvial flooding (i.e., riverine or river flooding).

Extreme heat events are extended spells of high temperatures. As heatwaves increase in frequency and duration, temperatures will more frequently exceed the capacity of infrastructure or its components, increase the stress on building materials, and impact operations and maintenance. Extreme temperatures are both a chronic and an acute hazard. For example, thermal expansion in brick walls during a high-magnitude heat wave is an acute impact, while the accelerated deterioration of air conditioning equipment used more frequently in warmer conditions is a chronic impact.

Freeze-thaw cycles (FTCs) are fluctuations between freezing and non-freezing temperatures that cause water to freeze (and expand) or melt (and contract). The melting and re-freezing of water accelerates the weathering of building materials, and damages infrastructure components that are exposed to the atmosphere. FTC damage is caused by the combination of temperature fluctuations around zero degrees and the presence of water. FTCs can be self reinforcing. When one occurs, it can leave cracks or gaps in building materials, creating the potential for further water infiltration and another cycle of freezing and expansion. “Deep” FTCs typically occur in winter and are defined as those that occur when the daily average temperature is less than 0°C.

The FAO partnered with the Canadian Centre for Climate Services (CCCS) at Environment Canada to acquire projections of key climate indicators for Ontario. To account for uncertainty in climate projections and in line with common practice in climate science, the median (50th percentile) projections of climate variables are presented, followed by ranges in parentheses. For Ontario climate indicators, the ranges indicate the 10th and 90th percentile projections from the ensemble of 24 climate models used by the Canadian Centre for Climate Services.

CCCS projections show that Ontario’s annual mean temperature will have increased by around 1.6°C between 1950 and 2019, faster than the global average rate of warming.[30] This trend reflects faster warming near the earth’s poles in part due to regional climate feedbacks.[31] Also, temperature in Ontario has increased more in winter than in warmer seasons.[32] Over the coming decades, extreme heat and extreme rainfall events are projected to become more frequent and severe, while the shortening winter seasons will somewhat reduce the number of annual freeze-thaw cycles (see Box 1 below for details).

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[27] National Building Code of Canada 2015, Table C-2. 2012 Building Code Compendium: Supplementary Standard SB-1, Ministry of Municipal Affairs.

[28] Extreme rainfall is usually defined as rainfall events with daily or sub-daily duration for a given return period of two to 100 years. For example, 15-min rainfall with 10-year return period and one-day maximum rainfall with 50-year return period are climate design variables listed in the National Building Code of Canada 2015.

[29] The FAO’s modelling approach captures the impacts of both chronic and acute hazards by averaging out extreme events across regions and over long periods of time.

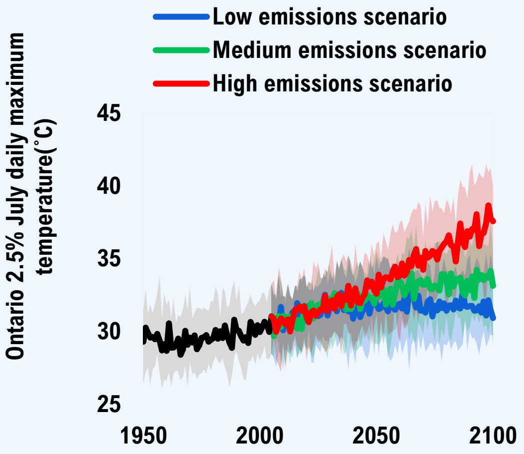
[30] Global mean temperature rose by around 1.1ºC between 1950 and 2019. Intergovernmental Panel on Climate Change, 2021, Figure SPM.1.

[31] Bush, E. and Lemmen, D.S., editors, 2019, Chapter 2.

[32] Ibid, Chapter 4.

