Climate-Resilient Asset Management

A City of Vancouver Research Project

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Executive Summary

This report is produced as a part of the Sustainability Scholars program with the City of Vancouver to develop a framework for incorporating a climate lens in their asset management risk framework. Climate changes are happening around the world and at a rate much higher than originally anticipated. Municipalities must incorporate climate resiliency in their asset management strategies in order to maintain essential services to the public in uncertain climate conditions.

The best approach to combat climate change is to adopt a combination of mitigation and adaptation strategies. Accordingly, two different frameworks, i.e., the BC Asset Management (BCAM) and Federation of Canadian Municipalities (FCM) frameworks, have been reviewed. Subsequently, contextual analysis has been made based upon the literature review and discussions with internal and external subject matter experts on City of Vancouver specific considerations. Further, the case for using a customized methodology based on the FCM guide was also discussed. Thereafter, the report highlights the gaps between the current state of asset management in the City of Vancouver and the proposed methodology.

The report makes specific recommendations. One of the most important recommendations is to follow a customized service delivery-centric approach based upon the FCM guide and PIEVC protocol instead of an asset-centric approach. However, once the asset is defined, the municipality needs to assess the risk and impacts of climate change on the level of service on that particular asset. Other important recommendations include evaluating risks due to climate change before determining the impact of climate change on level of service (LOS), use of risk-return on investment tools, and use of more green infrastructure initiatives (GII), especially leveraging the natural ecosystem to increase redundancies in the system.

Finally, the report suggests specific areas where more research is required. Some of the critical areas include exploring the asset management policy of the City of Guelph to understand their incorporation of the LOS framework in their asset management decision-making framework; exploring more risk return on investment tools for having the best bang for the buck; looking into the innovative flood mitigation strategies of Surrey and Edmonton; and studying more reports on PIEVC protocol for a better understanding of the incorporation of climate risk in Asset Management Plans.

Though the City of Vancouver has always been at the forefront in tackling the issue of climate change, as seen from their different plans and policies, there is a dire need to integrate all the good work done so far. This report provides an overarching framework to incorporate a climate

risk component into a central, standardized decision-making tool for all asset classes within the Engineering Services Department.

Introduction

Climate change refers to changes in the composition of the atmosphere caused by the enrichment of greenhouse gases and fluorocarbons, resulting in an increase in the earth's surface temperature. These environmental changes occur over time due to natural or human activity. According to the Intergovernmental Panel on Climate Change (IPCC), it is undeniable that the planet is warming up more quickly than previously projected. Consequently, as per the 2015 Paris Accords, of which Canada was also a signatory, a target to limit global mean temperature rise to 2 degrees Celsius (compared to pre-industrial levels) was established ("The Paris Agreement.," 2015). To achieve this target, the signatories broadly agreed to take action to reduce emissions while also preparing for the consequences of the changes that are already occurring and expected to intensify over the next few decades. As a result, it is more important than ever for all municipalities to incorporate a climate lens in their asset management decision-making framework.

Climate change is happening twice as fast in Canada as compared to global averages ("Canada Warming Twice as Fast as the Rest of the World, Report Says," 2019). The built environment across the nation is at serious risk from climate change effects, such as shifting temperature, altered precipitation patterns, and increased frequency of extreme weather events. Buildings and infrastructure in Canada are already facing service disruptions and financial losses due to climate-related hazards and catastrophic occurrences. For instance, disaster events brought on by a confluence of fire at the wildland-urban interface, hail, high winds, and floods cost the Canadian economy approximately $11 billion between 2015 and 2019 (Sandink & Lapp, 2021).

For the City of Vancouver, climate change means hotter, drier summers, warmer winters with more precipitation, more frequent and intense storms, more intense severe winds, and rising sea levels. These effects have a big influence on communities who receive essential services from an infrastructure system that is interconnected and interdependent. This means that changes in one system may trigger cascading and often unpredictable effects on other systems, which makes emergency planning more difficult. In addition to the technical interdependencies, municipal services frequently involve numerous infrastructure-owning organizations such as local governments, provincial governments, power and gas utilities, First Nations, etc. who are unaware of upstream vulnerabilities and downstream consequences and which adds additional complexity to issue. (Federation of Canadian Municipalities, 2019).

The City of Vancouver has always been at the forefront in tackling the issue of climate change and proactively working towards climate resilience. Evidence of their commitment to combat the effects of climate change appears in their different plans and policies, such as Climate Emergency Action Plan, Climate Change Adaptation Strategy, Greenest City Action Plan, and Resilient Vancouver Strategy. This project falls under the ambit of the Climate Change Adaptation Strategy. Integration of climate considerations in the asset management risk framework is one of the enabling actions to achieve the goals of the Climate Change Adaptation Strategy. This research project is a step forward in achieving the first goal of climate adaptation strategy, i.e., integrating a climate change adaptation lens into local policies, procedures, and planning. This research project attempts to present a framework to incorporate a climate risk component into the central decision-making tool to be used across various infrastructure assets.

Background

Climate change increases the risk ratings for service delivery and has direct impacts on service reliability thereby making it more difficult to deliver desired levels of service at a reasonable cost. Climate risks include physical risks to assets from climate change, the transitional risk from changes in technology or practices, and liability risks from legal and regulatory requirements.

The City has different plans and policies to combat climate change and its impacts that operate independently from centralized asset management initiatives. Work is being done to integrate these with the asset management plans of various infrastructural assets. This project aims to research industry best practices and standards and recommend a strategy to develop a climate-aware risk framework. As the strategic asset management program continues to mature, the risk framework will be an important component in incorporating a climate risk component into a central, standardized decision-making tool for all asset classes within the Engineering Services Department. The project will support decision-makers in reviewing the level of risk carried by various assets in the face of climate change and support capital planning decisions within the Engineering Services Department of the City of Vancouver. The project will also benefit the public, ensuring that the city is providing an acceptable level of service given the changing demands on infrastructure due to climate change.

Project Scope

In order to complete the objectives of this project, a series of activities were identified to be within scope. As this project focuses primarily on benchmarking against industry practices and standards, a thorough literature review was conducted. Guidelines, reports, and frameworks reviewed were then analyzed through in City of Vancouver context. This included review of current asset management plans and a series of three interviews with staff in Engineering

Services who are subject matter experts in the field of asset management. In comparing industry standards to current City practices and level of maturity, a gap assessment was completed. Finally, a review of the proposed methodology for implementing a risk-based approach to assessing climate hazards to City assets was reviewed by industry subject matter experts in the field of asset management.

Literature Review

Regulatory Guidelines and Practices

The regulatory landscape around asset management in Canada varies across jurisdictions, which leads to variations in maturity and complexity of asset management practices and policies. The Province of British Columbia does not currently require local governments to develop asset management policies or plans nor report on their assets. However, grants and funding opportunities, particularly from federal government, are requiring local governments to have asset management plans in place. Faced with these changes and the benefits formal asset management practices can bring, many local governments have started work on developing asset management strategies and plans.

While asset management is a multi-disciplinary practice, engineers have taken a lead role in many organizations in helping to shape asset management processes. Consequently, Engineers and Geoscientists BC developed the *Professional Practice Guidelines- Local Government Asset Management* as a guide to Engineering and Geoscience Professionals who provide a range of professional services to Local Governments in the practice of asset management. Acknowledging the significant impact of climate change on planning and design for maintenance and development of municipal infrastructure, the Guidelines take steps in highlighting opportunities to incorporate climate change in decision-making. In alignment with the Code of Ethics' tenant to protect the environment, the guideline outlines that natural asset should be captured within the asset management plans and policies. The need, scope, and principles of these guidelines summarized in Appendix B (Engineers & Geoscientists BC, 2021).

The City of Guelph's Approach (Federation of Canadian Municipalities, 2019)

The City of Guelph has effectively integrated the adaptation and mitigation strategies in addressing the impacts of climate change in their strategic asset management policy. Wherein, the adaptation strategies alleviate the impact of service disruption due to natural disaster, mitigation strategies aim to reduce the alterations in the climate itself. A combination of the two systems reduces risks, and produces economic, environmental and social benefits. They have accounted for the impacts of climate change by incorporating a level of service framework using climate-related key performance indicators.

