Climate Risk Assessment Framework and Process Guide – v4

January 11, 2024

Version Control

Version No.	Date released	• Revisions
Version 1	July 2021	• Original version detailing Climate Risk and Resilience Assessment (CRRA) process
Version 2	October 2021	• Updated to include climate profile and climate hazard likelihoods
Version 3	October 2022	• Updated climate projections based on January 2022 release of the Climate Projections for Calgary Report • Update likelihoods based on Middle Baseline Method (ICLR, 2021)
Version 4	January 2024	• Updated to include CRRA and CRSA framework to support decision-making (pages 7-9) • Updated consequence table to include environmental impacts (pages 12-13) • Added Table 7 – as a new requirement for the appendix in all CRRAs (page 15) • Updated to include the Climate Risk Screening Assessment (CRSA) process (page 16) • Addition of some indicators and corrections to the Calgary Climate Profile section (page 19 onwards)

Summary

The Climate Risk Assessment Framework and Process Guide is separated into two sections: 1) the Climate Risk Assessment Framework, which is made up of the Climate Risk and Resilience Assessment (CRRA) and the Climate Risk Screening Assessment (CRSA) processes and 2) Calgary's Climate Profile (climate profile).The first part of this document outlines the framework and associated CRRA and CRSA processes, which will inform resilience and adaptation measures for infrastructure projects as a full assessment and scaled down assessment approach, respectively. The second part of this document highlights the projected changes to Calgary's climate.

The Climate Risk Assessment Framework is intended to be used by consultants, design teams and/or City project management teams. The objective of a CRRA or CRSA is to identify and evaluate the risk[1] that climate hazards[2] may have on infrastructure, the natural environment and the human users of the asset over its lifetime. An assessment results in recommended resilience[3] measures to decrease the impact of these hazards, reduce vulnerability[4] of the infrastructure to climate change and improve adaptive capacity[5].

The CRRA process was developed in alignment with the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol (ICLR, 2016), the High Level Screening Guide (ICLR, 2021), The City of Calgary Risk Matrix and requirements for the Federal Infrastructure Canada *Climate Lens Resilience Assessment* (GOC, 2019). The CRRA process is informed by The City of Calgary's *Climate Change Adaptation Technical Report* (The City of Calgary, 2017) and The City of Calgary's Integrated Risk Management Process. Similarly, the CRSA is a streamlined version of the CRRA process that can be used by project managers, without the use of a speciliazed consultant where a CRRA is not required. To determine if a CRRA is required or if a CRSA is an option for the project, see Figure 1.

The climate profile presents the nine main climate hazards that impact[6] Calgary. For each hazard, the frequency of occurrence and magnitude are analyzed in the baseline climate (1981-2010), in the 2050s

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[1] Risk: a metric used to understand climate impacts, determined by the interactions between climate hazards, the exposure to each hazard and the community vulnerability of the affected system or human to the hazard.

[2] Hazards: the potential occurrence of a climate change driven event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources (WaterSMART Solutions Inc, 2017). Climate change amplifies the intensity, frequency and variability of climate hazards.

[3] Resilience: the ability of social, economic and environmental systems to cope with a climate-driven hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation and transformation.

[4] Vulnerability: the degree to which a system may be adversely affected; vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and system response capacity.

[5] Adaptive Capacity: organization and public capacity to change in response to, and in expectation of, the impact of climate hazards.

[6] Climate Impact: the adverse effects of climate-related acute events (climate hazards) or long-term trends on the human-valued attributes of built, natural & human systems. The magnitude of impact(s) is dictated by the event and/or trend itself, the vulnerability of the systems impacted based on their sensitivity and response capacity and the exposure of the system affected (WaterSMART Solutions Inc, 2017).

(2041-2070) and 2080s (2071-2100). All projections data presented in this report are based on the RCP8.5[7] scenario. By determining the likelihood of occurrence, the annual frequency of a climate hazard is compared to a threshold relevant to the asset being considered. Thresholds can be determined based on design guidelines, historical information, professional guidance, etc. The likelihood of occurence of the nine main climate hazards and relevant indicators for those hazards are provided to support the risk assessment process. The climate profile information is used in the risk assessment process to incorporate the interaction between a hazard and infrastructure asset, the likelihood[8] of occurrence and the consequence of the interaction.

[7] RCP8.5: Representative Concentration Pathway 8.5: the high emissions scenario, is a future where few restrictions are placed on emissions. Emissions in this scenario increase rapidly through this century and only stabilize in 2250. In Canada, RCP8.5 would mean an average temperature increase of 6.3°C by the end of the century compared to a baseline period of 1986-2005 (climatedata, 2023).