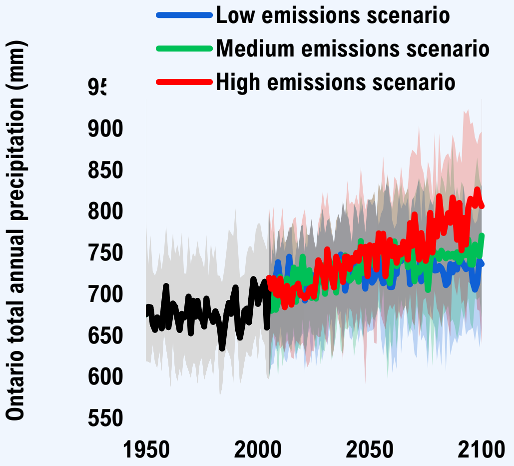
Box 1

Changing climate hazards in Ontario



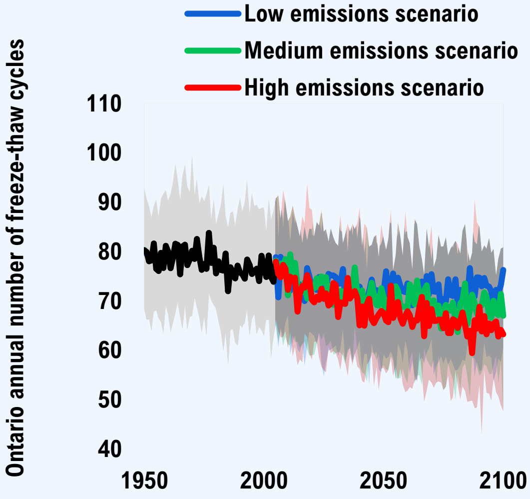
Extreme heat to rise

- Projected changes in Ontario's peak July temperatures differ significantly in the low and high emissions scenarios. Compared to the 1976-2005 average, the base period for this report, Ontario's peak July temperatures are projected to be 1.7°C (1.3 to 2.0°C) higher in the low emissions scenario by the 2030s. By the 2080s, peak July temperatures are projected to increase by 1.9°C (0.9 to 2.8°C) in the low emissions scenario and by 6.5°C (4.3 to 7.6°C) in the high emissions scenario.
- There is high confidence in the projected trends and ranges of temperature variables based on strong scientific evidence in the causes of observed changes.



Extreme rainfall to increase

- Average annual precipitation in Ontario is projected to increase by 6.0 per cent (5.3 to 6.6 per cent) in the low emissions scenario by the 2030s. By the 2080s, average annual precipitation is projected to rise by 7.1 per cent (4.0 to 7.8 per cent) in the low emissions scenario and by 15.0 per cent (6.2 to 18.2 per cent) in the high emissions scenario.
- Confidence in the projected trends and ranges of aggregate precipitation variables is somewhat lower (high-to-medium) than for temperature variables as there is less confidence in how well climate models represent the climate processes involved.



Freeze-thaw cycles to decline

- Annual FTCs are the number of days in a year when the temperature crosses 0°C. Over the coming decades, the winter season will shorten due to rising temperatures. Ontario average FTCs are projected to decline by 4.9 per cent (1.5 to 11.9 per cent) in the low emissions scenario by the 2030s. By the 2080s, annual FTCs are projected to decrease by 5.5 per cent (0 to 15.2 per cent) in the low emissions scenario and by 15.1 per cent (0 to 24.9 per cent) in the high emissions scenario.
- There is high confidence in the projections of annual FTCs and medium confidence in deep FTCs based on the amount of evidence for projected trends and ranges.

Source: Canadian Centre for Climate Services.

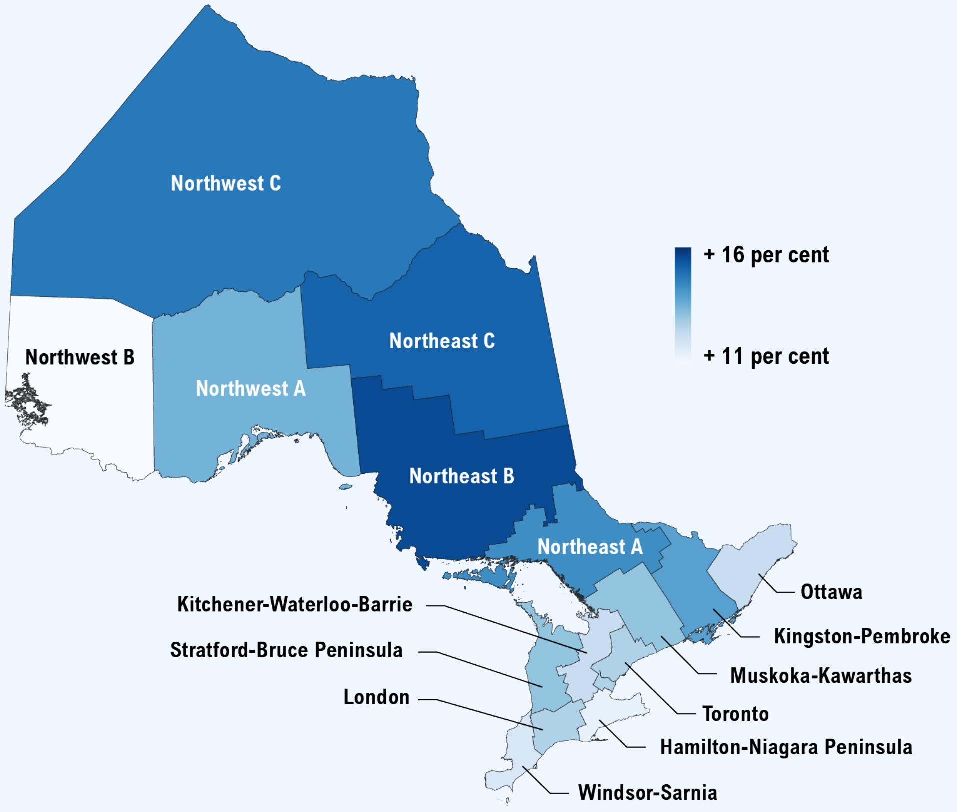
Ontario is a very large province that spans from the southern Great Lakes region to the Hudson Bay Lowlands in the far north. Regional variation in climate change means that infrastructure located in southern Ontario will experience different impacts compared to that located in northern Ontario.