Frameworks for Climate Change and Asset Management Integration

BC Asset Management Framework (Asset Management BC, 2019)

The BCAM framework for climate change in AM was reviewed for applicability to the City of Vancouver AM Program. It focused on an asset-centric model that begins with the identification of asset types and then applies climate risk to the individual assets. Subsequently, the municipality devises strategies for upkeep and maintenance of those assets. However, this approach misses out on consideration for service delivery of assets that deliver similar services. For example, in order to provide transportation services various assets such as Bridges, roads, trails, curb and gutter, sidewalk, road signs, streetlights, traffic lights, buses, light rail, etc. could be involved. But this framework would only talk about a one particular asset and not take into account the other assets which may be delivering the same services or may be impacted by the same hazards. But once an asset is selected this approach is important to formalize and create an asset management plan. Asset Management plan for a particular asset evaluated risks from various threats including the climate hazards. For more details regarding the BC Asset Management approach see Appendix C.

Federation of Canadian Municipalities Framework for incorporating climate lens into Asset Management (Federation of Canadian Municipalities, 2019)

This framework uses a service delivery-centric approach, see Figure 1. The city first identifies the benefits it currently provides or aims to provide to its residents and then subsequently devises a strategy to ensure that it continues to provide those services or can achieve the desired level of services over the expected timelines.

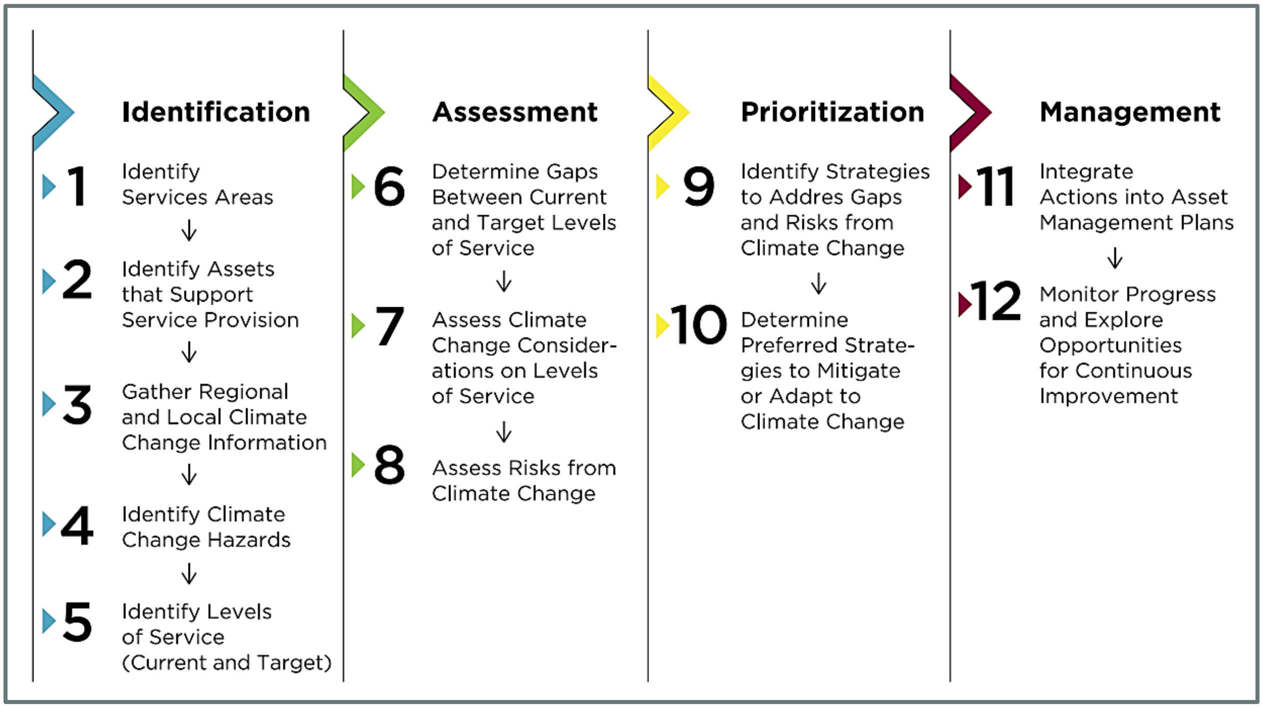


Figure 1 – Framework for Integrating the Climate Lens (Federation of Canadian Municipalities, 2019)

Service levels and risk are intertwined in asset management. Considering both levels of service and hazards in a single process is efficient. It helps to identify synergies that may yield relatively simple solutions to the complex problem of climate change. The overarching purpose of this process is to answer the following questions:

- How will climate change affect our municipality?
- How will it affect our ability to deliver municipal services?
- How do we prepare for the future?

To incorporate climate lens in the asset management framework there are four main approaches.

1. **Begin from the ground up**: This approach is suitable for municipalities who are new to the arena of asset management and are yet to begin their process of formulation of asset management plans and strategies. This approach focuses on following all the steps as mentioned above in Figure 1 step by step. However, sometimes the process may become overwhelming and the municipality may not be able to reach to any conclusions as a lot of time would be consumed in fully completing all the different steps. Hence, a better approach would be to select some limited-service areas and complete the process for all the twelve steps.
2. **Level of service approach**: This approach is suitable for those municipalities who have completed their infrastructure risk assessment due to climate change separately. Using this approach involves following steps 1 to 7 followed by step 11 and 12 as highlighted in Figure 1. It is generally seen that most municipalities complete their level of service

assessment and their risk assessment separately as it may be too overwhelming to do everything at the same time.

3. Risk management approach: This approach is suitable for those municipalities who have completed their level of service assessment due to climate change separately. Using this approach involves following steps 1 to 4 followed by steps 8 to 10 and steps 11 and 12 as highlighted in Figure 1.
4. Adapting an existing framework approach: This approach is suitable for municipalities who have already have an asset management framework in place and now wants to incorporate the climate lens in the existing framework. Using this approach involves following steps 3-4 followed by steps 8 to 10 and steps 11 and 12 as highlighted in Figure 1.

Depending on the stage the municipality is at related to its AMPs for different infrastructural assets, the municipality can decide upon the approach it wants to follow. A more detailed description of all the steps is mentioned in Appendix D

Concept of Greenwashing

The term is mainly used in the context of private investment firms. But greenwashing in the context of municipality means investing in creation of some infrastructural assets or services that do not create that much positive environmental impact than they were believed to have created. Understanding the concept of greenwashing is important for a municipality because municipalities are accountable to the taxpayers who primarily fund all the municipal assets and services. Staff working in the municipality shall work in a manner that utilizes the public money to give the best bang for the buck and for benefit of the community.

In case of private firms, generally greenwashing has been seen as deliberate malpractice. However, in the case of municipalities, greenwashing can also occur inadvertently due to the lack of accurate data. As such, asset managers through public hearings should prioritize disclosing to the public any data limitations that may have affected their climate risk assessments.

Current State of Asset Management Practices at the City of Vancouver

Strategic Asset Management Program and Levels of Maturity

The City of Vancouver hired Associated Engineering (AE) to review its asset management and infrastructure planning practices across the City's Engineering Services department, particularly critical asset-owning branches. Based on this review, AE provided the following observations and recommendations, see Table 1 (AE Associated Engineering, 2020).

Table 1 – Desired capabilities and desired actions (Associated Engineering, 2020)

Current State	Desired Capability	Priority Actions
Lack of common framework: Inconsistent practices and nontransparent approaches	Use of common framework: Consistent and transparent approaches	• Strategic Asset Management Plan • Asset Management Plans • Criticality Evaluation • Risk Framework • Levels of Service Framework • Condition Assessment Strategy
Lack of common language: Different understandings of asset management and infrastructure planning and definitions used	Use of common language: Common understanding of asset management infrastructure planning and definitions used	• Asset Management Policy
At times, reactive decision-making for capital planning	Proactive decision making framework for capital planning (equitable and optimized infrastructure investments	• Decision Making framework • Information Management Strategy • Inventory Review and Build-Out
Occassionally, decisions are made in silos, collaboration may be informal or inconsistent	Decisions are generally made from collaborations across Branches where needed	• Asset Management Governance Structure • Roles and Responsibilities

AE also provided a roadmap for Engineering Services to align itself with current and future needs in asset management. They further proposed tools and processes to deliver on the 30-year vision, 10-year Capital Strategic Outlook, and 4-year Capital Plan.

