Canadian Network of Asset Managers

APPLIED CLIMATE ACTION COHORT

WORKSHOP NO. 3

2023

CONTENTS

This initiative is offered through the Municipal Asset Management Program, which is delivered by the Federation of Canadian Municipalities and funded by the Government of Canada.

SESSION 3: CLIMATE CHANGE AND RISK MANAGEMENT

LEARNING GOALS

After completing this module, you will be able to:

1. Identify the steps in risk management and understand the purpose of each step.
2. Identify how to integrate climate risk into asset management processes.
3. Evaluate available tools and resources to choose what is best suited to your needs.
4. Identify lessons learned from other organizations to inform your team and organization's approach.

USING THIS WORKBOOK

LEARNING GOAL

Specific learning outcome to be achieved.

ACTIVITY

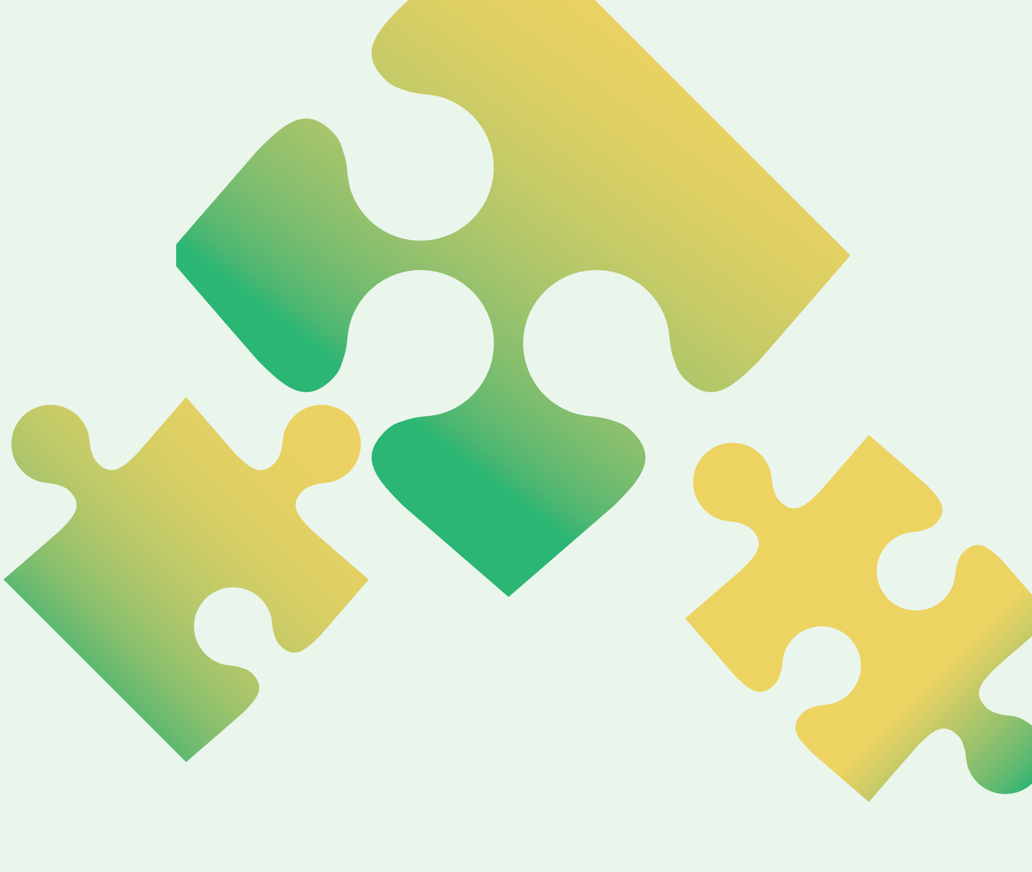
Individual or group exercises that provide practical learning opportunities.

GLOSSARY

Definitions of words and phrases used throughout the course.

RESOURCES

Additional helpful materials related to the topic.



WELCOME

Welcome to the third workshop of the CNAM Applied Climate Action Cohort! Today is all about climate change and risk management. To start the day, your facilitators will be setting up breakout room discussions between municipalities with some suggested topics based on what was heard during check-in support. This is an opportunity for you to both learn about other participants' journeys so far, as well as to share your own.

Here are a few prompting questions to help you along:

- How has your team collaborated since the last workshop?
- Are you making progress in the goals/objectives you defined in the first workshop? What has been helpful in making progress/what challenges have you run into?
- Have any other goals related to integrating climate action with asset management come up for you along the way?
- What's one piece of advice you'd give to others that are working towards the same goals?

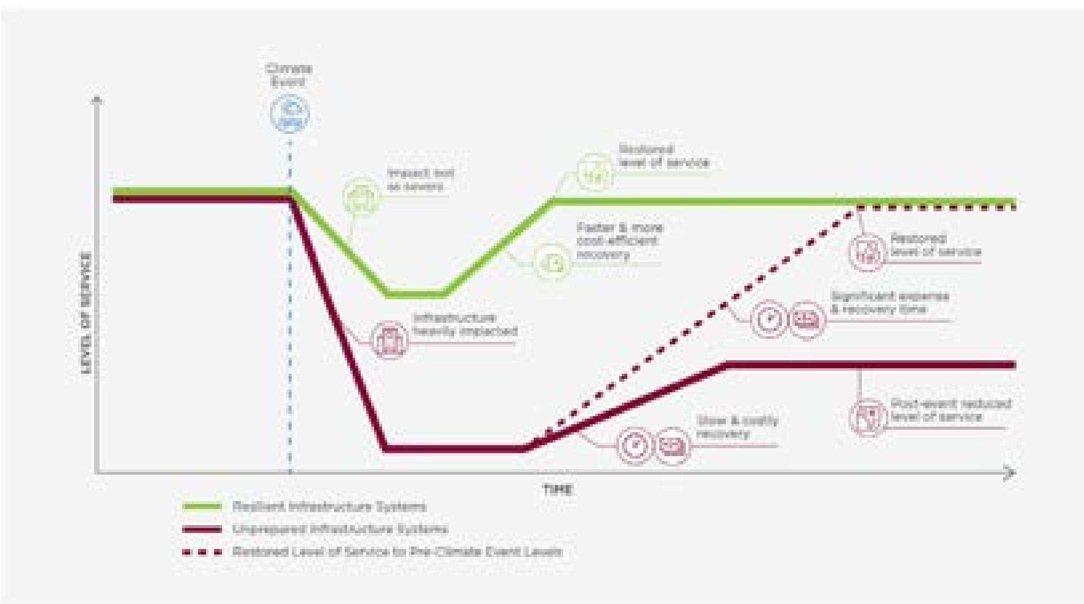
SETTING THE STAGE

Asset management is a process that involves managing service, risk, and cost—all of which are inherently connected and required to meet the main objective of asset management: to ensure sustainable service delivery. In today's world, ensuring sustainable service delivery requires us to adapt our services to be resilient to the challenges of a changing climate.

Integrating climate considerations into the asset management process is a way of building that resilience. Building resilience does not mean impacts to services will not occur, but organizations can build the necessary 'muscles' required to respond more effectively these challenges. In a resilient system, impacts will be less frequent or less significant, and recovery will happen more quickly.

The diagram below shows how services may be disrupted given a climate event. An infrastructure system that is not adapted to climate change may face significant long-term disruptions. The infrastructure systems that is resilient may still face disruptions, but the impacts are minimized, and recovery happens more swiftly.

Figure 1: Resilience Infrastructure Systems



Source Reference - FCM: Operations and Maintenance for Climate Resilience, https://fcm.ca/en/resources/mamp/tools-operations-and-maintenance-climate-resilience

Risk management processes are critical in achieving resilience by allowing organizations to focus on what matters most. While risk is a seemingly straightforward concept - a product of consequence and likelihood - it becomes more complex when we attempt to scale it up to a systems-level. As we consider many different types of risk, various probabilities of uncertain events, different perceptions of impact, and multiple different options for risk assessment processes or tools, it can quickly become overwhelming.

Despite this complexity, we all deal with risk in our day-to-day lives, using our intuitive perceptions of risk to inform our decisions. However, to manage risk at the organizational level, we need a more structured and comprehensive approach. This is where risk management processes come in, providing a framework for identifying, assessing, and treating risks in a systematic and consistent manner.

Over the next two days, the purpose is to: build a common understanding of the basics of risk management; review practical approaches to integrating climate risk into asset management through case studies; and provide an opportunity to share experiences, challenges, and lessons learned with each other, ultimately strengthening our collective ability to manage risk and build resilience.

WHAT WE WILL COVER:	WHAT WE WILL NOT COVER:
. Foundations of risk management, including steps in the process . Practical applications of risk management to climate and asset management . Integration of climate risk and asset management . Culture of risk management . Time to discuss and learn from other participants . Case studies of risk management in action	. Detailed guidance of how to implement each stage of risk management . Time to complete a risk assessment

RISK MANAGEMENT

Risk management is not a one-off, nor a standalone process. It is an ongoing process that involves continuous improvement to incorporate changes over time and integration to other processes within the organization. Risk management should be integrated into strategic planning, project management, and operational decision-making to ensure that risks are considered at various levels and in alignment with the organization and the community's objectives.

The purpose of risk management in asset management is to support decision-making and resource allocation to ensure services that the community depends on are reliable. Through asset management processes, we seek to manage many kinds of risks that impact sustainable service delivery – including climate risk.