With the assistance of the CCCS, it was determined that averaging the climate change projections into 15 regions in Ontario would adequately capture regional variability. These regions were defined using Statistics Canada's definition of economic regions,[33] with the northeast and northwest regions each divided into three sub-regions due to their size and climate variability.

For example, changes in annual precipitation are expected to be more significant in Northern Ontario than in Southern Ontario in the high emissions scenario.

Figure 7

Median projected change in total annual precipitation from 1976-2005 to 2071-2100, RCP8.5



Source: Canadian Centre for Climate Services. Note: Colour distribution is based on multi-model median projections.

Since the location of provincial and municipal assets is included in the FAO's asset database, it was possible to link these regional climate projections to the assets in those regions.

Changes in these three climate hazards will impact Ontario's public buildings and facilities in different ways. A typical building has many components, including its structure, envelope, equipment and finishing, mechanical and electrical systems, as well as civil infrastructure and landscaping. Figure 8 describes these key building components and provides examples of the interaction between those components and the three climate hazards.

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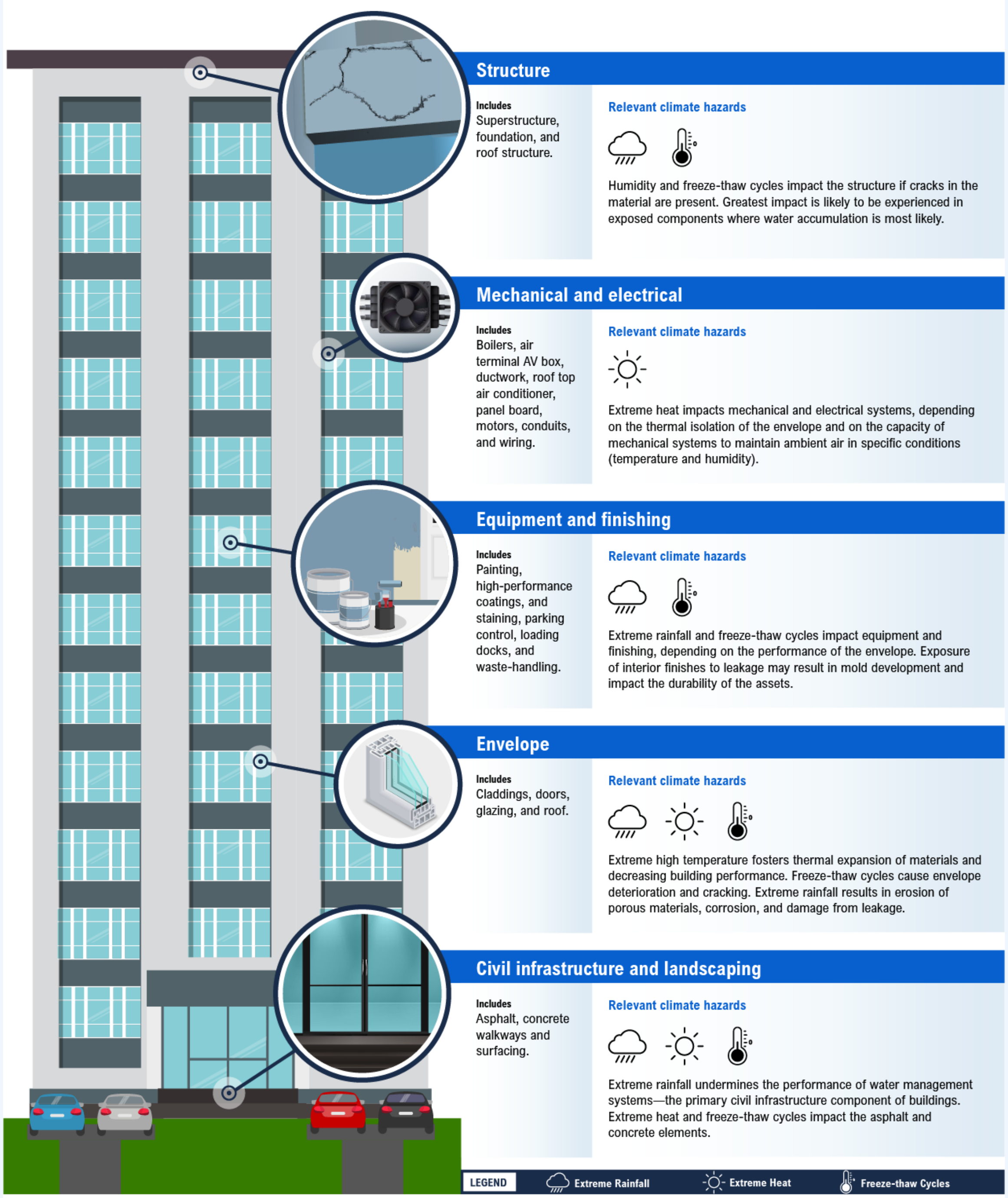
[33] See Statistics Canada's definition of economic regions.