The exercise conducted by AE provided a broad framework under which asset management plans for various infrastructural assets were conceptualized and commenced. Engineering's service areas and assets groups were divided into cohorts for an incremental approach to development of asset management plans (AMPs). This approach is primarily based on readiness and maturity of the service areas as well as the overall criticality of the assets. To date, three Asset Management Plans (AMPs) have been substantially completed for subset of asset classes for:

sewers, traffic & electrical, and water. More AMPs are in progress for streets, SCADA, fleet, and energy and utility.

The level of maturity and completeness of the AMPs varies across the service areas and integration of climate change considerations is inconsistent across the different asset groups. However, the City has also established the Green Infrastructure Implementation (GII) branch, which in itself is a climate change adaptation measure that would increase redundancies in the system and would lower demand on sewer systems.

Understanding the Context of Asset Management in Engineering Services

Discussion with the subject matter experts (SMEs) from the Sewers and Drainage Design branch, Traffic, Electrical Operations and Design branch, and Green Infrastructure Implementation branch at the City of Vancouver illustrated unique considerations for each of the asset systems. Identifying where different asset areas shared commonalities or had different needs and priorities is a key step in identifying how Engineering Services can best develop a risk framework and subsequent decision-making framework.

Both of the frameworks considered during literature review, i.e., FCM *Guide for Integrating Climate Change Considerations into Municipal Asset Management* and BC Asset Management *Climate Change and Asset Management: A Sustainable Service Delivery Primer*, are valuable frameworks. In general, considering the organizational focus on delivery of services to the public, a more service delivery-centric approach, as outlined by the FCM guide, is better suited to the needs of the asset owners.

AMPs are living documents will be continuously improved to incorporate new and evolving climate risks and the effect of those risks on the levels of service in subsequent versions. Redundancies are being incorporated into the AMPs to safeguard critical infrastructural assets from the impacts of climate change. In Sewers AMP, there is a provision for separating storm and sewer pipelines, creating overflow structures (pipes to divert stormwater), and installing standby pump stations (Sewers and Drainage Design Branch, 2020). In Electrical AMP, there is a provision of higher density conduits and the Internet of Things (IoT) use (Traffic & Electrical Operations and Design Branch, 2021). GII itself is acting as redundancy for infrastructures such as sewers (Sharma, 2022). However, if we see it at a micro level within GII, it has provisions for traffic bulges, permeable pavement, etc., to include redundancies in the system (Sharma, 2022).

Capacity building and sensitization of staff & other stakeholders towards climate change impacts and introduction of new initiatives is being implemented in different branches. However, the nature and intensity of implementation varies. In Sewers branch, capacity building is done through training and seminars about climate change (Wells & McPherson, 2022). Also, many new initiatives, such as incorporating flood management infrastructure, pump stations, etc., are under process for inclusion in the subsequent iterations of AMP (Wells & McPherson, 2022). In Electrical branch, new initiatives in creating an EV ecosystem are under process (Bethell, 2022). Whereas in GII branch, efforts are being made to collaborate with other departments such as Urban Forestry for integration and effectiveness (Sharma, 2022). But since GII is a response to climate change, people are pretty much sensitive and aware of its importance and significance.

Regarding the use of Spatial analysis and GIS for estimating missing data different asset owning branches had different reasons for either using or not using the GIS data. Sewers branch used proxy data (~10%) to compute gaps in data (Wells & McPherson, 2022). However, wherever more accuracy was required, they used spatial analysis. Electrical and GII branch on the other hand relied more on the use of the GIS data (Bethell, 2022; Sharma, 2022). However, the reasons for using the spatial data were different for both the branches. Electrical branch used GIS data because in order to know the bottleneck and make repairs, the location needs to be accurate. E.g., fixing a street light would require us to know its exact location (Bethell, 2022). Whereas, GII branch used spatial data because at present they had less inventory (Sharma, 2022). However, in the future, depending upon the criticality of the missing data, they can decide whether to use proxy values or GIS data.

Findings and Analysis

Based on the literature review and discussions with internal and external subject matter experts, analysis has been conducted to decide upon a better framework approach, reasons for customizing the FCM framework approach, a case for a dedicated team incorporating climate lens in the decision-making framework and concern for the issue of greenwashing.

FCM Versus BCAM

Both the frameworks considered in this report are complementary to each other as both aim to address climate-related risks and its impact on levels of service. However, in doing so, the BCAM Framework evaluates everything from the perspective of a particular asset only. In contrast, FCM Framework takes a more comprehensive view which entails all other assets that a specific climate hazard may impact. So, by following the FCM guide, none of the critical assets from the climate point of view would be left out, leading to a more comprehensive and effective asset management plan.

For example, instead of identifying an asset, such as a bridge, and then assigning a risk rating to the asset, consider the hazard that affects the community, such as flooding. One or more assets could be tied to flooding, for example, the bridge, nearby pump stations, etc. Hence, the plan would be developed not only for the bridge but also for the pump station. Hence, the asset management plan of both the assets, i.e., bridge and pump station, is developed, thereby making the overall system more robust and resilient to climate change (Federation of Canadian Municipalities, 2019).

Also, the delivery-centric approach is more strategic in deciding the Asset Management Strategy as by using this approach one is certain that all critical assets that provide services or redundancies in the system are not missed out. Hence, for incorporating a climate lens into asset management plans, the delivery-centric process of the FCM guide is better. However, once the scope is defined (asset is selected), we need to calculate the risks and impacts on the level of service for that asset.

Customizing the framework approach based on FCM Guide and not following it as it is

FCM guide talks about assessing Climate Change Considerations on Levels of Service (step 7) before assessing the risks from climate change (step 8). However, as per discussion with external experts and my judgment, the impact of climate change on the level of service would always be a function of risk. So, how is it possible to assess and integrate the Level of Service component relating to climate change in the decision-making framework of asset management plans without first accounting for the risks due to climate change?

Case for a dedicated team for incorporating climate lens in the decision-making framework

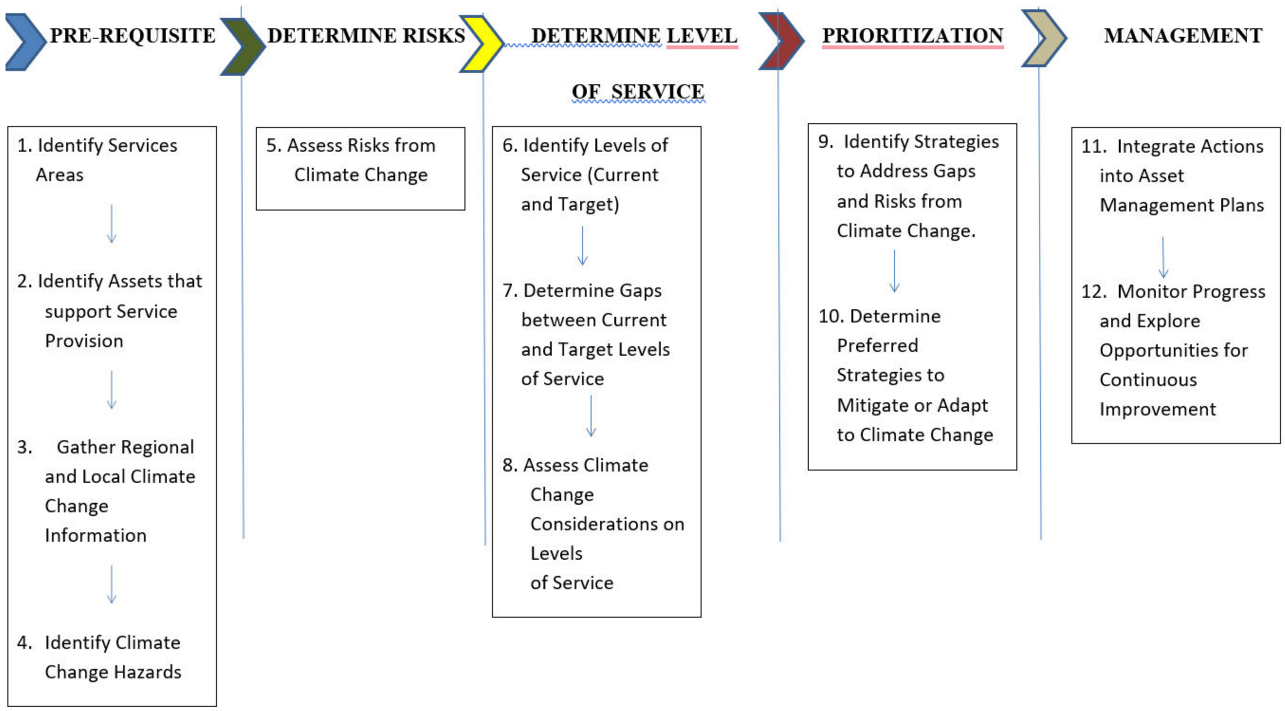
Currently, within the city, the Sustainability Group leads the development of a range of climate change and adaptation strategies. Through the recent capital planning processes, the Group has provided overarching guidance on City-wide initiatives, however, it would be helpful if there was a joint team to incorporate the climate lens in the AMPs and participate actively in the decision-making processes. The team can integrate the best practices from different departments and act as a source of information for the best practices. To do this, we also need an Asset Management champion for each department to touch base and ensure proper synchronization. Apart from the central team, there should be cross-disciplinary meetings for appropriate coordination of decision-making (Buckert & Bhalla, 2022).