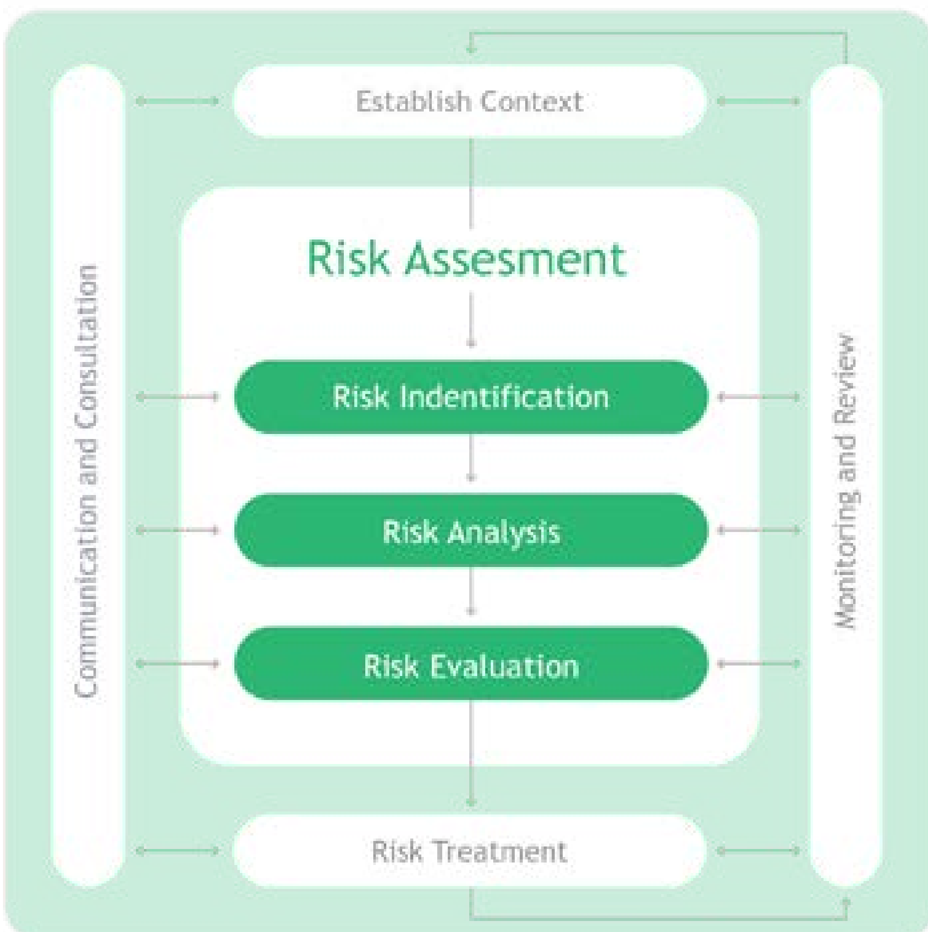


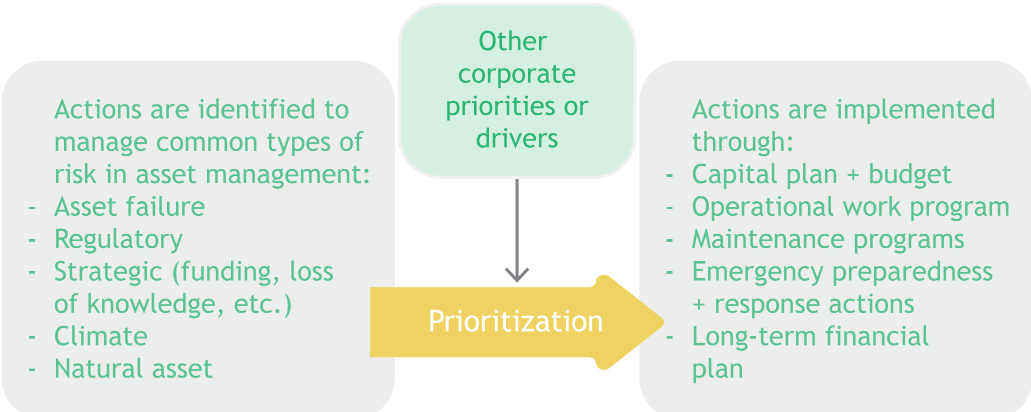
Figure 2: ISO 31000 Risk Management Process

INTEGRATING CLIMATE RISK AND ASSET MANAGEMENT

There are many approaches, tools, and resources to support local governments in identifying and assessing different types of risk (these will be discussed later), including climate, asset risk, and other kinds of risk.

CLIMATE RISK ASSESSMENTS	ASSET RISK ASSESSMENTS	OTHER RISKS ASSESSMENTS
What are the risks that climate hazards pose to service delivery and supporting infrastructure?	What are the risks that asset failure poses to service delivery?	Can include strategic risks, financial risks, environmental risks, health and safety risks, social risks, etc.

When it comes to taking action to treat risks, local governments need to be able to integrate information about different kinds of risk and make decisions about what should be done and in what order. Actions or projects to manage risk are also prioritized against actions or projects driven by other factors, like increasing service levels or servicing growth.



Often, the discussion around climate risk is focused on the identification and assessment of risk. This is an important step, but too often the results of the assessment do not inform action.

When we think about our approaches to risk identification and assessment, we need to think ahead to how the information will be used and how projects or actions will be coordinated with or prioritized against other projects.

This module will be focused on climate risk management and the integration with asset management.

What processes do you have in place to identify, assess, and manage risk to service delivery? Brainstorm some ideas in the space below.

STEP 1: ESTABLISH CONTEXT

Setting the stage for your risk assessment process will help you define and customize the risk assessment process to enable appropriate and effective risk treatments. It starts with:

1. Establishing clear objectives. What decisions will be informed by this work?
2. Identifying what risks you are assessing. Is this assessment approached through a climate lens? An asset lens? A strategic lens?

Identifying the scope, context, and criteria of your risk assessment will help you choose the best tools and resources for meeting your assessment objectives.

SCOPE defines the boundaries for the assessment both physically and in time that guide the expected results. Where and what is being assessed, and over what timeframe?

CONTEXT directs the focus of the work internally or externally, and in many cases both (aka a blended approach). Is the focus on systems that are under the direct control of the organization? Or is the focus on effects on other parties, or even broad social impacts?

Getting the right people involved depending on the context is crucial. Who's involved in setting the context, assessing risks, determining options for risk treatment, and implementing actions?

- An **external context** includes influences that are outside of the organization, but that impact the organization such as: social, cultural, political, legal, regulatory, financial, technological, economic, natural and competitive environments.
- An **internal context** includes influences with the control of the organization that impact the organization. It should consider the organizational objectives and processes that will affect or be affected by the risk management process, and the people and roles who will be impacted.

CRITERIA creates conditions for achieving outcomes that are aligned with the values, objectives, and resources of the organization. How much risk is the organization willing to take (or not take)? How will the organization determine the significance of those risks? Factors to consider when defining risk criteria:

- The nature and types of causes and consequences that can occur and how they will be measured
- How likelihood will be defined
- The timeframe(s) of the likelihood and/or consequence(s)
- The views of stakeholders
- The level at which risk becomes tolerable
- Whether combinations of multiple risks should be considered and, if so, how and which combinations should be considered.

CASE STUDY: INTEGRATING CLIMATE CHANGE INTO ASSET MANAGEMENT RISK ASSESSMENTS IN THE CITY OF CASTLEGAR

<table>
<tr><th></th><th>WHAT DOES THAT LOOK LIKE FOR CLIMATE RISK?</th><th>WHAT DOES THAT LOOK LIKE FOR ASSET RISK?</th></tr>
<tr><td rowspan="2">SCOPE</td><td colspan="2">The objective of this case study is to summarize the risk-based approach to integrate climate change with asset management into the capital planning process for the City's linear infrastructure (roads, water, sanitary and drainage).

The City's infrastructure assets inventory is the foundation of both the Asset and Climate Risk Assessment. After preparing the inventory, decisions are made about which infrastructure will be considered in the risk assessment.</td></tr>
<tr><td>. Local Climate Data
. Local Climate Events
. Time Frame
. Projected Climate Changes</td><td>. Approximate age
. Estimated remaining life
. Location (ideally in a mapped form)
. Anecdotal information about asset condition</td></tr>
<tr><td>CONTEXT</td><td>External context

Climate events are outside of the influence of the City, but impact how the City delivers services.</td><td>Internal context (mostly)

Asset risks are under the influence of the City. The context is largely based on the asset lifecycle of infrastructure owned and operated by the City. However, age and condition are influenced by external environments.</td></tr>
<tr><td>CRITERIA</td><td>. Likelihood of climate contributing to asset failure (Failure Mechanism Likelihood Scoring Matrix based on climate hazard)
. Impact on service life of assets (modeled parameters; assets impacted)</td><td>. Likelihood Scoring Descriptions based on age or condition.
. Failure Consequence Descriptions based on potential impacts and the factors influencing the magnitude of impact.
. Risk Score Matrix</td></tr>
</table>

COMMON PITFALLS IN ESTABLISHING CONTEXT

CONTEXT IS DEFINED BY ONE PERSON/DEPARTMENT.

When context and scope are developed in isolation from all participants, it can be difficult for others that weren't involved in the development to engage in the process effectively. It may also limit the ability of the results to inform other decision-making. Including multiple perspectives ensures that the effort of the risk assessment can be used to inform decisions made by many audiences. It can also build understanding and buy-in of the ultimate results.

INEVITABILITY OF BIAS IN CONSEQUENCE AND LIKELIHOOD DEFINITIONS AND EVALUATION.

Despite best efforts, there will be bias in setting the context of your risk assessment. There is no absolute in determining what likelihood or consequence will be, and acknowledging this will support you in using the results of the risk assessment in appropriate ways.

STEP 2: ASSESS RISKS

STAGE	KEY STEPS & CONSIDERATIONS
RISK IDENTIFICATION What risks could we consider?	. Generate a comprehensive list of risks within your defined scope and context that could impede achievement of objectives. You may not end up analyzing or evaluating all these risks, but it's important to cast the net wide to start. . Explore risk combinations and/or secondary risks that are effects of primary risks, causing cumulative impacts. . Important to have updated and relevant information to support good exploration of identified risks and understand the limitations of your information.
RISK ANALYSIS What is the source of the risk, and what could affect likelihood and/or consequence?	. Consider consequences and associated likelihood. . Consider existing controls and their effectiveness/ efficiency. . Consider the interdependence of different risks and their sources. . Highlight assumptions, uncertainty, different opinions, quality of available information. . Analysis can be qualitative, semi-quantitative or quantitative, or a combination. . Provides input into making decisions when treatment options involve different types and levels of risk.
RISK EVALUATION Based on what we know about it, how does this risk rank in our likelihood and consequence evaluation framework?	. Intended to be a decision-making support by identifying which risks rank higher relative to others in the evaluation frameworks. . Guides discussion about the need and options for risk treatments. . Compares level of risk with risk tolerance, can inform adjustments to risk tolerance. . Can identify where further analysis is needed to better understand level of risk.

CASE STUDY: INTEGRATING CLIMATE CHANGE INTO ASSET MANAGEMENT RISK ASSESSMENTS IN THE CITY OF CASTLEGAR

<table>
<tr><th></th><th>WHAT DOES THAT LOOK LIKE FOR CLIMATE RISK?</th><th>WHAT DOES THAT LOOK LIKE FOR ASSET RISK?</th></tr>
<tr><td>RISK IDENTIFICATION</td><td>Failure processes, i.e. climate-dependent processes that can result in reduced service life for various types of infrastructure.</td><td>Condition and Capacity Risk</td></tr>
<tr><td>RISK ANALYSIS</td><td>Risk scores are the product of the severity and likelihood scores.

Since the consequence of failure severity scores are already determined as part of the asset management risk assessment, only weighted likelihood scores are required for the climate change risk assessment.</td><td>Combined risk score of the two primary drivers of asset failure: condition and capacity. For each of these drivers, the risk assessment is divided into three parts:
. Likelihood of failure (i.e., probability)
. Consequence of failure (i.e., severity of environmental, social, and economic impacts)
. Assignment of total risk scores added together (after modification, if any and combination of scores)</td></tr>
<tr><td>RISK EVALUATION</td><td colspan="2">Merging process to yield a hierarchy of upgrades based on risk scores.
1. Identify assets that have a high-risk score in each category - condition, capacity, and climate change.
2. Identify assets that have a high-risk score in one of the categories - condition, capacity or climate change.
3. Identify assets that have a high likelihood of failure risk score in one category condition, capacity, and climate.