Figure 8

Examples of climate hazard impacts to key components of public building infrastructure



Structure

Includes
Superstructure, foundation, and roof structure.

Relevant climate hazards

🌧 🌡

Humidity and freeze-thaw cycles impact the structure if cracks in the material are present. Greatest impact is likely to be experienced in exposed components where water accumulation is most likely.

Mechanical and electrical

Includes
Boilers, air terminal AV box, ductwork, roof top air conditioner, panel board, motors, conduits, and wiring.

Relevant climate hazards

☀

Extreme heat impacts mechanical and electrical systems, depending on the thermal isolation of the envelope and on the capacity of mechanical systems to maintain ambient air in specific conditions (temperature and humidity).

Equipment and finishing

Includes
Painting, high-performance coatings, and staining, parking control, loading docks, and waste-handling.

Relevant climate hazards

🌧 🌡

Extreme rainfall and freeze-thaw cycles impact equipment and finishing, depending on the performance of the envelope. Exposure of interior finishes to leakage may result in mold development and impact the durability of the assets.

Envelope

Includes
Claddings, doors, glazing, and roof.

Relevant climate hazards

🌧 ☀ 🌡

Extreme high temperature fosters thermal expansion of materials and decreasing building performance. Freeze-thaw cycles cause envelope deterioration and cracking. Extreme rainfall results in erosion of porous materials, corrosion, and damage from leakage.

Civil infrastructure and landscaping

Includes
Asphalt, concrete walkways and surfacing.

Relevant climate hazards

🌧 ☀ 🌡

Extreme rainfall undermines the performance of water management systems—the primary civil infrastructure component of buildings. Extreme heat and freeze-thaw cycles impact the asphalt and concrete elements.

LEGEND 🌧 Extreme Rainfall ☀ Extreme Heat 🌡 Freeze-thaw Cycles

Source: WSP. Note: For more examples of how these climate hazards impact building components, see WSP 2021.

These three climate hazards impact the physical deterioration of public buildings, and extreme rainfall and extreme heat are projected to increase in the future. While climate projections have been available to asset managers for a long time (with various levels of granularity, detail, and quality), to date the FAO is not aware of efforts to explicitly incorporate them into infrastructure deterioration models for costing purposes.

Climate cost elasticities

Economists have been using the concept of "elasticities" since Alfred Marshall's Principles of Economics was published in 1890. In economics, an elasticity measures one variable's sensitivity to a change in another variable, expressed as a ratio of percentage change in variable A over percentage change in variable B.

For example, a famous study by Card and Krueger[34] examined the elasticity of employment with respect to wages and showed how the impact of an increase in the minimum wage ultimately effects employment. In this case, the elasticity reflected the aggregate outcome of all the specific employer or employee changes that occurred in the labour market due to the increase in the minimum wage.

The core idea of the CIPI project was to import the elasticity concept from economics to engineering and derive an aggregate relationship that expresses the percentage change in a specific type of infrastructure cost due to a change in the relevant climate variable. To complete this part of the CIPI project, the FAO hired WSP, a large engineering firm with expertise in all aspects of public sector infrastructure, including asset management, public infrastructure construction and operations, and climate change impacts. [35] The FAO specified the model relationships which WSP estimated and referred to as "climate cost elasticities".