Proposed Methodology

The general methodology for developing the framework for incorporating the climate lens in Asset Management Plans has been primarily derived from the Federation of Canadian Municipalities *Guide for Integrating Climate Change Considerations into Municipal Asset*

Management and the PIEVC protocol. The Figure 2 depicts the framework. The main components of the framework are Pre-requisites, Determining Risks, Determining Levels of Service, Prioritization, and Management.

Figure 2 – Proposed Methodology



Pre-requisite[1]

STEP 1: Identify Service Areas (Federation of Canadian Municipalities, 2019):

This is the primary step that lays the foundation of the delivery-centric approach. Also, this step is crucial in framing an Asset Management Policy and Strategy. This step forms the basis for incorporating a climate lens in the decision-making framework because if a municipality is not aware of the services it wants to provide its residents, it cannot improve it. Some of the services municipalities offer to their subjects are- Water, Sewer, Drainage, Recreation, Health/Emergency Services, Transportation, Solid Waste/Recycling, Electrical, etc.

STEP 2: Identify Assets that Support Service Provision (Federation of Canadian Municipalities, 2019):

[1] *After completion of the pre-requisites, an infrastructural asset is selected to incorporate the climate lens in its Asset Management Plan, i.e., an Asset Management organization shall be performing the subsequent steps for a selected asset*

Once the services are identified, the municipality must find the assets that facilitate those services. Again, this is a high-level step critical in formulating Asset Management Policy and Strategy. Now, there could be a scenario where different assets are providing the same service, i.e., there can be redundancies in the system as shown in Table 2. It is essential to be aware of all such redundancies to prepare a comprehensive plan. E.g.-

Table 2 – Asset Examples by Service Area (Federation of Canadian Municipalities, 2019)

Service Area	Assets
Water	Wells, reservoir, treatment facilities, pump stations, water mains, service connections, hydrants
Sewer	Sewer mains, manholes, service connections, pump stations, treatment facilities, outfalls
Drainage	Catch basins, manholes, culverts, storm mains, open channels/ditches, wetlands, detention ponds
Recreation	Community buildings, parks, equipment
Health/Emergency Services	Hospital, ambulances, fire hall, fire trucks, ambulance station, police station
Transportation	Bridges, roads, trails, curb and gutter, sidewalk, road signs, streetlights, traffic lights, buses, light rail
Solid Waste/Recycling	Trucks, landfill, recycling depot
Electrical	Transmission lines, transformers, generators, lighting, telecommunications

Step 3: Gather Regional and Local Climate Change Information (Federation of Canadian Municipalities, 2019):

After identifying services and the assets that provide them, gathering information about the climate projections that may impact the municipality in the short and long term is essential. It is a crucial step because until the municipality does not know about this data, we cannot predict how climate change will impact natural and built assets. There are several authentic sources from which this data can be made available at the federal and local levels. For E.g.- at federal level we have the *Canadian Centre for Climate Services (CCCS)*, a government-hosted website which offers a variety of information resources and assistance, and *Climate Network*, which in collaboration with Environment Canada provides historical climate data from across the country. Similarly, at the local level we have the *Climate Atlas of Canada,* a web-based science and education portal hosted by the Prairie Climate Centre and the University of Winnipeg, and *Pacific Climate Impacts Consortium*, which is a regional climate service center based at the University of Victoria, that offers useful information regarding the Pacific and Yukon.

Step 4: Identify Climate Change Hazards (Federation of Canadian Municipalities, 2019):

In order to address the climate-related risks, it is essential to identify the climate change hazards that impact the municipality. Hazards are physical events or phenomena that can cause habitat damage, injury or death, or economic disruption. Different municipal Infrastructural systems are being impacted by different types of climate hazards. For e.g. Sewer systems are impacted by excessive rainfall that may cause their capacity exceedance leading to surface surcharging and basement flooding. Long-term stagnation of water in the sewers due to capacity exceedance may lead to changes in wastewater effluent characteristics. Further, the cascading effects of flooding includes damage to buildings, tankage, and housed process equipment. Similarly, Transportation systems such as roads, bridges, culverts, etc. are adversely impacted by flooding, erosion, landslides, embankment failure, and more frequent thawing/freezing of soil. Also, the Health systems are impacted by different climate hazards that leads to higher demand for emergency services, damage to emergency services structures, longer response times, and reduced aide capacity.

Determine Risks

Step 5: Assess Risks from Climate Change (Federation of Canadian Municipalities, 2019):

The following methodology shown in Table 3 is based on PIEVC Protocol that shall be adopted to assess climate change risks (Sandink & Lapp, 2021).

Table 3 – PIEVC Steps and Main Tasks (Sandink & Lapp, 2021)

Step	Description	Main Tasks
-	Preparation	• Identify infrastructure for assessment (existing or new) • Determine the scope of assessment, including budget, timeline, and participants • Assemble Project Assessment Team
1	Project Definition	• Define structural and non-structural infrastructure components • Define climate parameters of interest/concern • Define future climate period(s) of interest – tied to the infrastructure life cycle • Define geographic location and boundaries • Determine risk levels and scoring (e.g., three, five, or seven levels – defined by the municipality and consultant • Determine high, medium, and low-risk scores

Step	Description	Main Tasks
2	Data Collection, Compilation, and Analysis	• Define climate parameter thresholds that would include component failure • Compilation and analysis of historical climate data to determine the probability of threshold exceedance and conversion to a likelihood score • Utilize climate projection models to determine the probability of exceedance in future climate periods of interest • Assemble infrastructure component information such as design drawings, age, condition assessments, etc.
3	Risk Assessment	• Conduct a Yes/No Analysis – is there an interaction with/between the component and climate parameter • Determine probability/likelihood score for exceedance of climate thresholds, for current and future climate • Determine the consequence score for a component climate parameter interaction, given that there is an interaction and that the climate threshold has been exceeded • Calculate the risk score for all climate/component interactions • Classify risk scores into risk levels to develop a current and future climate risk profile
4	Conclusions and Recommendations	• Describe risk profile (climate parameter/component interactions classified into risk levels – e.g., high, medium, low) • Identify high-risk interactions for early action, medium for future action, and low for monitoring • Develop recommended adaptation actions to reduce risk levels
-	Reporting	• Complete Project Assessment Report • Document all executed steps, including risk matrix or risk profile for current and future climate • Disclose limitations, gaps, and unknowns

A simple depiction of the risk assessment consequences from urban floods based on drainage services, health/emergency services, and transportation on a small, medium, and large scale (1–3) as shown in Table 4, Table 5, Table 6, and Table 7 would help to clarify the concept.