This methodology results in a three-tiered prioritization of projects, which provides input to a list of capital priorities.</td></tr>
</table>

COMMON PITFALLS IN ASSESSING RISKS

Expectations of what a risk assessment will do (and produce!). Risk assessments can produce some visuals and colour-coded lists of all the things you could possibly worry about. While lovely, these outputs don't make decisions on their own or in isolation – critical thought is still needed to integrate the results of the context-bound risk assessment with other assessments or information needed to make good decisions about what to do next.

Putting all time, effort, and financial resources into the risk assessment step. The risk assessment step is one of the more straightforward and linear parts of risk management, and there are many frameworks or processes available for you to use. While this brings a sense of confidence, a considerable amount of effort, integration, and conversation is required to both set the context and make use of the results of the risk assessment. The time and effort needed for these other steps should not be underestimated!

Process is too complex, making it difficult to update or replicate. Risk management is an iterative process – for it to be successful it needs to be simple enough for people to replicate in the same or different scopes. Starting simple and adding complexity as needed during replication is a great way to settle on the right level of detail.

Uncertainties of climate change. Including or integrating climate change considerations in setting the context and assessing risks means introducing additional sources of uncertainty. This uncertainty does not mean that the results are unreliable – it means that these uncertainties need to be considered in the development of your risk management approach.

Some climate-related uncertainties include:

- Climate projections based on emissions forecasts
- How projected changes will affect assets and services
- How individuals will interpretation and use results

Risk assessment results can be used to target where you will invest additional effort to reduce uncertainty (where possible).

A completed risk assessment feels like you've managed your risks. Risk assessments can bring about a false sense of security - just because you've done a risk assessment doesn't mean you've managed your risks! Some organizations will not advance past the risk assessment step and have difficulty prioritizing and implementing actions – which is what actually has an impact on the risks you've assessed.

> Some available tools to help you with climate risk assessments :
>
> PIEVC resources, which can be navigated through the Catalogue: PIEVC Catalogue of Resources
>
> Building Adaptive and Resilient Communities (BARC) BARC Praogram | ICLEI Canada
>
> ISO 31000 – Risk Management ISO - ISO 31000 Risk management
>
> A helpful resource for evaluating risk assessment frameworks: Guidance on Good Practices in Climate Change Risk Assessment (ccme.ca)

BREAKOUT DISCUSSIONS

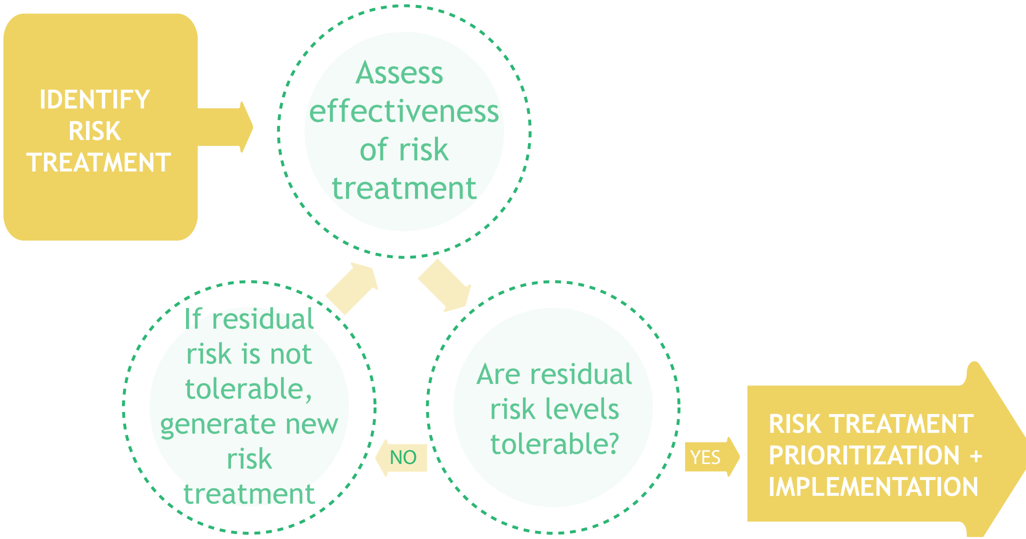
In a small group with others from different municipalities, discuss your experience in setting context and/or assessing risks. Here are a few prompting questions to help you along:

- What kinds of risk assessments has your organization completed? What were the drivers behind them?
- Who was involved in the assessment? Do you think it was the right group of people? Was anyone missing?
- How did you approach scoping your risk assessment? Why?
- Who was involved in developing the likelihood/consequence scales? What references did you use?
- How did you identify the risks to evaluate? How did you decide how detailed to get?
- Who led the risk assessment?
- What went well during the assessment? What was challenging?

What are some things you've learned from others that you'd like to bring back to your team? Note them below.

STEP 3: RISK TREATMENT

Once risks have been assessed, the next step is to identify, prioritize, and implement interventions (or actions) to control risks. Identifying risk treatments is a cyclical process: the process must incorporate a feedback loop to understand how risk will change after the intervention:



Residual risk is the risk that remains after the risk treatment has been applied. Risk treatments or combinations of risk treatments will reduce the likelihood and/or consequences of a risk but may not eliminate the risk. Comparing the residual risk with your risk tolerance is part of assessing the effectiveness and acceptability of the risk treatment[1].

[1]ISO 31000

IDENTIFYING AND PRIORITIZING ACTIONS

IDENTIFYING ACTIONS

Your risk assessment process likely already identified a number of options for treating risks. Another process is required to evaluate the options in support of deciding which option or combination of options is appropriate to implement in your context.

RISK TREATMENT OPTION	EXAMPLE
Avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk.	Choosing to not redevelop properties in the floodplain.
Removing the hazard (risk source).	Decommissioning a playground that is identified as high risk due to poor condition.
Changing the likelihood.	Renewing assets to improve condition and decrease likelihood of failure.
Changing the consequences.	Adding a secondary road access to a remote or isolated community in case of emergency evacuation.
Sharing the risk with another party or parties (including contracts and risk financing).	Joining a regional water commission.
Retaining the risk by informed decision.	Adopting a "run to failure" philosophy for select assets.

Risk treatment options can identify actions that require implementing new or adjusting existing assets through a capital response, or actions that require implementing new or adjusting existing programming or maintenance activities through an operational response. Both are acceptable, and your risk tolerance context will drive which combination of options is more appropriate for you.

OTHER CONSIDERATIONS IN SELECTING RISK TREATMENTS

Many additional factors need to be considered in risk treatment prioritization that require inputs at the organizational level. Some examples of additional considerations include:

- Organizational strategic goals
- Levels of service (current and target)
- Available human and financial resources to implement the action
- Scale of impact
- Value for money
- Others?

> Your risk assessment helps you to collect and organize the magnitude of risks you face. The assessment does not tell you what makes the most sense to tackle next!

Other considerations may be context-specific for your community, such as the preservation of historical resources or the protection of natural areas. Balancing all of these considerations may require you to develop another framework for evaluating all of your potential actions, which will help you in the next step of prioritizing actions.

COMMON PITFALLS IN IDENTIFYING ACTIONS

Overlooking actions that may be contradictory. Actions identified in isolation may have detrimental impacts when considered in another way. For example, cutting down trees may reduce wildfire risk, but will increase soil erosion which has negative impacts to soil and downstream water body health. When identifying actions to treat risks, consider what the unintended consequences of these actions may be.

Scoping risk management actions too narrowly and missing opportunities for co-benefits. Start with the action to manage the risk, but then ask - what else could this action achieve? Can the project or program be tailored to also achieve other objectives, or coordinated with other projects for efficiency?

Overlooking risks because there is an assumption nothing can be done. You may not be the owner of the infrastructure that your service depends on, but you may have other opportunities to influence risk management through communication or partnerships.

PRIORITIZING ACTIONS

All communities face several risks, and there are not enough resources available to be able to tackle them all at once. It also may not make sense in your context to start with only the highest risks first - doing so could mean you miss out on some opportunities that will provide multiple benefits to your community.

Prioritizing actions identified in risk management is often done through capital planning, master planning, or asset management planning as priorities need to consider all the various drivers of investment.

FLEXIBILITY V. RIGIDITY

As you prioritize actions to integrate them into infrastructure and capital planning, it is important to keep in mind how much flexibility you require to adapt to changing factors.

If you develop another framework for evaluating all of your potential actions, you may be inclined to include any number of the considerations mentioned above (organizational strategic goals, levels of service, human and financial resources, scale of impact, value for money).   The more considerations you integrate into prioritizing actions, the more effort will be required to update your priorities.

Developing a detailed action plan broad range or criteria may seem attractive: it can be effective, make good use of resources, support with long term financial planning, and support achieving other important objectives . However, these plans can become out of date quickly and need to be updated often. Developing detailed long-term plans can create a false sense of certainty around implementing the plan and may lead to a misalignment of expectations.

The reality of implementation is that circumstances change and can render a well-laid-out plan, out of date. It is important to be prepared to update plans to adapt to changing criteria.

On a spectrum from simple/high-level to detailed/rigid, there are benefits and drawbacks at each end. It is up to each municipality to determine where on the spectrum aligns with their needs and best supports effective decision-making.

SIMPLE & FLEXIBLE: Actions to mitigate climate and asset risks are prioritized based on risk levels.

DETAILED & RIGID: The more lenses you integrate the more rigid your priority actions are.

COMMON PITFALLS IN PRIORITIZING ACTIONS

Making the prioritization process too onerous or complicated. Like risk assessment, a prioritization process that is too onerous is difficult to replicate consistently over time.

Developing a prioritization process/framework that is out of alignment with community goals. A process that yields results that are out of alignment with community goals will not feel successful to those that are using the services.

IMPLEMENT ACTIONS

You've prioritized your plan. You've aligned your resources. Now it's time to implement those actions! Successful implementation requires organizational buy-in and conviction at all levels.

Some key considerations in implementing your prioritized actions:

- How are you going to measure the success of the action once implemented? How will you know if your goals are achieved?
- Communicate with everyone: decision-makers, staff, service users, and others. From the public's perspective, implementation of actions is the most visible part of risk management.

COMMON PITFALLS

Misaligned expectations of what successful implementation means. If decision-makers are expecting an action to address more than what it is designed to, this can lead to disappointment in the outcomes. Managing expectations through clear communication about the actions before implementation can build and maintain understanding and conviction throughout the process.

Insufficient communication about the decision-making process that resulted in the implementation. It isn't possible to include everyone in a community in all decision-making processes, and inevitably there will be disagreement about the actions you implement. The goal isn't to have everyone in agreement about the best course of action, rather it is to adequately communicate the process and considerations that went into making the decision in balance with all your other priorities.

BREAKOUT DISCUSSIONS

In a small group with others from different municipalities, discuss your experience in identifying, prioritizing and implementing actions. Here are a few prompting questions to help you along:

- How have you identified and scoped risk management actions? How did you avoid unintended consequences, or maximize other potential benefits of the action?
- How have you prioritized actions? How have you prioritized climate risk management actions with actions identified to manage other asset risks?
- Who was involved in prioritizing? Who made decisions about which actions should be prioritized over others?
- What went well? What was challenging?
- Think of a time that implementation has gone well for your community. Why was it so successful?
- Think of a time that implementation has not gone so well for your community. Why was it so challenging?
- What are some of the barriers to implementing risk management actions? How have you overcome these barriers?
- What are some things you've learned from others that you'd like to bring back to your team? Note them below.