WSP engineers consulted with their subject-matter experts (SMEs) and selected the most appropriate climate variable to proxy the hazard in question for each asset class and/or asset component.[36] For instance, rail infrastructure is most impacted by extreme heat. For rail track alignments the number of days with temperatures above 30°C was determined to be the most relevant climate indicator for extreme heat.[37]

Once the key climate indicators were selected, WSP conducted a survey of the relevant SMEs. The survey provided the worst-case scenario projection of each climate indicator by late century (the upper 90th percentile projection in the high emissions scenario) and calculated the indicator's change from the reference period (1976-2005).[38] It then asked SMEs to independently estimate[39] the impact of these changes for two types of infrastructure costs: damage costs and adaptation costs.

Damage Costs

WSP estimated two types of damage cost relationships, which would manifest in the absence of adaptation.

1. A change in useful service life (USL) due to a change in climate variable. Climate change will alter the historical deterioration patterns of infrastructure. Assets may deteriorate more rapidly (or more slowly in some cases) due to long term changes in key climate variables. Accelerated deterioration requires more frequent or additional rehabilitation costs, and faster asset renewals.
2. A change to operations and maintenance (O&M) expenses due to a change in climate variable. The cost of O&M may also be impacted, such as more frequent inspections raising the annual cost of operations.

Using these relationships, the FAO was able to project infrastructure costs under the "damage cost" strategy which assumes that AMs do not undertake any adaptation measures to address these hazards. Instead, AMs

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[34] See: Card, D and Krueger, A, 1994.

[35] See WSP's website.

[36] For buildings, WSP SMEs estimated the impacts of each climate variable on each building component in figure 8 where relevant, and the results were aggregated to the building level by each component's share of total replacement value.

[37] See WSP, 2021, for more details.

[38] A significant portion of Ontario's current public infrastructure was built and designed to the climate of that period, and CCCS's climate data for Ontario are only available from 1950 onward.

[39] The SMEs' answers to these questions reflect their engineering knowledge of federal and provincial building codes, their understanding of the literature on climate-infrastructure interactions, the broad characteristics and nature of the assets in scope, and the average climate vulnerability of these assets. WSP aggregated the survey results into a probability distribution with optimistic, pessimistic and most-likely values.

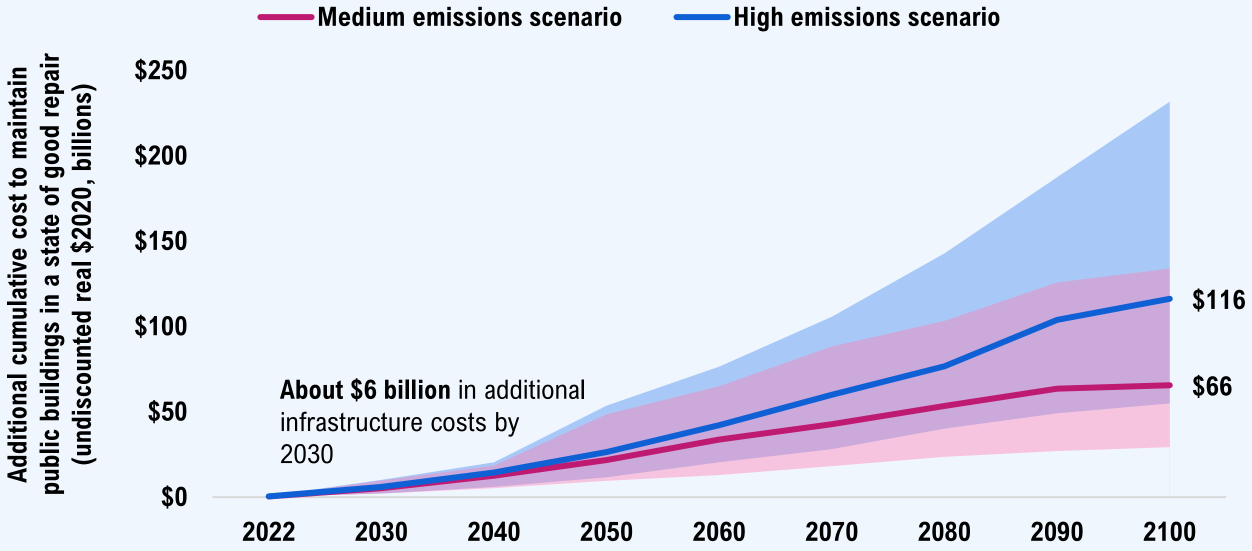
allow their assets to suffer accelerated infrastructure deterioration and simply pay the higher repair costs and increased operating expenses that result.

The FAO estimates these three hazards will add roughly **$6 billion** (8.0 per cent increase over baseline) to the costs of maintaining public buildings and facilities in a state of good repair over the remainder of this decade (2022-2030). These costs would be in addition to those projected in the base case.