Table 4 – Sample Consequence Table (Federation of Canadian Municipalities, 2019)

Consequence	Public Health/ Safety	Financial	Service Interruption	Regulatory
1 - Insignificant	Nil	Insignificant (<$10k)	< 4 hours	No consequence
2 - Minor	Minor injuries/ illness	<$100k	Up to 1 day	Report violation
3 - Moderate	Severe injuries/ illness	$100k to $500k	1 day to 1 week	Ministry review, possible order
4 - Major	Major injuries to multiple parties, possible death	$500k to $1 million	1 week to 1 month	Financial penalty
5 - Catastrophic	Major injuries to multiple parties, possible death	$500k to $1 million	1 week to 1 month	Financial penalty

Table 5 – Sample Likelihood Table (Federation of Canadian Municipalities, 2019)

Likelihood	Descriptor	Frequency of Occurrence
1 – Rare	May occur only in exceptional circumstances	Beyond 20 years
2 – Unlikely	Could occur at some time	Within 10 to 20 years
3 – Possible	Will probably occur at some time	Within 5 to 10 years
4 – Likely	Will probably occur in most circumstances	Within 1 to 5 years
5 – Almost Certain	Expected to occur in most circumstances	Within 1 year

Table 6 – Sample Risk Matrix (Federation of Canadian Municipalities, 2019)

		Consequence				
		1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
Likelihood	1 - Rare	(1) L	(2) L	(3) L	(4) M	(5) M
	2 - Unlikely	(2) L	(4) M	(6) M	(8) M	(10) H
	3 - Possible	(3) L	(6) M	(9) H	(12) H	(15) H
	4 - Likely	(4) M	(8) M	(12) H	(16) H	(20) E

	5 – Almost Certain	(5) M	(10) H	(15) H	(20) E	(25) E

Table 7 – Sample Urban Flooding Risk Assessment (Federation of Canadian Municipalities, 2019)

Service Area	Vulnerability	Implications	Consequence	Likelihood	Risk Rating
Drainage	Community buildings and housing susceptible to damage during flooding	High volume or blockage; undersized resulting in sedimentation and overtopping	Medium (2): potential flood damage to structures or pooling on properties near undersized culverts	Low (1)	2 - Low
Health/ Emergency Services	Access to emergency services could be delayed during flooding	Road washout; lack of access to services, delayed emergency response	High (3): could delay emergency response	Medium (2)	6 - Medium
Transportation	Minor thoroughfares Streets are susceptible to flooding	Traffic delays; flooding and damage to road structure	Medium (2): traffic delays and rerouting to major roads	Medium (2)	4 - Medium

A more detailed description of climate-component interaction in assessing the climate risks using the above-mentioned PIEVC Protocol for GLENBOW MUSEUM, ALBERTA is enclosed along with the report as Appendix E (Bell A & Hawker R, 2022).

Determine Levels of Service

Step 6: Identify Levels of Service (Current and Target) (Federation of Canadian Municipalities, 2019):

Before incorporating the climate lens in the Asset Management Framework, it is vital to know the current levels of service (LOS) the assets can provide. Further, the levels of service need to be identified not only from internal/technical perspectives but also from the customer perspectives. After identifying the current LOS, one should determine whether the current LOS can fulfill the municipality's requirements. The LOS may be judged based on broad parameters such as regulatory requirements, safety, capacity availability, quality, reliability, and sustainability. It may not be possible that each of these indicators is quantifiable, but these must be measurable, i.e., either quantitative or qualitative.

If the current LOS is not satisfactory, then Council may set the target LOS to improve the services to its residents. The following Table 8 depicts the drainage level of service examples for safety and reliability service categories on a 4-point scale from low to very high to determine the current situation in the municipality.

Table 8 – Sample Drainage Level of Service (Federation of Canadian Municipalities, 2019)

		Drainage	
Service Categories		Safety	Reliability
Service Indicator		Buildings are protected against flooding	Streets are not susceptible to flooding
Example Levels of Service	1 – Low	Many areas and or critical services are exposed to significant flood risk, but do not have adequate flood protection	Flooding due to overflow and/or backup is frequent and significant
	2 – Moderate	All critical areas of the community have adequate flood protection but some other areas of the community exposed to significant flood risk do not have adequate flood protection	Flooding due to overflow and/or backup is frequent but not significant
	3 – High	Nearly all areas of the community exposed to significant flood risk have adequate flood protection	Flooding due to overflow and/or backup is not frequent and not significant
	4 – Very High	All areas of the community exposed to significant flood risk have adequate flood protection	Flooding due to overflow and/or backup rarely occurs

Step 7: Determine Gaps Between Current and Targeted Levels of Service (Federation of Canadian Municipalities, 2019)**:**

The municipality must identify service levels for which the present performance (i.e., current status) exceeds or falls short of the level of service obligation. The municipality must then identify the service levels that might be affected by a hypothetical future service delivery gap. Changes in land use, population, the economy, immigration, and other demographic factors can all affect the quality of service. This will help inform how the gaps can be overcome, for example, if current commitments need to be reconsidered. The following Table 9 depicts the gap and proposed actions between existing and committed LOS for drainage.

Table 9 – Sample Levels of Service Matrix (Federation of Canadian Municipalities, 2019)

Service Characteristic	Current Level of Service	Level of Service Commitment	Performance Gap	Options and/or Recommended Action to Address Gap
Regulatory	Discharges comply with statutory requirement	Minimum Level of Service	No	
Capacity/ Availability	Stormwater infrastructure is accessible for servicing lots through the service area	Some areas of the community do not have the opportunity to connect to the drainage system (but want/need to)	No	
Safety	Buildings are protected against flooding	Nearly all areas of the community exposed to significant flood risk have adequate protection	All critical areas of the community have adequate flood protection, but *some other areas of the community exposed to significant flood risk do not have adequate flood protection*	Upgrade drainage assets to provide adequate capacity during design flood events so that all areas of the community exposed to significant flood risk have adequate flood protection
Reliability	Streets are not susceptible to flooding	Flooding due to overflow and/or backup is infrequent and not significant	Flooding due to overflow and/or *backup is frequent but not significant*	Do nothing
Environmental	Providing the service generates a low environmental	Minimal reductions in GHG emissions (compared to	No	

Service Characteristic	Current Level of Service	Level of Service Commitment	Performance Gap	Options and/or Recommended Action to Address Gap
	impact	baseline)		

Step 8: Assess Climate Change Considerations on Levels of Service (Federation of Canadian Municipalities, 2019):

After assessing the risks of climate change, we evaluate the impact of climate change on the Levels of Service. Generally, the Level of Service due to climate change would always be a function of risks due to climate change, so we should assess the impact of climate change on LOS after the risk assessment due to climate change.

The municipality should determine the vulnerability of the infrastructural asset due to climate change based on their exposure, sensitivity, and adaptive capacity. Thereafter, the municipality shall determine the implications of vulnerability on the infrastructure, organization, and systems. Subsequently, also find out the impact of climate change on future vulnerabilities based upon the data gathered in Step 3. Finally, the municipality shall identify the infrastructural asset's top 3–5 vulnerabilities.

Some communities are updating their IDF curves to include climate change projections in order to address the issue of identifying future vulnerabilities. E.g., The City of Kitchener did this as part of their Stormwater Master Plan, based on the University of Waterloo's predictions.

Prioritization

Step 9: Identifying Strategies to Address Gaps and Risks due to Climate Change (Federation of Canadian Municipalities, 2019):

The municipality should prioritize the identified gaps (for both risks and LOS) from high to low for an infrastructural asset. For each unacceptable LOS gap or risk, identify alternative remedies such as generating new assets, adopting an O&M strategy, disposing of assets, demand management, and doing nothing. A few e.g., of climate change mitigation and adaptation are:

Mitigation

- Supporting low-emissions fleet and transportation options.
- Improving the energy efficiency of existing and new facilities.
- Protecting/enhancing natural assets using land-use policies and bylaws.

Adaptation

- Increasing system redundancy to enhance system robustness.
- Increased culvert maintenance to improve flood resilience.
- Increasing drinking water storage capacity.

Step 10: Determine Preferred Strategies to Mitigate or Adapt to Climate Change (Federation of Canadian Municipalities, 2019):

The municipality shall look at effectiveness, feasibility, equitability, flexibility, or similar values that are important to the community. Subsequently, the municipality shall list several financially feasible options, including a lifecycle cost assessment. The preferred strategies can be those the municipality feels are most appropriate to tackle immediate concerns or consist of short- and longer-term actions. Addressing climate change is not a one-time task. So, the municipality will want to review its strategies on a cyclical basis to ensure they still make sense and are appropriate from a lifecycle costing perspective.