STEP 4: MONITOR AND REVIEW[1]

The purpose of ongoing monitoring and review comes back to supporting continuous improvement to defining and customizing the risk assessment process to enable appropriate and effective risk treatments.

It's crucial to conduct ongoing monitoring at two levels:

- Monitoring and identifying changes in risk levels (likelihood and/or consequences) based on implementing the risk treatment
- Reviewing the framework itself for its effectiveness in achieving the established objectives.

Risk changes over time, and in accordance with change to the internal and external context. Continued review and monitoring seeks to understand if:

- Assumptions about risks remain valid.
- Expected results and performance are being achieved.
- Results of risk assessments are consistent with what was anticipated based on experience, knowledge, or expectations.
- Risk assessments are applied appropriately, consistently, and are working effectively.
- Risk treatments are effective.

The results of monitoring and review should be incorporated in reporting and communication activities.

[1] ISO 31000

COMMON PITFALLS IN MONITORING AND REVIEWING

… **not monitoring!** Without ongoing monitoring and review of risk management processes, the organization may not be aware of new or emerging risks or might fail to identify gaps in the existing approach.

Not communicating the results of monitoring to stakeholders. Choosing to invest in risk treatment often means spending money to prevent something from happening that you don't have complete certainty will happen, and you would rather not happen in the first place. Following up with stakeholders about the impacts and benefits of investing in risk treatment can encourage future investments in risk treatment. When risk treatments are determined through monitoring to be ineffective, those results can be shared to inform future decisions and improve the effectiveness of actions.

BREAKOUT DISCUSSIONS

In a small group with others from different municipalities, discuss your experience in monitoring and reviewing actions. Here are a few prompting questions to help you along:

1. How does your community monitor the impact of actions on identified risks? What kind of information do you collect or use to monitor?
2. How does your community evaluate any changes to risk tolerance? Who decides what your risk tolerance is?
3. How do you know when to re-do your risk assessment? What triggers that?

What are some things you've learned from others that you'd like to bring back to your team? Note them below.

TEAM DISCUSSION

1. What are your biggest takeaways from what you heard from other cohort participants?
2. What do you think would work for your community in risk management? What do you think wouldn't work?
3. Who else are you going to share your learnings with? Why do they need to hear about what you learned?

COMMUNICATING / CONSULTING AND RISK MANAGEMENT

Communication and information management is a key part of the continuous improvement process of asset management. It is inherently linked to communicating about risk management and consulting with stakeholders.

The mobilization of efforts put into the steps of risk management is facilitated through good communication. Below are some considerations for you in developing your risk management communication approach:

Common Language: The ideas discussed in this workshop use a common language in alignment with ISO 31000. While it is important to spend time making sure everyone involved understands the terms used in the same way, it is also important to spend time building understanding of the elements of the process that are unique to your context.

Risk management is a process: This has been emphasized several times in this workshop, but it's worth mentioning again! When bringing others along in risk management, having clarity about the value of the process and how all the outputs work together is essential.

Make it meaningful: Different roles and perspectives will have different inputs and expectations of the risk management process. When communicating with these groups, spend some time communicating the benefits of the process to the things they care about the most.

Some perspectives you may be communicating with include:

- Your team
- Staff outside of your team
- Decision-makers
- Other critical infrastructure owners
- The Public

BREAKOUT DISCUSSION

Think of an example of when communication about risk management has been done well. (This doesn't have to be from your community!). Who was the audience? What was compelling about it? What were the outcomes?

Now think of an example of when communication about risk management has not been done well. (This also doesn't have to be from your community!). Who was the audience? What were the gaps in communication that you identified? What was the impact of this approach?

APPENDIX A

A Tale of Two Case Studies

KANAKA BAR INDIAN BAND

Kanaka Bar Indian Band is in the Fraser Canyon in British Columbia, alongside the Fraser River and surrounded by mountainous terrain. The area experiences harsh weather conditions, often facing extreme heat in summers, cold winters, and high amounts of precipitation. Located inside of the canyon along Highway 1, this road provides the only major transportation network in and out of the community.

Source: Google Earth Pro, Capture April 24, 2023

Kanaka Bar members and staff have been deeply committed to building self-sufficiency in its economy, food security, and energy systems, as well as building resilience to climate change.

In 2018, the community completed a Climate Change Vulnerability Assessment that identified water resources, forest fires, traditional foods, and access roads as the areas of the greatest vulnerability and community priority. Adaptation strategies were developed with a focus on these key vulnerabilities. These included food production initiatives in the community, continuation and expansion of a culvert inspection and cleaning program to prevent road washouts, and expanded strategies to achieve energy self sufficiency.

It did not take long for the criticality of this work to be demonstrated. In November 2021, multiple rain systems in southwestern British Columbia resulted in record rainfall levels in the region. Rainfall records were broken across the province. In Kanaka Bar, the 1 in 100 year expected single day rainfall amount (67mm) was exceeded two days in a row: 68mm on November 14th, and 76mm on November 15th. The rainfall resulted in extraordinary flows in surrounding creeks and rivers, completely overwhelming road drainage infrastructure.

Landslides and overflowing rivers resulted in multiple highway closures through the area; two area of Highway 1 near to Kanaka Bar were destroyed, effectively isolating the community from the rest of the province, preventing access to critical services and delivery of supplies.

Source: Kanaka Bar December Newsletter (https://www.kanakabarband.ca/downloads/december-2021.pdf)

Kanaka Bar's prior implementation of adaptation strategies identified in the Climate Change Vulnerability Assessment helped to limit the impacts of this unprecedented natural disaster. A community led Necessities Store stocked essentials for members that could not leave the community to shop for food and supplies, and previous food security initiatives meant that fruits and vegetables were available within the community. Solar installations maintained power for critical services in the community, and a band-owned cell tower maintained communications.

COQUIHALLA HIGHWAY

The Coquihalla Highway is a 4 lane, divided, high-speed provincial roadway where the posted speed is 110 kph, with a maximum grade of 8% with climbing lanes and crawling lanes. The highway in its current form was constructed in 3 phases from 1986-1990. Travelling through mountainous terrain, the highway is known as particularly dangerous during the winter seasons and stretches of it are among the deadliest in BC.

Source: Google Earth Pro, Capture April 24, 2023

A PIEVC Climate Risk assessment conducted by the Ministry of Transportation and Infrastructure in 2010 concluded that, overall, the highway was relatively robust with respect to climate change. Key risk events were identified that present significant risks to the highway. Among these were Pineapple Express events, which posed significant drainage management issues. The team raised concern that these events will increase in both frequency and magnitude with climate change, and that the infrastructure is already exhibiting vulnerability to high intensity rainfall events. Based on this, the team concluded that these issues would be exacerbated by climate change and raise greater challenges to the ongoing operation and maintenance of the highway. Despite that general prediction, more refined data was needed to forecast with greater confidence the impacts of climate change on the frequency of Pineapple Express events of concern, as the studies that would be required to achieve this were not feasible in the timeframe of the original assessment.

No emergency maintenance or upgrades were conducted as an outcome of this assessment, but it did inform the standards to which maintenance and upgrades were built to, and the assessment formed part of a general shift in the way that climate change was considered at the Ministry and by key stakeholders. (Source: CRI discussions – Jody)

In 2021, it was a Pineapple Express event that contributed to record breaking rainfall in Southwestern BC, and large sections of the Coquihalla Highway near Hope were entirely washed out. Many bridges partly or completely collapsed, creating millions of dollars in damage and isolating BC from the rest of the country while repairs were underway.

Source: Global News https://globalnews.ca/news/8381003/bc-flooding-new-photos-coquihalla-highway-damage/

In the wake of this disaster, Ian Pilkington, the Chief Engineer with MoTI said in an interview with On-Site magazine that his ministry has been gearing up for some time to adapt its climate change standards. The ministry is also participating with Engineers Canada and Natural Resources Canada in an international Public Infrastructure Engineering Vulnerability Committee (PIEVC) that produces risk assessments and analyses, and working through forums such as the Pacific Climate Impacts Consortium at the University of Victoria to develop anticipatory data.

“We’ve learned we can no longer rely on historical data,” Pilkington said. “We have to look at ‘future’ data our designers can use to help account for climate change.”

Integrating Climate Change into Asset Management Risk Assessments

Case Study

Draft

Purpose of this Guide

This guide has been written for staff of local governments. It introduces an approach that was piloted in the City of Castlegar to integrate climate change considerations into an asset management risk assessment process for its linear assets. The focus of the project was on the risk of failure due to asset condition (deterioration) and capacity for linear water, sewer, and stormwater assets as well as major roads assets. Risk assessment for extreme events that may be triggered by climate change, such as flooding or land slides which can cause significant damage or destruction, was excluded except for stormwater management assets.

Included in the Guide:

KEY CONCEPTS

KEY STEPS

to integrate climate change with traditional asset management risk assessment processes

CASE STUDY

for the City of Castlegar

The approach outlined in this guide has been designed to help municipalities who are in the asset management planning stage and need resources to support the inclusion of climate change into their asset management and capital programs. The case study will summarize:

1. What risk is and how it is assessed.
2. What types of hazards are to be considered.
3. How likelihood and consequence are defined.
4. How risk ratings are assigned to assets.
5. Relative priorities.

The framework allows City staff to prioritize limited resources for inspection, rehabilitation, and replacement of assets, make decisions based on risk (not risk perception) and help answer the question "What assets really require attention?"

Key Concepts

ADAPTIVE CAPACITY

The ability of the infrastructure system to adjust to the impacts of the climatic change.

ASSET

A physical component of a system that has value, enables services to be provided and has an economic life of greater than 12 months.

ASSET MANAGEMENT

The process of making decisions about the use and care of infrastructure to deliver services in a way that considers current and future needs, manages risks and opportunities and makes the best use of resources.

ASSET CONDITION

The state of an asset, particularly regarding its appearance, quality or working order.

CATASTROPHIC FAILURE

A sudden and total failure of an asset from which recovery is impossible.

CUMULATIVE IMPACT

The effect on assets which results from the incremental on-going influence of changing climatic factors. These changes in climate will likely result in decreased infrastructure service-life. For example, an increased frequency of freeze/thaw events will degrade roads (reduce service life).

CLIMATE CHANGE

A change in global or regional weather patterns that persists for an extended period, usually decades or longer. In the context of mitigation and adaptation planning, climate change typically refers to changes that are attributed to human activity that are in addition to natural climate variability observed over comparable periods of time.

EMISSIONS SCENARIOS

Each Global Climate Model (GCM) is run using an emission scenario that quantifies concentrations of the full suite of greenhouse gases (GHGs), aerosols and chemically active gases. The Fourth IPCC Assessment Report (AR4) used scenarios from the Special Report on Emissions Scenarios (SRES4). These focus on "storylines" regarding global growth, economic development and energy use. In general, the following describes the resulting emissions scenarios.