Over the long term, the extent of global climate change will influence the severity of these climate hazards and their impacts to public buildings. In a medium emissions scenario, the cumulative cost of maintaining the existing portfolio of public buildings in a state of good repair will increase by **$66 billion** (8.2 per cent increase over baseline), or $0.8 billion per year on average over the rest of the 21st century. However, in a high emissions scenario, cumulative costs would increase by **$116 billion** (14.5 per cent increase over baseline), or $1.5 billion per year on average over the rest of the century.

Figure 9

More extreme rainfall and heat will raise the cost of maintaining the current portfolio of public buildings in the absence of adaptation actions



Notes: The solid line is the median (or 50th percentile) projection. The coloured bands represent the range of possible outcomes in each emissions scenario given the climate and engineering uncertainties. The costs presented in this chart are in addition to the projected baseline costs over the same period. Source: FAO.

Adaptation Costs

While damage cost scenarios are useful projections to gauge the costs of inaction on climate change adaptation, all levels of government, the private sector and many other institutions are currently working on various adaptation solutions. A wide range of adaptation options is currently available to asset managers, and options differ depending on the context, climate hazard and asset in question.

Adapting public infrastructure to specific climate hazards could take many forms. In some cases, it might involve updating infrastructure design parameters to a higher standard.[40] In others, it might mean upgrading certain asset components to accommodate changing climatic conditions. Adaptation could also mean that infrastructure

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[40] Cannon, A.J., Jeong, D.I., Zhang, X., and Zwiers, F.W., 2020.

is redesigned or replaced with other options, such as the use of green infrastructure including planting trees, enhancing wetlands or installing green roofs instead of relying on stormwater pipes or ditches to accommodate higher rainfall intensities. In the FAO's framework, adaptation is modelled as an alteration of a building's physical components to prevent damage costs caused by changes in extreme rainfall and heat.

In this study, "adaptation costs" are defined as the cost of actions that would address the impacts of select climate hazards to ensure that assets perform to the same standards for which they were initially designed (e.g., stormwater pipes that would not overflow in more extreme rainfall events), and to prevent accelerated asset deterioration and additional O&M expenses despite changed climate variables.

WSP estimated two types of relationships between changes in climate variables and infrastructure adaptation costs.

1. The cost of retrofits to adapt to a change in climate variable. One adaptation option for asset managers is to retrofit an asset before the end of its service life. "Retrofit" in this project means replacing components of an asset with ones that are adapted to changed climate variables. For example, retrofitting would include waterproofing a building's foundation.[41]
2. A change in the cost of asset renewal to adapt to a change in climate variable. Climate change adaptation can also occur at the end of an asset's service life if it is replaced with one that is designed to withstand the changes in climate variables. Adaptations at renewal can only occur when an asset is fully replaced, while adaptation as a retrofit can occur at any point during the asset's life.

Figure 5-2 presents some examples of adaptation measures for each building component.[42]

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[41] See WSP, 2021, for a full description of retrofit examples.

[42] For a full description of adaptation examples see WSP 2021.

Figure 10

Examples of building component adaptations to extreme rainfall and extreme heat

Structure

Upgrade roof structure to handle greater loading due to stormwater detention. Costs could also include the addition of waterproof membranes and drains.

Mechanical and electrical

New or added cooling capacity will be required to maintain comfort conditions indoors.

Equipment and finishing

Relocate exterior equipment outside of potential flooding areas due to increase in frequency and intensity of short-duration / high-intensity rainfall events.

Envelope

Finishes on the exterior need to be more sustainable to withstand heat and maintain the thermal protection of the indoor environment, shielding other building components from much of the stress of extreme heat events.

Roof drainage needs to be sized for future rainfall projections and sufficiently graded to limit ponding.

Civil infrastructure and landscaping

Stormwater ponds, infiltration galleries, and retention or detention tanks to slow and minimize rainwater runoff rate and quantity.

Note: For more examples of how building components can be adapted to climate hazards, see WSP 2021.
Source: WSP.

Using these relationships, the FAO was able to project infrastructure costs under two adaptation strategies.

- ***Reactive adaptation* strategy:** Buildings are only adapted at the time of renewal. This approach results in a gradual increase in the share of adapted buildings over the century, with roughly 77 per cent of assets adapted by 2100.[43]
- ***Proactive adaptation* strategy:** Buildings are adapted at the first available opportunity. This occurs either during a building's next major rehabilitation through a retrofit[44] or at renewal, whichever comes first. In this approach, all buildings are adapted by the 2060s.