In order to select the preferred strategy, the municipality can use risk-return on investment tools that evaluate the impact of the hazard from social, economic, and environmental perspectives and offer the best return on investment based on Net Present Value and Internal Rate of Return for using that strategy.

Management

Step 11: Integrate Actions into Asset Management Plans (Federation of Canadian Municipalities, 2019):

The next step in the process is to determine what actions will be required when they will be required, who will be responsible, how much they will cost, and how they will complete the steps. This can be incorporated into your corporate or service-specific asset management plan(s), or, in some cases, through your corporate asset management strategy's action plan. The critical components of an action plan are shown in Table 10 below

Table 10 – Key Components of Action Plan (Federation of Canadian Municipalities, 2019)

Actions	Justification	Timeline	Responsibility	Resources	Budget
What steps need to be taken? • Consultation • Plans • Strategy implementati on	Why is this important? How does it support Council's existing policies,	When does it need to be done by? Do we have a way to monitor	Do we have goals, buy-in, and priorities? Who is responsible for implementation?	Who is a part of the project team? Do we need an expert?	Do we have a way to monitor budget? Are there pressures on the long-

• Monitoring • Review	strategies, or Strategic Plan?	progress?			range capital budget?

Step 12: Monitor Progress and Explore Opportunities for Continuous Improvement (Federation of Canadian Municipalities, 2019):

Monitoring and evaluation are tools that can help with continuous improvement. The goal should be to make it easier for users and decision-makers to understand what works well and what should be changed over time. In order to do this effectively, the municipality needs to-

Develop a plan to track the implementation progress and effectiveness of adaptation and mitigation measures.

Set timelines for assessing frameworks and processes. This is a chance to rethink internal capacity, when to introduce additional services, etc.

Establishing a record-keeping system to ensure all key stakeholders have access to program components and new information is documented promptly.

Finally, communicate accomplishments.

Gap between the methodology and the current practice:

Following are the gaps which need to be addressed:

- Incorporation of climate lens in the asset management plans.
- Use of a common framework having a consistent and transparent approach.
- Use a common language for understanding asset management infrastructure planning and definitions.
- Proactive decision-making framework for capital planning
- Collaborations across Branches, where needed, for better coordination and effective achievement of goals (Buckert & Bhalla, 2022).
- More work needs to be done for capacity building and sensitization of staff and other stakeholders towards climate change impacts.

Recommendations

Some of the recommendations for the City of Vancouver towards their goal for incorporating climate risk component into their central decision-making tool to be used across all assets within their Engineering Services Department include- Incorporating the climate lens up-front while preparing the Asset Management Plans as it is more streamlined and efficient to do it that way (Buckert & Bhalla, 2022). Also, one can integrate future demand into account. It is often challenging to incorporate the climate lens afterward (Buckert & Bhalla, 2022); Following a delivery-centric approach instead of an asset-centric approach. However, once the asset is defined (i.e., after step 4 as defined in the methodology), we need to assess the risk and impacts of climate change on the Level of Service on that particular asset; Evaluating the risks of climate change prior to evaluating the level of service component as impacts of climate change on LOS cannot be significantly calculated until we are aware of the risks; Using step by step approach mentioned in PIEVC protocols for evaluating the risks (Sandink & Lapp, 2021); Using Risk return on investment tools to help decide the preferred strategies (Zimmer C & Tariq A, 2020); Incorporating climate-related risks and its impacts on LOS in their Sewers AMP expeditiously as the most significant climate hazard for the City of Vancouver is flooding, and the primary asset which can contribute the most to making the system resilient to flooding is sewers; Selecting scenario 1 (100% segregation of sanitary and stormwater sewers by2050) (Sewers and Drainage Design Branch, 2020)may not be the best bang for the buck. Hence, a combination of other options shall be explored expeditiously to decide upon the preferred strategy; Using GII strategies more proactively to increase redundancies in the system, especially more use of natural ecosystem shall be encouraged (Buckert & Bhalla, 2022); Using low carbon emission materials for construction. E.g., using plastic waste in the construction of pavements and streets would reduce the carbon footprint by less consumption of asphalt and ease the pressure on landfills due to the non-accumulation of non-biodegradable plastic; Increasing sensitivity and exposure of staff towards the impacts of climate change and providing trainings for skill development in this area.

More Research Required

Some of the areas that require more research for better incorporation of climate risk component in the Asset Management Plans include- Studying Asset Management Policy of the City of Guelph wherein climate change has been integrated using climate-related key performance indicators into their Level of Service Framework (Federation of Canadian Municipalities, 2019); Exploring more on Risk Return on Investment tools for having the best bang for the buck based on Net Present Value and Internal Rate of Return (Zimmer C & Tariq A, 2020); Looking into flood mitigation strategies of Surrey and Edmonton as they are performing better than Vancouver

(Feltmate B & Moudrak M, 2021); Exploring and studying more reports on PIEVC protocol to better understand the incorporation of climate risk in Asset Management Plans (Sandink & Lapp, 2021); Explore the use of Green Infrastructure Initiatives in natural ecosystems (Buckert & Bhalla, 2022); Exploring the option of use of low carbon emission materials in construction.

Summary

The adverse impacts of climate change can be seen all around the world and it is high time that municipalities incorporate the climate lens in all of their decision-making strategies. The best approach to address the problem of climate change is to use a combination of mitigation and adaptation strategies.

Two different frameworks, i.e., the BC Asset Management (BCAM) and Federation of Canadian Municipalities (FCM) frameworks were reviewed and discussions were held with internal and external subject matter experts on City of Vancouver specific considerations. Thereafter, the current asset management plans of various infrastructural assets were also reviews and issues in the current state of asset management in the City of Vancouver were highlighted. Based upon the literature review, discussions with the subject matter experts, and the shortcomings in the current state of asset management in the City of Vancouver a case for using a customized methodology based on the FCM guide and PIEVC protocol was discussed.

The research has proposed a comprehensive framework to include a climate risk component into a central, standardized decision-making tool for all asset classes within the Engineering Services Department. One of the key takeaways in the report is to adopt a specialized service delivery-centric strategy based on the FCM guide and PIEVC protocol as opposed to an asset-centric strategy. Other key takeaways include assessing climate change risks before determining the impact of climate change on level of service (LOS), using risk-return on investment tools, and implementing more green infrastructure initiatives (GII), particularly leveraging the natural ecosystem to increase system redundancy.

Finally, the report suggests specific areas where more research is required for a better understanding of the incorporation of climate risk in Asset Management Plans. For e.g., exploring the asset management policy of the City of Guelph; exploring more risk return on investment tools; looking into the innovative flood mitigation strategies of Surrey and Edmonton; and studying more reports on PIEVC protocol.

Conclusion

In order to incorporate a climate lens in the asset management plans of the infrastructural assets, it is proposed that the City of Vancouver follows the proposed methodology mentioned in the report above, which is broadly founded upon the Federation of Canadian Municipalities guide and PIEVC protocol for assessing risks due to climate change. The proposed methodology is based on a delivery-centric approach rather than an asset-centric approach and is more comprehensive in terms of coverage of all the different infrastructural assets.

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Appendix A – Glossary of Terms

Risk: It is the possibility of unfavorable outcomes as a result of an incident, event, or occurrence. This comprises the consequence and likelihood of a service disruption or asset failure. Risk = probability x consequence. To assess the risks to service delivery in our communities, we must comprehend the potential hazards to which assets may be exposed, the vulnerabilities that may exist, the possibility that a hazard could exploit a vulnerability, and the resulting impacts and consequences. For e.g, increased precipitation combined with inadequate drainage systems could result in localized flooding. Flooding can have a range of effects and consequences, from low if it occurs in a parking lot or field to severe if it occurs in a populated region or prevents access to emergency services (e.g., loss of life or property) (Federation of Canadian Municipalities, 2019).

Level of service: These are specific parameters describing the extent and quality of services the municipality provides to users. Local factors, decision-maker priorities, provincial, territorial, and federal rules, and customer expectations determine service levels. Community expectations are essential when assessing service levels, costs, and risks over the lifecycle of assets (Federation of Canadian Municipalities, 2019).