- A1 and A2 reflect high and moderately high increases in GHG emissions respectively.
- B1 and B2 reflect more sustainable practices, with continued low emissions growth and peaking, then declining

emissions respectively.

The Fifth IPCC Assessment Report (AR5) uses Representative Concentration Pathway (RCP) scenarios to describe emissions scenarios. Four RCPs were selected from the published literature, and are described below:

- RCP2.6 Radiative forcing peaks at approximately 3 W/m2 before 2100 and then declines.
- RCP4.5 and RCP6.0 Radiative forcing is stabilized at approximately 4.5 W/m2 and 6.0 W/m2 respectively after 2100.

RCP8.5 Radiative forcing reaches >8.5 W/m2 by 2100 and continues to rise for some amount of time. This RCP reflects what is often called "business as usual".

GCM

Acronym for Global Climate Model (also know as a General Circulation Model), which projects climate behavior by simulating the physical, chemical and biological properties of its components, their interactions, and feedback processes. They model the entire global system using a relatively coarse grid pattern (typically 500 km x 500 km). Each model is run using different greenhouse gas emissions scenarios (RCPs), and is often run several times using different initial boundary conditions. Output from these models are often statistically downscaled (10 km x 10 km) to better reflect regional climate patterns.

LONG TERM CAPITAL PLAN

A multi-year plan (10+ years) that identifies the capital infrastructure projects and their cost to address the current and future service objectives.

LEVEL OF SERVICE

The defined standard for the provision of a particular service. Components of defining these standards include: quality, quantity, reliability, responsiveness, environmental acceptability and cost.

RISK

The product of the likelihood of an impact occurring (related to the vulnerability of a system) and the consequence of that impact on service delivery.

RISK ASSESSMENT

The process whereby identification of capital infrastructure upgrades in an asset management context is completed based on an assessment of the likelihood and consequence of failure related to condition and/or capacity of the assets.

Figure 1 – *Risk Score Matrix*

increasing likelihood of failure ↑

5	10	15	20	25
4	8	12	16	20
3	6	9	12	15
2	4	6	8	10
1	2	3	4	5

increasing consequence of failure →

RISK ASSESSMENT INTEGRATED WITH CLIMATE CHANGE

Two primary factors are considered within the context of asset management – condition, which is an indication of service life; and capacity, which can trigger replacement or upgrades before service life has been reached. Therefore, for the purposes of asset management, only climate changes that impact condition or capacity of an asset have been considered. While it's true that an asset can be affected by catastrophic events such as floods, landslides, stream bank erosion, and/or forest fires – all potentially impacted by climate change – the occurrence of such events is typically not a factor in determining when to replace or upgrade a capital asset. The exception is for drainage assets, which are designed to protect most other infrastructure from surface runoff, and which can be impacted by climate change.

Risk is defined as the product of likelihood and consequence of failure. Since the consequence of failure has already been determined as part of the asset management assessments, the climate change risk assessment focuses on developing the likelihood that a future change in climate variables will result in a material change in the processes that cause reduced capacity and/or reduced service life for each infrastructure asset. This approach has been taken since it is often the combination of climate variables, rather than a single climate variable, that contributes to the impact that each process has on an asset's capacity and/or longevity.

SERVICE LIFE

The estimated lifespan of a depreciable fixed asset, during which it can be expected to contribute to a municipality's operations.

TOTAL ANNUAL AVERAGE LIFECYCLE INVESTMENT (AALCI)

Budget based on annual average of the total replacement value of an asset over its expected service life.

VULNERABILITY

Infrastructure and natural assets that are exposed to climate change is the product of both sensitivity to specific climate events and the adaptive capacity of the system.

Key Steps

Typically, identification of capital upgrades in an asset management context is completed based on an assessment of condition and/or capacity; however, the approach that guided this process includes prioritization of capital upgrades based on condition and capacity and risk with an additional scenario where changing climate conditions are considered. The Case Study following this section illustrates the process and summarizes results for the City of Castlegar.

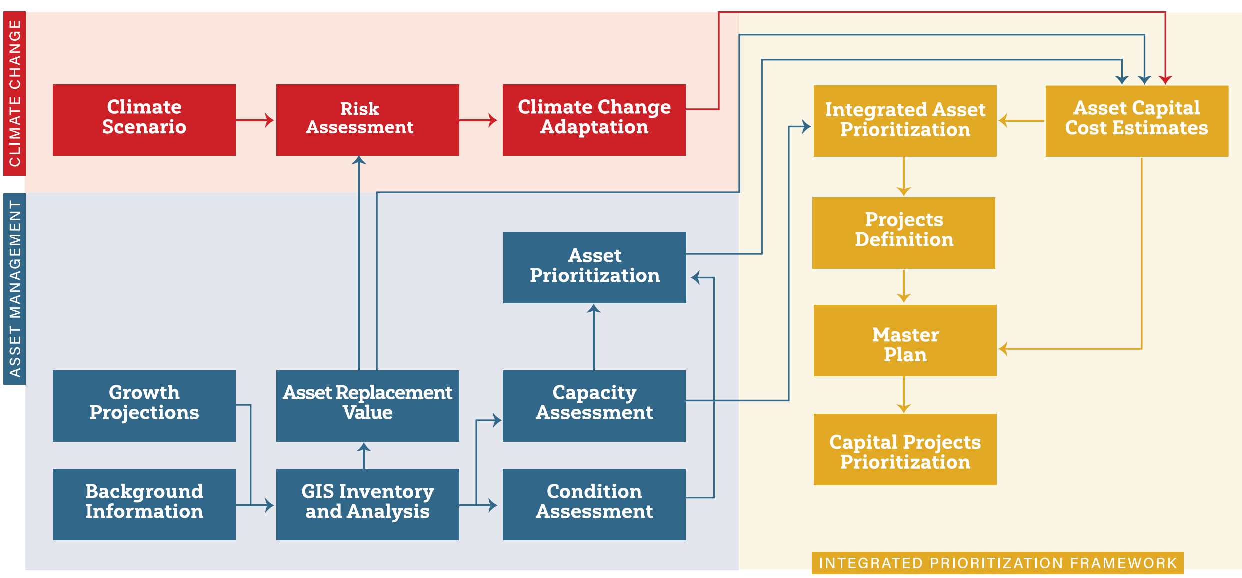
Determining the list of capital priorities in Castlegar followed a scenario-based assessment of levels of service, which required two key analyses: network hydraulic modeling and a risk assessment with and without climate change. The following graphic illustrates the key steps required to achieve this objective.

STEP 1

Compile Asset Inventory for Infrastructure to be Evaluated

This inventory is valuable for both condition and capacity assessments as well as the climate risk assessment. The inventory should be as complete and accurate as feasible to be useful. It should list the assets including their approximate age, estimated remaining life and location (ideally in a mapped form). Anecdotal information about asset condition and age is enough for getting started.

Figure 2 –*Process to Integrate Climate Change Risk Assessment into the Asset Management Assessment*



STEP 2

Identify Local Climate Data, Events, Time Frame and Projected Climate Changes

In the Castlegar example, a PIEVC (Public Infrastructure Engineering Vulnerability Committee) Engineering Protocol was completed previously to identify these factors. If this information is not available, several organizations provide online tools that summarize output from downscaled GCMs for a range of RCPs.

The Pacific Climate Impacts Consortium (PCIC) offers two such tools that are particularly useful for the purposes outlined in this Guide:

- Plan2Adapt provides a broad overview of key climate parameters for pre-defined regions within BC and three future periods (2020s, 2050s, and 2080s) Changes are projected for mean temperature, precipitation, snowfall, growing degree days, heating degree days and frost-free days on an annual or seasonal basis. The results are statistically derived from an ensemble of 15 downscaled GCMs using emissions scenarios A2 and B1.
- The Regional Analysis Tool is based on the same GCM and emissions scenario runs used for Plan2Adapt. It provides, however, greater user control with respect to geographic area selection. It also offers projections for a greater number of climate variables and time periods (including monthly means).
- The Climate Atlas of Canada offers an interactive map which allows the user to obtain summarized climate projections for a selected grid region or specific community. The projections reflect the mean value from an ensemble of 12 downscaled GCMs using RCP 4.5 and RCP 8.5 emissions scenarios (“less climate change” and “more climate change” respectively). Projections are available for the recent past, 2021-2050, and 2051-2080, and include several climate variables grouped into hot weather, cold weather, temperature, precipitation and growing season.

- The IDF-CC Tool offers projected rainfall intensities for combinations of storm duration (sub-daily) and return period. This information is currently not offered by any other resource, and is useful for evaluating impacts from design rainfall events.

It is useful to first summarize current climate values from historical records. This provides the historical baseline for estimating projected future changes. It is also important to understand that projected changes from each GCM run are relative to the modeled baseline from the same GCM. That is, each GCM is run for a period extending (usually) from 1950 to 2100 using a daily time-step. Results are reported in reference to a baseline period (usually 30 years long). For example, the PCIC Regional Analysis Tool uses a baseline from 1961 to 1990. The percent change for the period 2040-2069, for example, is calculated using the projected and baseline values from the same GCM. The percent change can be applied to historical baseline values to obtain more relevant projected climate values.

STEP 3

Identify Failure Processes and Sensitivity to Them

Within the specific context of asset management, we are interested in how projected changes in climate may impact infrastructure service life. The case study summarizes climate-dependent processes that can result in reduced service life for various types of infrastructure. These are called "failure processes". Currently, little research has been completed to identify climate-dependent failure processes for municipal infrastructure, and more importantly, to quantify impacts to service life. Appendix A lists the most pertinent studies referenced for this Guide. Table 1 summarizes several failure processes and their relevance to each linear asset system.

Each of the failure processes is influenced by one or more climate variables – annual precipitation, extreme temperatures, cycling between freezing and thawing, etc. The objective is to identify each climate variable that could influence the failure processes, consider the amount of change projected for the future and determine how sensitive each asset or asset class is to the projected change. This requires consideration of asset exposure to the hazard and its inherent resilience to the projected climate change. For example, all pipes may be subject to the same soil movements, but ferrous pipes have more strength, and plastic pipes have more flexibility than cement-based pipes – making them less sensitive to increased wetting and drying cycles due to wetter winters and drier summers.

Table 1 – *Failure Processes and Asset Sensitivities*

FAILURE PROCESS	ASSET ELEMENTS MOST SENSITIVE TO FAILURE PROCESS			
	Water	Sanitary	Storm	Roads
Extreme high temperatures	n/a	n/a	n/a	asphalt strength
Freeze/thaw cycles	n/a	n/a	n/a	asphalt longevity
Groundwater infiltration	n/a	capacity for infiltration	n/a	n/a
High streamflow	n/a	n/a	culvert capacity	n/a
High streamflow sediment loads	n/a	n/a	concrete and CMP culverts	n/a
Soil acidification	ferrous pipes	ferrous force-mains	Ferrous pressure-mains	n/a
Soil moisture	n/a	n/a	n/a	road base strength
Soil moisture-induced soil movement	cement-based pipes in clay soils	cement-based force-mains in clay soils	cement-based pressure-mains in clay soils	n/a
Surface stormwater runoff	n/a	capacity for inflow	storm sewer capacity	n/a
Water supply acidification	ferrous pipes	n/a	n/a	n/a

STEP 4

Condition and Capacity Risk Assessment

The asset risk assessment focuses on the two primary drivers of asset failure: condition and capacity. For each of these drivers, the risk assessment is divided into three parts:

- Likelihood of failure (i.e., probability)
- Consequence of failure (i.e., severity of environmental, social, and economic impacts)
- Assignment of total risk scores (after modification, if any and combination of scores)

The combined risk score incorporates the likelihood of failure score and consequence of failure score into a single score ranging from 1 to 5, with 1 indicating a low risk and 5 indicating a high risk. Once risk scores are assigned, prioritization of asset replacement is completed according to which assets have the highest combined risk scores.