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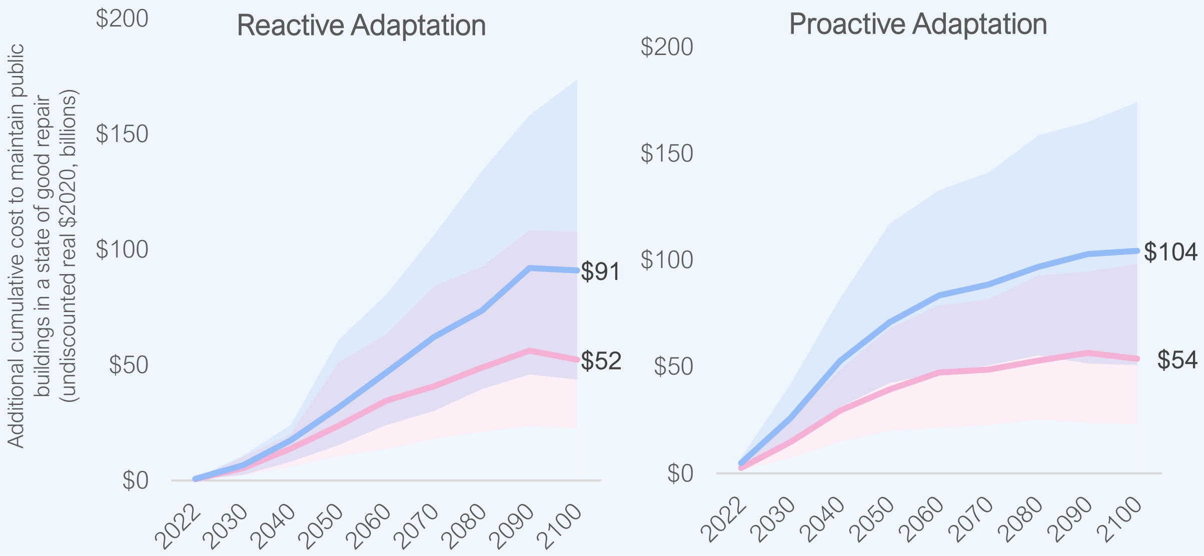
[43] The remaining 23 per cent have service lives that extend beyond 2100 and are not renewed or adapted over the projection. These buildings incur accelerated deterioration and higher O&M costs over the duration of the outlook.
[44] A retrofit is an adaptation made during the building's service life. Adapting as a retrofit to an existing building typically costs more than adapting while designing and constructing a replacement building.

For example, under the *reactive adaptation strategy*, maintaining Ontario's public buildings in a state of good repair would cost an additional **$52 billion** (6.5 per cent over baseline) cumulatively in the medium emissions scenario to 2100. In the high emissions scenario, the costs would instead increase by **$91 billion** (11.4 per cent over baseline).

Figure 11

***Broad adaptation* strategies will also add to long-term infrastructure costs**



Notes: The solid line is the median (or 50th percentile) projection. The coloured bands represent the range of possible outcomes in each emissions scenario given the climate and engineering uncertainties. The costs presented in this chart are in addition to the projected baseline costs over the same period. Source: FAO.

Climate change decision support for public infrastructure managers

Previous studies have assessed climate risks to public infrastructure either in qualitative terms[45] or for specific assets,[46] but have not taken the step of estimating cost impacts. To address this knowledge gap, this study provides reliable cost impacts of three key climate hazards to Ontario's public buildings and quantifies the possible range of budget impacts over the short term and long term in the absence of adaptation actions. This provides public sector AMs with a broad sense of the budgetary consequences of not adapting their assets to these hazards.

While damage cost scenarios are useful projections to gauge the costs of inaction on climate change adaptation, there is significant work underway on various adaptation solutions. To gauge the long-term budgetary implications of adapting Ontario's public buildings to withstand these hazards, this study provided cost projections of two broad adaptation strategies. This shows that the financial impact of these climate hazards will be material to the province and municipalities regardless of which asset management strategy is pursued (see figure 3).

Comparing cost projections of the three strategies at the broad asset class level reveals that adaptation

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[45] See: Council of Canadian Academies, 2019.

[46] See: The PIEVC protocol.

strategies will be somewhat less costly for AM budgets over the long term. However, the societal costs of planned or unplanned service disruptions were excluded and incorporating them would raise the comparative benefits of adaptation.

The portfolio level costing results in this report are not intended to inform asset-specific management decisions. Determining the most cost-effective strategy for an individual asset would require comparing the costs of different adaptation strategies over its service life, for a broader range of climate hazards and societal costs, and with the asset's specific circumstances taken into consideration. However, this methodology could be extended for use at the asset level to inform AM decision-making.