Climate change mitigation strategies: Strategies that reduce the magnitude and rate of climate change, typically by reducing greenhouse gas emissions (Asset Management BC, 2019).

Climate change adaptation strategies: Strategies that increase a community's resilience to climate change's impacts (Asset Management BC, 2019).

Exposure: It refers to whether infrastructure systems will be impacted by the climatic change (Asset Management BC, 2019).

Sensitivity: It is an evaluation of how much the climatic change will impact the functionality of the infrastructure system (Asset Management BC, 2019).

Adaptive capacity: The infrastructure system can adjust to the impacts of climatic change (Asset Management BC, 2019).

Vulnerability: It is the product of sensitivity and the system's adaptive capacity (Asset Management BC, 2019).

Appendix B – EGBC Guidelines (Engineers & Geoscientists BC, 2021)

The Engineers and Geoscientist of British Columbia framed *Professional Practice Guidelines- Local Government Asset Management* to assist and help the Engineering and Geoscience Professionals who provide a variety of professional services to Local Governments in the area of asset management. However, it is important to understand the need, scope and principles for framing these guidelines.

Need for framing such guidelines:

- To highlight the importance of Asset Management to local governments.
- To maintain consistency across British Columbia as there was a lack of understanding & participation by some Engineering and Geoscience professionals.
- To standardize the approaches to Asset Management as different professionals followed different approaches.

Scope of these guidelines:

- These guidelines are not intended to provide technical or systematic instructions for how to carry out these activities; rather, these guidelines outline considerations to be aware of when carrying out these activities.

Principles of these guidelines:

- These guidelines are based on the principles outlined in "Asset Management for Sustainable Service Delivery: A BC Framework" (Asset Management BC 2019), which provides a high-level, systematic approach to assist Local Governments in achieving service, asset, and financial sustainability through an Asset Management process.

Appendix C – BCAM Framework (Asset Management BC, 2019)

This section covers the BCAM framework in detail. The key point to consider here is that after identification of the critical infrastructural asset this approach is used to formalize and create an asset management plan. This approach was not selected as the recommended choice for City of Vancouver but allows for additional considerations and integration when building a risk framework and developing decision-making tools for Strategic Asset Management. There are certain pre-requisites which a municipality should fulfill to use this approach for formulating an Asset Management Plan. Firstly, the municipality should be aware and have knowledge of the asset inventory they have. Secondly, the municipality should be aware about the impacts of climate change happening in their jurisdiction and their impact on service delivery. The second step is very important because this awareness would enable the municipality to integrate the climate change response into asset management to manage liability risks. The following Figure 3 depicts the Asset Management Framework.

Figure 3 – Asset Management Framework (Union of BC Municipalities et al., 2019)

ASSESS:

Assess Asset Management Practices:

Assess AM practices to identify the existing level of integration, gaps, and potential for expanding the integration of climate change response throughout the AM Process. Using a climate response lens to evaluate asset management methods reveals how well these efforts are integrated with existing asset management processes and points out areas for improvement. Climate change is one of the 21 assessment categories. High-level deficiencies in integrating asset management and climate change can be found using this assessment category.

Assess the current state of Assets:

Assess asset vulnerability to climate change and purchase lifecycle emissions. The goal is to determine how climate change will affect service levels, risk, and cost.

PLAN:

Asset Management Policy:

Formalize in the AM policy the organization's commitment to combining climate change response with AM. The policy may specify where climate change response and asset management should be linked throughout the lifecycle of an asset. The AM strategy or plan and not the AM policy will outline the specifics of how climate change response and asset management are merged.

Asset Management Strategy:

Determine the organization's strategy for combining climate change adaptation, mitigation, and asset management. Asset management strategies should specify precise objectives and targets for strengthening community resilience to climate change through asset management, as well as the strategy for achieving those objectives.

Asset Management Plan:

These plans give us a chance to think about the effects of climate change in the context of other asset risks, costs, and service goals, and to come up with a set of actions that are both integrated and cost-effective.

Activities involved in this are-

- Clarify desired service levels using identified asset vulnerabilities, and categorize how climatic changes will impact the ability to deliver service levels.

- Identify opportunities for climate risk management through other asset management activities: (e.g., when replacing an asset due to poor condition or capacity, design the replacement to reduce climate risk).
- Evaluate the costs benefit analysis of available adaptation approaches.
- Choose the appropriate approaches and levels of service. Approaches should be developed to maximize benefits, which should be taken into account when weighing costs and benefits.
- Determine opportunities for emission reductions through other asset management activities (e.g., choosing energy-efficient or low emissions models when replacing assets).
- Determine the operational and maintenance activities that will be carried out to reduce climate risk and mitigate climate change.

Long Term Financial Plan:

It includes climate change mitigation and adaptation in the long-term financial plan. It includes funding strategies and risks to those funding strategies. When implementing adaptation and mitigation efforts, it's important to consider how climatic changes may affect service delivery costs and funding.

Activities involved in this are-

- Evaluate the costs of delivering current service levels and managing risks without investments in adaptation.
- Identify the increase in costs for incorporating climate change and ways to minimize these costs.
- Determine revenue and funding sources.
- Identify strategic level funding concerns associated with climate change.

IMPLEMENT:

Implement Asset Management Practices:

Implement AM practices in conjunction with an integrated climate change response. This is about putting plans into action.

Measure and Report:

Report to staff, council or the board, and the public on the organization's climate resilience and services.

Appendix D – FCM Framework for incorporating climate lens into Asset Management (Federation of Canadian Municipalities, 2019)

A brief description of the various stages is as follows:

Step 1: Identify Service Areas: The municipality shall identify the services it provides or aims to provide to the community.

Step 2: Identify Assets that Support Service Provision: The municipality should figure out what built or natural assets are required to deliver these services.

Step 3: Gather Regional and Local Climate Change Information: The municipality shall find out the climate projection data that is available regionally & locally and try to derive information on the basis of the available data so that suitable actions or decisions could be taken.

Step 4: Identify Climate Change Hazards: The municipality should know that what are the hazards that most impact their jurisdiction. For e.g for one municipality it may be floods, whereas for the other municipality it may be a heat wave and for the third municipality it may be both.

Step 5: Identify Levels of Service (Current and Target): The municipality shall have information about the level of service being provided and is it different from their committed level of service. They should also be aware that how climate change is impacting the delivery of each service.

Step 6: Determine Gaps Between Current and Targeted Levels of Service: The municipality should know that whether there is any gaps between their existing and desired levels of service. If the municipality is meeting their desired level of service, then they should assess that can their performance be sustained over time.

Step 7: Assess Climate Change Considerations on Levels of Service: The municipality should know the impacts of climate change on their level of service of different infrastructural assets. They should also evaluate where they are most vulnerable.

Step 8: Assess Risks from Climate Change: Municipality should work out the consequence and likelihood of the occurrence of a climate hazard. They should also incorporate the impacts of the climate change in their future designs.

Step 9: Identifying Strategies to Address Gaps and Risks due to Climate Change: Municipality shall try to figure out viable strategies to address current and future gaps. Municipality needs to be more proactive in its approach to tackle impacts of climate change.

Step 10: Determine Preferred Strategies to Mitigate or Adapt to Climate Change: Using risk-return on investment tools the municipality should select a preferred strategy for each unacceptable risk or LOS gap.

Step 11: Integrate Actions into Asset Management Plans: Municipality should have a dedicated team or a champion who can move all their planning into action.

Step 12: Monitor Progress and Explore Opportunities for Continuous Improvement: Municipality should continuously evaluate and monitor itself to improve further.

Appendix E – GLENBOW MUSEUM, ALBERTA (Bell A & Hawker R, 2022)

Background:

The Glenbow Museum Revitalization Project ("the revitalization") is being led with funding support from federal and provincial grant programs, including funding through the Investing in Canada Infrastructure Program – Community, Culture, and Recreation stream. As a requirement for receiving this funding, the revitalization project must complete a Climate Lens Assessment, including GHG Emissions Assessment and Climate Change Resilience Assessment.

Scope:

It has two aspects to it. Firstly, structural and non-structural components of the museum are impacted due to risks of climate change. Secondly, the climate change hazards. Understanding climate change risks requires understanding how climate change could directly affect the site and how impacts on broader municipal systems (e.g., roads and water systems) could have knock-on effects on museum infrastructure and services.