STEP 5

Climate Change Risk Assessment (Likelihood and Severity)

The purpose of this step is to identify the risk for each asset with respect to projected climate, and the corresponding impacts on level of service and estimated costs. Risk scores are the product of the severity and likelihood scores. Since the consequence of failure severity scores are already determined as part of the asset management risk assessment, only weighted likelihood scores are required for the climate change risk assessment. This is completed using the following methodology:

1. Assign a likelihood score to each climate variable change.
2. Assign "climate contribution scores" to reflect the contribution that the projected change in each climate variable associated with each process has on that process. (These can range from a negative value, which means that the climate change will reduce the impacts of the failure mechanism, to a positive value, which means that the climate change will strengthen or accelerate the failure mechanism – zero means no contribution at all.)
3. Calculate the average of the weighted likelihood for each failure process - using the sum of the climate variable likelihood scores multiplied by the corresponding contribution scores.

These calculations are illustrated in the Castlegar case study. Note that developing and applying these likelihood and contribution scores relies heavily on engineering judgement and experience. Until more research is available to support analyses, applying judgement and experience is our most reliable method.

STEP 6

Integrate Results and Prioritize

To prioritize the inventory of risks into a strategic list of assets in sequence of importance, complete a three-step merging process to yield a hierarchy of upgrades based on risk scores.

1. Identify assets that have a high-risk score in each category - condition, capacity and climate change.
2. Identify assets that have a high-risk score in one of the categories - condition, capacity or climate change.
3. Identify assets that have a high likelihood of failure risk score in one category condition, capacity and climate.

This methodology results in a three-tiered prioritization of projects, which provides context to create a list of capital priorities.

CASE STUDY:

City of Castlegar Asset Management and Climate Change Prioritization Framework

(Integrated Prioritization Framework)

CASTLEGAR

happily ever after

Introduction

Climate change is an important issue for British Columbia. One of the most serious impacts of climate change is the increase of extreme events – warm days and precipitation. Forecasts suggest that the province will experience temperature increases by mid-century, relative to historical average, of between 2 to 4^{o}C. It is anticipated that the number of heavy precipitation events will increase in frequency and magnitude and there will be a shift in the seasonal pattern of occurrence. These changes will result in a longer growing season, and increased likelihood of floods and droughts. This change in climate will likely result in decreased infrastructure service-life. For example, an increased frequency of freeze/thaw events may degrade roads, and increased frequency and magnitude of extreme precipitation events may result in floods and potential infrastructure damage due to undersized drainage capacity.

Incorporation of climate change into asset management and master plans has so far been limited, with the vast majority of new infrastructure continuing to be designed using established codes or history-based, asset-specific environmental criteria. The impacts of climate change will increase infrastructure costs as we move forward. The climate-related challenges that communities face are compounded by the maintenance, monitoring and replacement costs of aging infrastructure.

The objective of this case study is to summarize the risk-based approach to integrate climate change with asset management into the capital planning process for the City's linear infrastructure (roads, water, sanitary and drainage).

Background

In 2010, a PIEVC (Public Infrastructure Engineering Vulnerability Committee) Engineering Protocol was used to complete a Climate Change Infrastructure Vulnerability Assessment for the City of Castlegar's stormwater infrastructure. The intent of this assessment was to improve the community's understanding of the context for developing local climate change adaptation strategies. The results of the PIEVC assessment had not yet been incorporated into any of the City's plans.

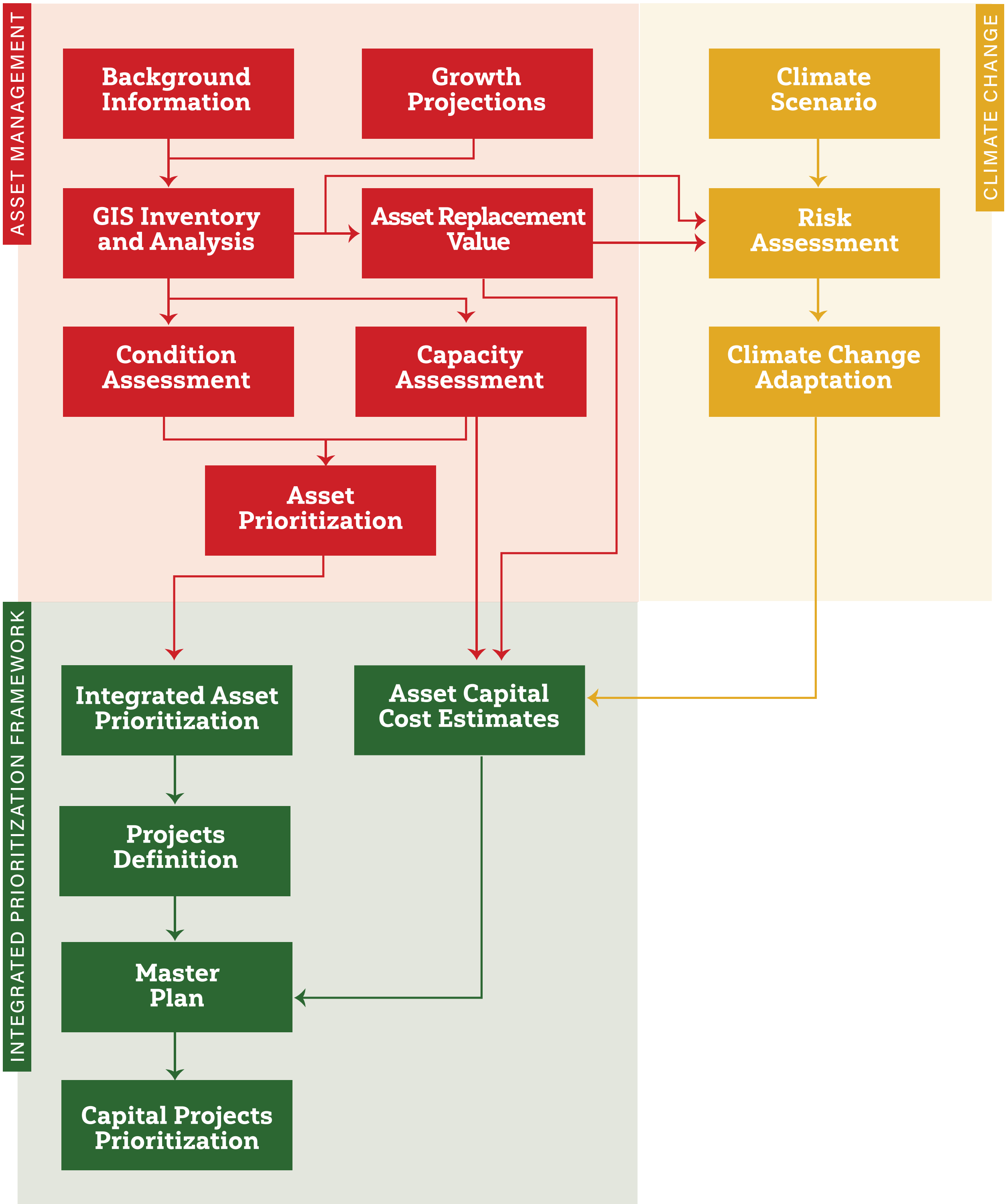
In 2016, the City received funding from the Strategic Priorities Fund to develop a framework for infrastructure planning that utilizes a risk-based approach that considers climate change (as well as other risk factors such as condition of materials and infrastructure capacity) for ultimately developing a prioritized long term capital plan.

Framework Process

The objective of the Climate Change Prioritization Framework is to develop a risk assessment process for integrating asset management with climate change factors (see Figure 3). This framework provides the City of Castlegar with a systematic approach for ensuring that it has the tools and information necessary to create a viable plan to maintain sustainable service delivery even though future climate conditions are uncertain. This approach gives staff the confidence to make informed decisions in order to provide quality services today and into the future.

The process consists of completing an asset management plan and a climate change vulnerability assessment to inform the capital planning process. The innovative step is to initially develop, then apply the integrated prioritization framework to prioritize each asset based on the condition, capacity and climate vulnerability risk scores from the first two processes.

Figure 3 – *General Asset Management & Climate Change Integration Process*



Risk Assessment

The asset management risk assessment was completed with a focus on the two primary drivers of failure: condition and capacity. For each of these drivers, the risk assessment was broken down into three parts:

- Likelihood of failure (i.e., probability)
- Consequence of failure (i.e., severity of environmental, social and economic impacts)
- Assignment of total risk scores (after modification, if any, and combination of scores)

Prioritization of asset replacement was completed according to which assets had the highest combined risk scores and workshopped with Castlegar staff.

The likelihood (probability) of asset failure for pipes is based on the condition (if the data exists) or age (based on standard service lives) of the asset.

Table 2 – *Likelihood Scoring Descriptions*

Likelihood of Failure	Description	As Indicated by Condition Rating (if available)	As Indicated by Age (if condition data is unavailable)	Assigned LOF Score
Very Low	Unlikey in foreseeable future	excellent	Asset age is <75% of useful life	1
Low	20+ years	good	Asset age is >75% to <100% of useful life	2
Medium	10-20 years	fair	Asset age exceeds useful life by >=0% to <25%	3
High	5-10 years	poor	Asset age exceeds useful life by >=25% to <50%	4
Very High	<5 years	immediate attention	Asset age exceeds useful life by >=5-%	5

The consequence of failure is based on the actual location of the infrastructure and the financial, social and environmental consequence that might occur, if the infrastructure failed.

Table 3 – *Failure Consequence Descriptions*

Type of Consequence	Potential Impacts	Factors Influencing the Magnitude of Impact
Financial	▪ cost to restore service ▪ third party liability	▪ road classification ▪ pipe size ▪ depth of pipe
Social	▪ service interruptions to downstream customers ▪ impacts to public health and safety (sewer assets in particular)	▪ road classification ▪ pipe size ▪ proximity to structures and type of structure
Environmental	▪ environmental contamination (sewer assets in particular)	▪ proximity to environmentally sensitive area and type of ESA

The risk score combines the likelihood of asset failure and the consequence of failure into a single 1 to 5 rating. A risk score of 5 represents the highest risk and a score of 1 the least risk. When assigning priorities for capital planning, assets with high risk scores are typically given higher priorities.