Strengths, areas for further research, and caveats

This approach has numerous strengths that would help AMs incorporate climate change impacts into public infrastructure decision making. There are also some aspects of the method that could be enhanced with further research to further improve it as a tool for infrastructure planning and decision support. Finally, there are a few caveats to using this approach to assist in infrastructure planning decision making.

Strengths

This methodology takes some important steps in providing reliable cost impacts of key climate hazards on public infrastructure. It does so by enhancing a commonly used infrastructure deterioration modelling framework with simple relationships that allow significant flexibility in evaluating the impact of climate change costs to infrastructure.

This approach provides the ability to:

- model cost outcomes in different emissions scenarios;
- cost average climate impacts over the forecast horizon to capture long-term climate trends; and
- isolate the cost impact of specific climate hazards or cost types, such as climate impacts to O&M, rehabilitation or renewal costs.

The long-term costs in the base case and climate scenarios each incorporate the age structure of public infrastructure, and account for when public assets require investment over the coming decades and how climate hazards can impact this timing.

The methodology also clearly quantifies the most important aspects of climate and engineering uncertainty.

- Climate uncertainties were quantified by projecting high, medium, and low emissions scenarios. To account for the range of climate model simulations within emissions scenarios, the FAO included results for the median, 10th and 90th percentile climate model simulations within each emissions scenario as part of the displayed uncertainty ranges.
- To account for the engineering uncertainty embedded in the climate cost elasticities, WSP estimated high, low and "most likely" cost relationships.

The uncertainty bands surrounding the long-term infrastructure cost projections can be seen in the coloured areas around the "median, most likely" projections in figures 9 and 11 above. The uncertainty bands incorporate both the engineering and climate uncertainties and estimates a range of possible outcomes.

Areas for further research

The FAO's approach also has some aspects that could be improved with further research.

- Climate cost elasticities were estimated for only three climate hazards where projections had a higher degree of scientific confidence, but more relationships could be developed between other climate hazards and infrastructure costs where reliable data permits.

- Public infrastructure provides vital public services, whose interruption can have significant social and economic consequences. The costs of planned or unplanned service disruptions were not included but would be significant in the absence of adaptation. Incorporating these societal costs would raise the comparative benefits of adaptation.[47]
- Climate cost elasticities were calculated for an average asset in Ontario, such as a typical building or a typical road segment. While the results are reasonable on an asset class basis, they may not be applicable for specific assets in Ontario, or in other jurisdictions with different asset portfolios and climates.
- Similarly, one climate cost elasticity is used for each asset type regardless of an asset's condition or age. Assets in poorer condition or built to older design standards would be impacted differently by changing climate hazards than assets in better condition or built more recently. Further research could refine the climate cost elasticities along these lines.

For these reasons, the FAO's damage cost results should be viewed as lower-bound estimates.

Caveats

Governments face competing priorities for scarce resources and, perhaps understandably, problems in the more distant future are often overlooked in favour of the pressing needs of today. In addition, provincial and municipal AMs in Ontario must allocate scarce resources between maintaining existing assets, enhancing them, or building new ones to service a growing population. In this context, adapting public infrastructure to changing climate hazards may only be one priority among several that AMs must consider.

The use of climate cost elasticities in projecting infrastructure costs is a new methodology and would be unfamiliar to most if not all AMs. Developing these infrastructure cost projections required significant resources, modelling capabilities and a reasonable degree of multi-disciplinary expertise (including in asset management, climate change and finance), which could stretch the resources of many AM departments.[48]

Conclusion

Changes in extreme rainfall, extreme heat and freeze-thaw cycles will raise infrastructure costs for Ontario and its municipalities, carrying significant budgetary impacts. The extent of these budget impacts will depend on how severe global climate change becomes in the coming decades. However, long term public infrastructure costs in Ontario can be lowered by adapting public buildings to avoid the impacts of these climate hazards.

The FAO's methodology compares the cost outcomes of different asset management strategies after accounting for the impacts of these climate hazards. This provides a basis upon which to gauge the size of the budgetary impact these climate hazards will cause, and a new evidence base with which to compare costs under different adaptation strategies.

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[47] In addition, the FAO's approach treats the impact of each climate hazard independently and does not account for the significant interdependencies between public infrastructure. Extreme weather events can cause cascading infrastructure failures, such as storms that knock out power to basement sump pumps, leading to basement flooding. Simultaneous hazards often carry impacts that are more than simply additive.

[48] Further research could be done to extract cost adjustment factors from the results that could be more easily used by asset management practitioners. For example, "climate cost multipliers" express the change in infrastructure cost for a given climate projection and could be incorporated into simpler spreadsheet-based infrastructure cost projections.

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