Regarding the first aspect (structural and non-structural components of the museum) as shown in Table 11, the scope of the assessment considered climate risks to built infrastructure assets, human wellbeing, and the natural environment.

Table 11 – Museum Component Assessed (Bell & Hawker, 2022)

Calgary Framework	Building Component	Sub-Components
Built Infrastructure Assets	Envelope & Enclosure	walls, air tightness, cladding, bellow grade walls, roof, glazing
	Structural	columns, beams
	Electrical Systems	lighting, power, access and security, emergency power, elevator controls, communications
	Mechanical Systems	boilers, ventilation and humidification, cooling and energy recovery, natural gas
	Plumbing & Storm/Sewers	domestic cold water, domestic hot water, stormwater drainage, sanitary drainage
	Renewables	solar PV
	Site Features	outdoor feature spaces (2), outdoor terrace
	Building Access	doors, ramps, and access, elevators, loading bays
	Museum Program Areas	collections, exhibits, visitor service space
	Construction	heavy vehicles, construction equipment, construction electricity
	Operations	maintenance equipment, maintenance activities
Human Wellbeing	Human Wellbeing	construction personnel
		operations personnel
		users
Natural Environment	Natural Environment	natural infrastructure
		ecosystem health and biodiversity

Regarding the second aspect, the assessment considered eight climate change hazards relevant to the Glenbow Museum site, which are as follows:

1. Short duration high intensity (SDHI) rainfall/storms
2. Extreme heat, heat waves
3. Increased air temperature in all seasons
4. Major River flooding
5. Severe storms (i.e., wind hail, ice, thunder, and lightning)
6. Heavy winter storms
7. Increase in drought days
8. Wildfire smoke.

The resilience assessment was undertaken using three core periods: • Present/Baseline (1981-2010); • the 2050s (2041-2070); and • 2080s (2071-2100).

Methodology:

Systemic Analysis of Risk:

The assessment considered vulnerability and risks from eight climate hazards on 39 individual building, site, and programming components grouped under 16 broader museum components or systems. There were a total of 312 hazard-component interactions, and out of which 197 interactions were screened and assessed for present-day, the 2050s, and 2080s conditions. The risk evaluation matrix and the climate risk rating scale is shown below in Table12 and Table13 respectively.

Table 12 Risk Evaluation Matrix (Bell A & Hawker R, 2022)

Consequences	Severe	Medium Risk	High Risk	High Risk	Very High Risk	Very High Risk
	Significant	Low Risk	Medium Risk	High Risk	High Risk	Very High Risk
	Moderate	Low Risk	Low Risk	Medium Risk	High Risk	High Risk
	Minor	Very Low Risk	Low Risk	Low Risk	Medium Risk	Medium Risk
	Negligible	Very Low Risk	Very Low Risk	Low Risk	Low Risk	Low Risk
		Very Low	Low	Moderate	High	Very High
				Likelihood		

Table 13 Climate Risk Rating Scale (Bell A & Hawker R, 2022)

Risk Classification	Rating	Description of Risk	Recommended Risk Treatment
Very Low	1-2	• No permanent damage • No service disruption	Tolerable: risks do not require further consideration
Low	3-6	• Minor asset or system damage • Minor service disruption may occur • Minor repairs or restoration	Monitor: controls or coping strategies recommended
Medium	5-9	• Limited damage to asset or system • Brief service disruption may occur • Minor repairs and some equipment replacement or restoration	Requires some attention: Some controls required to reduce risk levels. Monitor risk for changes over time.
High	10-16	• May result in significant damage, loss, or require complete replacement • Lengthy service disruptions may occur	Requires much attention: high priority control measures required.
Very High	20-25	• May result in significant damage, loss, or require complete replacement • Lengthy service disruptions may occur, alternate service delivery may be required	Not acceptable: Significant controls required.

Outcome of Climate-Infrastructure Interactions:

As per the Climate Lens Guidelines for risk treatment approaches, at least one (but often multiple) climate resilience measures were identified for each medium (n=150), high (n=142), and very high[2] (n=8) risks. This is shown below in Table14

Table 14 Climate-Infrastructure interactions by assessed periods (Bell A & Hawker R, 2022)

	Present	2050s	2080s
Low Risk Interactions	132	73	31
Medium Risk Interactions	28	68	54
High Risk Interactions	3	55	84
Very High Risk Interactions	0	0	8

Resilience Measures based on Climate-Infrastructure Interactions:

Resilience measures were identified for all medium, high, and very high-risk interactions to mitigate these risks and improve low-carbon resilience. The input was collated and expanded upon to reflect industry best practices and ensure at least one resilience measure was provided for each medium, high, and very high risk. Next, the resilience measures were categorized as either "base measures" or "enhanced measures" using a benefit-cost ratio (BCR) approach. The benefit (also referred to as "effectiveness") and cost of each measure were evaluated using a three-point rating scale. The BCR was evaluated for each resilience measure using the following formula: BCR = Benefit Score/Cost Score.

The resilience measure was categorized as strongly suggested for selection as a "base measure" if the BCR was equal to or greater than one. Resilience measures with a BCR of less than one was categorized as "enhanced measures" and considered optional measures for the design team to explore further. The Cost Rating Scale Criteria, Benefit/Effectiveness Rating Scale Criteria, and the co-benefits are mentioned in Table 15, Table 16 and Table 17 respectively.

[2] Wildfire and SDHI storms are the climate hazards responsible for the very high-risk interactions. Both of these climate hazards have a significant increase in likelihood in the 2050s and 2080s time periods.

Table 15 Cost Rating Scale Criteria (Bell A & Hawker R, 2022)

Rating Score	Rating Title	Rating Description
1	Lower cost	Measure can be implemented and maintained through minor adjustments to planned systems or using existing resources (e.g. staff).
2	Moderate cost	Time and capital costs to implement and maintain this measure over time are notable but considered reasonable.
3	Higher cost	Time and capital costs to implement and maintain this measure over time are significant. New structures or expensive materials or new technology with high or unknown maintenance requirements will be required.

Table 16 Benefit/Effectiveness Rating Scale Criteria (Bell A & Hawker R, 2022)

Rating Score	Rating Title	Rating Description
1	Lower or uncertain effectiveness	Measure would need to be combined with others to adequately treat the risk on this component to acceptable levels.
2	Moderate Effectiveness	Measure makes a significant contribution to treating risk but may require combination with other measures to fully treat risk.
3	Higher Effectiveness	Measure fully treats the risk to this component and reflects an innovative approach or industry best practice.

Separate from the BCR, resilience measures co-benefits were also listed where applicable.

Table 17 Co-benefits identified across resilience measures (Bell A & Hawker R, 2022)

Co-Benefit	Description
Operational GHG mitigation	Causes lower GHG emissions associated with energy use than other options
User comfort	Supports physical comfort of museum staff & visitors
Aesthetics	Supports happiness and enjoyment of museum staff & visitors
Accessibility support	Improves the ability of users of all abilities to enjoy the museum safely
Habitat enhancement	Provides or enhances habitat for wildlife
Worker health and safety	Protects health and safety of museum staff and construction workers
Water consumption reduction	Reduces environmental impact and demand for water for regular operation
Urban heat island reduction	Helps to mitigate climate impacts more broadly across the City

Co-benefits and the number of risks that each measure addresses provide additional considerations for the Design Team to take into account when refining and implementing “base measures” and “enhanced measures

Selected Resilience Measures:

The Resilience Team identified 94 unique resilience measures to address all identified medium, high, and very high climate-related risks for the Glenbow Museum. Of these, 88 were determined to be “base measures” (selected), with the remaining six measures identified as “enhanced measures" (optional). Measures were placed on prioritizing actions that address multiple risks, build-in system redundancy and adaptive management, and prioritize no-regrets options that are appropriate for a range of future scenarios.

Conclusion:

The revitalization of the Glenbow Museum in Calgary, Alberta, presents a significant opportunity to incorporate climate resilience into one of Calgary's key cultural landmarks. The Climate Lens Resilience Assessment for the Glenbow Museum took a comprehensive and holistic approach to consider how impacts from eight climate-related hazards could affect the museum building, site, and programs.