Figure 4 – *Risk Score Matrix*

Consequence \ Likelihood of Failure	1	2	3	4	5
5	3	3	4	5	5
4	2	3	4	5	5
3	2	2	3	4	4
2	1	2	2	3	3
1	1	1	2	2	3

A copy of the risk assessment process for the sanitary system is attached to the end of this document.

The risk assessment was completed for two scenarios:

1. Asset Management Risk Assessment
2. Asset Management + Climate Change Risk Assessment

Integrating Climate Change

Two primary factors are considered within the context of asset management – condition, which is an indication of service life; and capacity, which can trigger replacement or upgrades before service life has been reached. Therefore, for the purposes of asset management planning, only climate changes that impact condition or capacity of an asset have been considered. While it's true that an asset can be affected by catastrophic events such as floods, landslides, stream bank erosion and/or forest fires – all potentially impacted by climate change – the potential for such events is typically not a factor in determining when to replace or upgrade a capital asset. The exception is for drainage assets, which are designed to protect most other infrastructure from surface runoff, which can be impacted by a changing climate.

Risk is defined as the product of likelihood and the severity of failure consequences. Since the severity scores are determined during the asset management assessment, the climate change risk assessment focuses on developing the likelihood that a future change in climate variables will result in a material change in the processes that cause reduced capacity and/or reduced service life for each infrastructure asset. This approach has been taken since it is often the combination of climate variables, rather than a single climate variable, that contributes to the impact that each process has on an asset's capacity and/or longevity.

In keeping with the likelihood scoring method outlined for the asset management risk assessment (a 1-5 scale), weighted likelihood scores were also developed for the climate change risk assessment. This was done using the following methodology:

1. Identify processes that impact an asset's capacity and/or service life. These are called "failure processes" for the purposes of this assessment since, over time, these contribute to an asset's ultimate failure.

2. Determine the climate variables that impact each identified process.

3. Obtain the baseline value for each climate variable.

4. Obtain the projected values (or projected change in values) for each climate variable for applicable time periods. In this case, the time periods are:

    a. Baseline (1961-1990)

    b. 2020s (2010-2039)

    c. 2050s (2040-2069)

4. Assign a likelihood score to each climate variable change. Scoring is an integer from 1 to 5, with 1 being very unlikely and 5 being very likely.

5. Assign "climate contribution scores" to reflect the contribution that the projected change in each climate variable associated with each process has on that process. A scoring range of -2 to +2 was used, with the allowance of decimal fractions within that range. A score of -2 indicates that the projected change in the subject climate parameter significantly impacts the process but reduces or perhaps even reverses the reduction in capacity and/or service life. A score of +2 also significantly impacts the process but increases the reduction in capacity and/or service life. Note that this process relies heavily on engineering judgement based on experience.

6. Calculate the average of the weighted likelihood for each failure process - using the sum of the climate variable likelihood scores multiplied by the corresponding contribution scores. Note that the numerical average must be divided by 2 since our maximum contribution score has an absolute value of 2. Otherwise, it is possible to obtain a weighted likelihood score > 5.

Also note that the projected climate values are based on the PCIC ensemble of SRES AR4 - A1 runs. These represent the "business as usual" approach which means increasing concentrations of greenhouse gases at current rates.

Climate Change Impacts to Asset Service Life

The following table illustrates the process of determining the failure mechanism likelihood scores for sanitary sewers and forcemains. It lists the climate variables that influence one or more failure processes, as well as corresponding baseline and future values. It also lists the likelihood of the projected change for each climate variable and the assigned contribution scores, with the resulting weighted likelihood.

Table 4 – *Failure Mechanism Likelihood Scoring Matrix*

Sanitary Sewers / Forcemains		Climate Variables					
		temperature - average annual	precipitation - average annual	precipitation - high intensity (10Y; 15min)	precipitation - high intensity (100Y; 12 hr)	soil moisture - average annual	soil moisture content - annual fluctuation
baselines		1.8	897.9	48.0	4.0	567.8	94.1
baseline units		°C	mm	mm/hr	mm/hr	mm	mm
projected change (2050s) in baseline units		4.1	916.0	62.2	4.7	568.2	109.6
projected change (2050s) from baseline (%)		127%	2.0%	30%	18%	0.1%	16%
climate variable change likelihood		5	5	4	4	3	3
failure process	**weighted likelihood**	**climate contribution to failure mechanism (-2 to +2)**					
surface stormwater runoff	4.0	0.0	0.0	2.0	2.0	0.0	0.0
groundwater infiltration	0.4	-0.1	0.5	0.0	0.0	0.1	0.0
soil movement due to soil moisture change	0.8	0.0	0.0	0.0	0.0	0.1	1.0
soil acidification - exterior pipe corrosion	0.8	0.5	0.1	0.0	0.0	0.0	0.0

The weighted likelihoods of the identified failure process contributing to decreased linear asset capacity and/or service life were evaluated to develop an asset management risk assessment scenario that includes climate change as outlined below:

Table 5 – *Water, Sanitary and Drainage Pipe Networks*

Trigger	Modeled Parameters	Assets Impacted
Soil acidification caused by changes in soil moisture	Decrease service life by 3%	Ferrous water pressure mains
Weakening of pipes caused by increased soil moisture	Decrease service life by 3%	Concrete water pressure mains
Increased scouring of pipe due to higher sediment load from Inflow/ Infiltration	Decrease in service life: ▪ PVC/HDPE 3% ▪ Steel 5% ▪ Concrete 7% ▪ CMP 15%	All mains
High vulnerability risk assets as identified through PIEVC	Risk scores for 2037 scenario set to 5 (max)	Storm mains as identified through PIEVC as well as Water and water mains in immediate proximity to vulnerable storm infrastructure

Table 6 – *Road Network*

Climate Variable	Rational	Impact
Precipitation – Average Annual	Precipitation contributes to the overall volume of water in the soil matrix. This can reduce road base strength and increase potential for frost heaves	Decrease pavement service life by 15%
Freeze/Thaw Cycles (Inferred from seasonal temperatures)	More or less freeze/thaw cycles per year will decrease or increase average service life respectively.	
Annual Temperature Range (Function of Annual max and min temperatures)	Most pavements are designed to function within a specified temperature range. Exceeding the range limits is not recommended and can reduce service life through excessive contraction / expansion.	
Extreme High Temperature	Prolonged extreme high temperatures ($T > 30^{o}C$) can soften asphalt, reducing strength and making it more vulnerable to damage from traffic loads.	

The climate risk assessment indicates that in general, linear asset service life curves will decrease – the magnitude depends on the asset class. The assets identified in this study were prioritized (1,2 and 3) and sequenced based on their level of risk, which was further categorized based on various rankings or risk scores and translated into levels of service.

Summary of Key Results

This table summarizes the financial results of the risk assessment and prioritization process.

Table 7 – *Financial Impacts Summary*

Scenario	Drainage	Roadways	Water	Sanitary
Asset Management Risk Assessment				
# of Priority 1,2,3 Assets	248	223	495	202
Annual Replacement Cost	$511,000	$682,000	$882,000	$513,000
Asset Management Risk Assessment + Climate Change				
# of Priority 1,2,3 Assets	331	307	578	238
Annual Replacement Cost	$573,000	$786,000	$1,030,000	$518,000
Total Increase in Funding Needs	$62,000	$104,000	$148,000	$5,000

The City currently re-invests $1.8M into its assets. The asset management risk assessment recommends a $2.5M annual investment to maintain current levels of service and the climate change assessment suggests an additional $346,000. The total funding deficit accounting for climate change impacts on service life of assets is estimated to be $1.03M annually as shown on Figure 5.

The following list consolidates the key results of the risk assessment:

- Overall capital re-investment is under funded, with roads being significantly under (shortfall of $1M).
- Focus on high priority (P1) assets (high likelihood and high consequence) in order to meet affordability limits.

- Changing climate can cause catastrophic failure (one time failure) and long term cumulative impacts which reduce the longevity of infrastructure (i.e. increased freeze thaw cycles).
- Reduced service life is significant for roadways
- Sanitary assets are only impacted negligibly by the cumulative effects of a changing climate.
- Roads and drainage require significant investment into maintenance and replacement to maintain current service life estimates and assist in mitigating catastrophic failures Figure 6 summarizes the estimated funding needs.

Figure 5 – *Annual Renewal Investment by Asset Class*

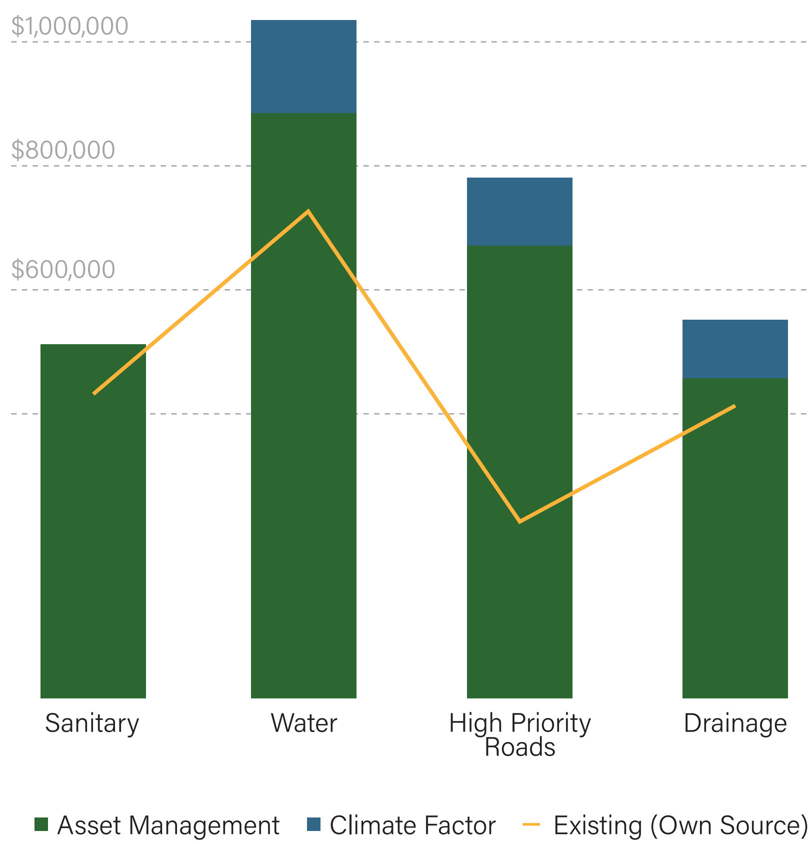
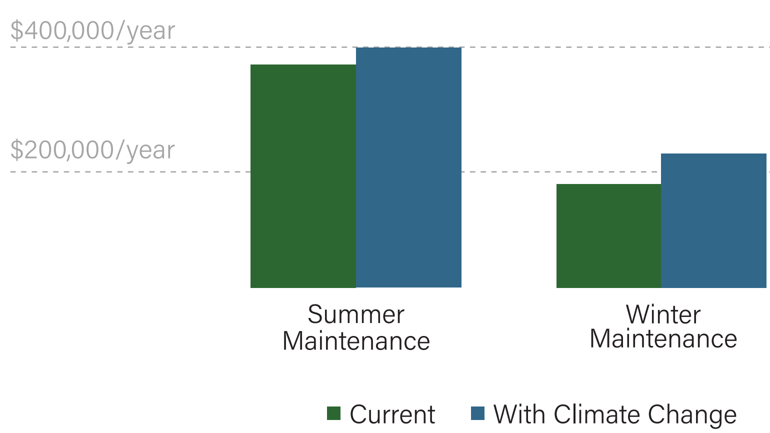


Figure 6 – *Annual Maintenance Costs by Season*



Mitigating the Cumulative Impact of Climate Change

Based on the results and analysis, there are also several other steps that Castlegar can take to mitigate the cumulative effect of climate change on reducing linear asset service life.

Revise Roadway Design and Construction Standards

One of the important factors for maximizing pavement service life and minimizing pavement maintenance cost is the selection of a gravel base with sufficient material resistance to damage under traffic loads and to environmental conditions.

Environmental Conditions

Frost action caused by moisture susceptibility is a major catalyst for pavement damage, which plays a key role in the performance of the pavement. The two basic forms of frost action (frost heave and thawing) both require water. Water is sourced in two categories:

1. SURFACE WATER: enters the pavement primarily by infiltration through surface cracks and joints, and through adjacent unpaved surfaces, during periods of rain and melting snow and ice.
2. SUBSURFACE WATER: can enter the road structure from three primary sources:
    - High groundwater table
    - Moisture held in soil voids or drawn upward by capillary forces
    - Moisture that moves laterally under the pavement from an external source

Mitigating the effects of frost action involves ensuring the roadway pavement design considers both surface water and groundwater impacts on the base and subgrade.

- Ensure the surface has a 2-3% crown
- Removing and replacing existing subgrade and granular base with non-frost-susceptible soils
- Design the pavement structure based on reduced subgrade support
- Providing a capillary break

Traffic Loading

Damage from traffic loading is also a major catalyst for reducing the service life and deteriorating the pavement condition. Subgrade and base gravels that are frost susceptible can result in significant pavement weakening with traffic loading. The City should consider using load restrictions on existing arterial, bus routes, collector and industrial roadways as well as increasing the pavement structure in these corridors with the inclusion of geotextiles or thicker gravels.

Increase and Focus Maintenance Activities

As mentioned above, surface water can lead to significant damage to the pavement structure if not addressed properly. Surface water can enter the pavement through infiltration through surface cracks and joints and through adjacent unpaved surfaces. Surface water which is permitted to pond on the pavement surface, shoulder or adjacent ditch line can significant increase the amount of water infiltration. In order to mitigate the infiltration of surface water, it is recommended that the City increase the following maintenance activities to extend the service life of its roadway assets which will minimize/defer expensive replacement:

- Pavement patching, crack sealing and pot hole repair
- Ditch and shoulder grading to ensure positive flow
- Culvert and catch-basin cleaning

Revise Capital Project Scoping and Planning

The intent of a long-term integrated capital plan is to organize the costs and expenditures over a 20 years horizon in one location so budgets can be adjusted to match. In order to do so pragmatically, the expenditures need to be prioritized. The following recommendations were developed to assist with the development of an integrated infrastructure capital plan.

- To phase in capital projects based on their risk trigger; i.e., condition or capacity. Existing condition and capacity is the primary driver for projects in the catchment and preparing for significant projects should start immediately.
- To budget for Priority 1 pipe replacement in the 5-year Capital and Financial Plans. Priority 1 pipes should generally be selected over Priority 2 pipes, unless critical capacity or condition issues occur.
- To pursue trenchless rehabilitation program for Priority 2 condition-based replacement. The scope of trenchless rehabilitation should be completed following CCTV assessment of each pipe identified as potential. This is a cost-containment program that must be scoped out after more detailed information on the existing infrastructure is collected.
- Determine funding requirements to address the municipal contribution gap in part, by potentially updating user fees/rates in 2019/2020.
- To fund and replace the Priority 2 pipes by first completing the highest order projects by capacity risk score.
- Consider increasing investment into asset renewal to account for the potential impacts of climate change on sewer infrastructure and to begin funding Priority 3 pipes.
- Conduct a risk assessment of the major system (overland flow and depression storage), as described in Section 2.0 of the Stormwater System Capital Plan report. This begins with acquiring high density LiDAR data over the entire community.
- Incorporate climate change adaptation strategies into asset maintenance and upgrades by considering the following:
    - improving inlet capacity,
    - ensure debris and sediment are regularly cleaned from culverts and pipes,

    - ensure natural assets such as creeks and streams are protected and maintained,
    - installing barrier curb and re-grading boulevards when undertaking road upgrades in the areas showing high vulnerability to climate change, and
    - Installing grizzly screens on the inlets of major culverts.
- Continue to update the data and model as more information becomes available such as addition or deletion of infrastructure, condition assessments and field measurements of infrastructure.
- Consider increasing investment into the storm utility in the future to account for potential impacts of climate change.

Closing

Ideally asset renewal and maintenance budgets should be set to optimize asset service lives of the City's infrastructure and mitigate the cumulative impacts of climate change. Reduced or inadequate maintenance budget levels reduce the service life of infrastructure (most notably roads and drainage) and increase the costs and frequency of more expensive renewal.

Based on the assessment completed, the City's current budgets appear to be inadequate to effectively ensure the service life and use of the infrastructure can be sustained long-term. As a result, it is recommended that an annual drainage, ditching and shouldering renewal budget be created to supplement the annual pavement renewal budget. This will increase roadway life and reduce future life cycle costs.

The assessment also indicates that several new drainage capital projects may be needed to mitigate and adapt to catastrophic events. These projects should be considered in the City's long term capital planning due to the high consequence of failure.

In 2019, City Council has received all the reports and analysis and is considering these recommendations in their five-year financial planning process.

Appendix A: Referenced Studies and Articles

Bienkowski, Brian; Acid Trip: Great Lakes Could Face Similar Acidification Risk as the Seas; The Daily Climate; December, 2015.

Cromwell, John E; Smith, Joel B; Raucher, Robert S; Implications of Climate Change for Urban Water Utilities; Association of Metropolitan Water Agencies; 2007.

Ho, E. and Gough, W.A.; Freeze Thaw Cycles in Toronto, Canada In A Changing Climate; Theoretical and Applied Climatology; September, 2005.

Le Gauffre, Pascal; Aubin, Jean-Baptiste; Bruaset, Stian; Ugarelli, Rita; Benoit, Celia; Trivisonno, Franco; Van den Bliek, Kim; Impacts Of Climate Change On Maintenance Activities: A Case Study On Water Pipe Breaks; European Union – Seventh Framework Programme; 2010.

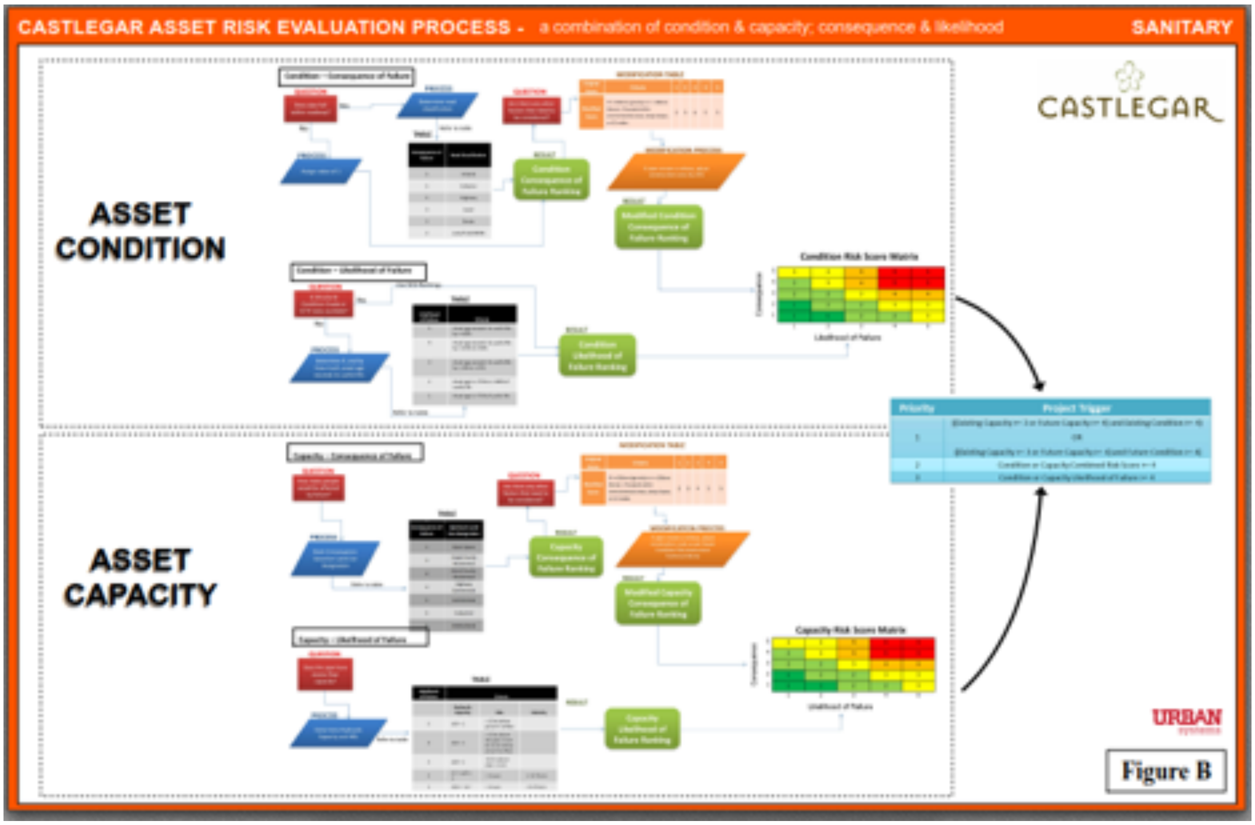
Natural Resources Conservation Service (NRCS), United States Department of Agriculture (USDA). Soil Quality Kit – Guide for Educators.

Rayburn, Chris; Effects of Climate Change on Water Utilities; AWWA Research Foundation; 2008.

Roshani, E. and Filion, Y.R.; Water Distribution System Rehabilitation under Climate Change Mitigation Scenarios in Canada; American Society of Civil Engineers Journal of Water Resources Planning and Management; Volume 141 Issue 4 - April 2015.

United States Environmental Protection Agency (US EPA); Report on the Environment – Acidity in Lakes and Streams; circa 2016.

Wols, B.A. van Daal, K., van Thienen, P. (Wols et al), 2013. Effects of Climate Change on Drinking Water Distribution Network Integrity: Predicting Pipe Failure Resulting From Differential Soil Settlement. 12th International Conference on Computing and Control for the Water Industry, CCWI2013


CASTLEGAR ASSET RISK EVALUATION PROCESS - a combination of condition & capacity; consequence & likelihood
SANITARY
ASSET CONDITION
ASSET CAPACITY
CASTLEGAR
URBAN
Figure B