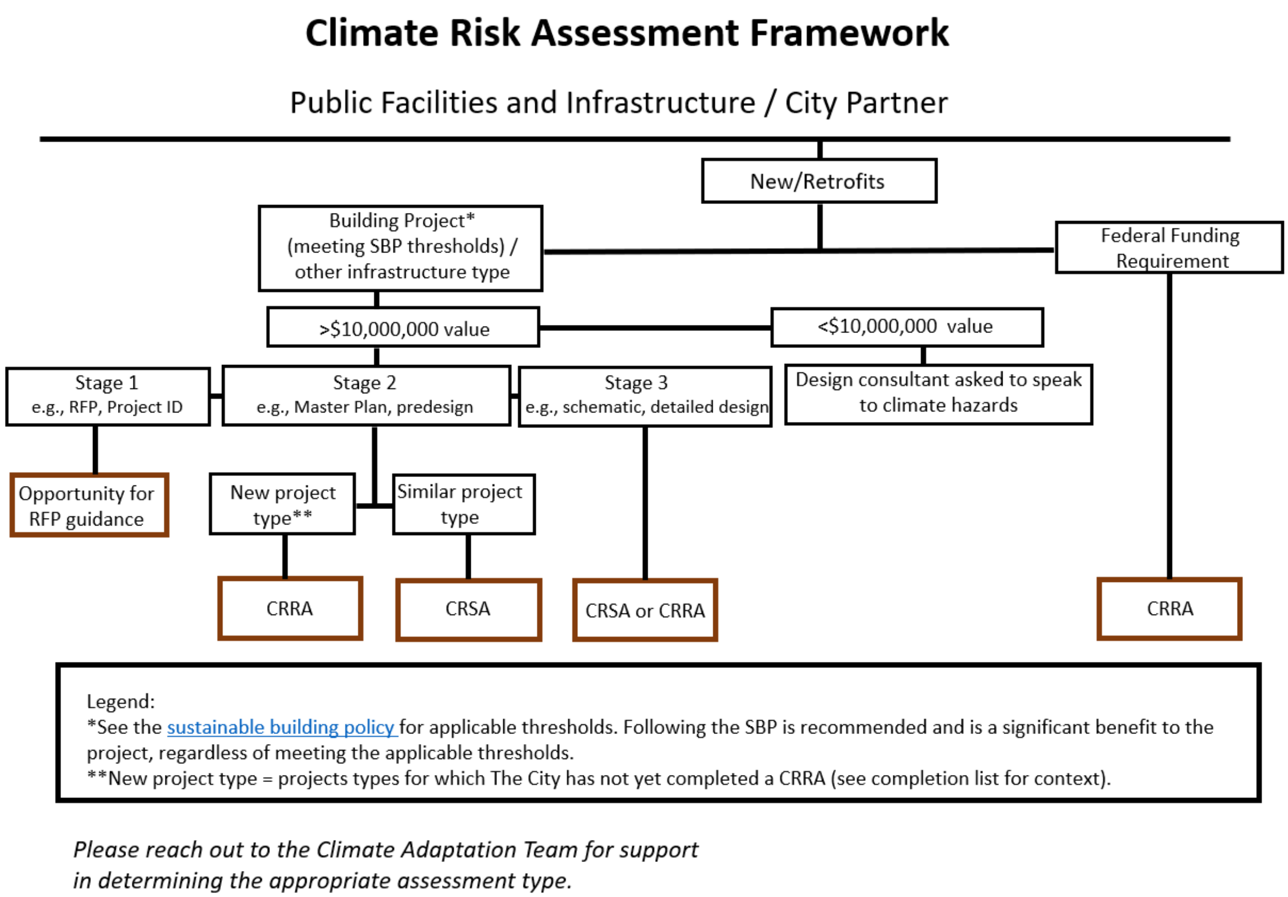
[8] Likelihood: the probability of a climate hazard and/or trend occurring due to climate change.

1.0 Assessment Process

Climate Risk Assessment Framework

As part of the CRRA and CRSA processes, The Corporation of The City of Calgary (The City) has developed a framework (Figure 1) for project managers to determine which type of climate risk assessment is required or recommended for their project. The CRRA and CRSA processes (and accompanying Excel tool, available online: Calgary.ca/ClimateRiskAssessmentFramework) will be discussed in detail in this document. For buildings and infrastructure projects, the flow chart in Figure 1 should be followed to determine which climate risk assessment process is required and/or recommended.

Figure 1: Recommended Climate Risk Assessment Framework



Public infrastructure / City Partnerships for new builds and retrofit projects

The framework shown in Figure 1 can be used to determine an appropriate climate risk assessment process for new builds or retrofit public infrastructure projects and City Partnership projects.

Climate Risk Assessment drivers

Federal funding requirements

For some federally funded projects, a CRRA (or equivalent) is required to access funding (Climate Lens[9]). The CRRA process meets the requirements of a Climate Lens, however the CRSA does not. Therefore, for any project requiring a Climate Lens or equivalent to be eligible for federal funding, a CRRA is required.

Buildings

In 2023, the Sustainable Building Policy (SBP) was updated to require the completion of a Climate Risk and Resilience Assessment (CRRA) for applicable city-funded or city-owned building projects[10] (COC, 2021b), (COC, 2023) and to plan, design and construct the building as per the Sustainable Building Guidance Document (SBGD). For building projects that meet these thresholds, a CRRA or CRSA (depending on the project type as shown Figure 1) must be completed.

Other infrastructure projects

To contribute to a climate resilient city, the Climate Strategy directs that infrastructure projects should assess and manage climate risk. If there is a significant opportunity to reduce climate risk (e.g., for people, built, and environmental systems) and the infrastructure project is greater than $10,000,000 in value with an expected life span of greater than 30 years, a CRRA or CRSA is recommended.

Design phase

Once the climate risk assessment driver is established, climate risk reduction measures can be incorporated into the project commensurate with the design stage (see Figure 2).

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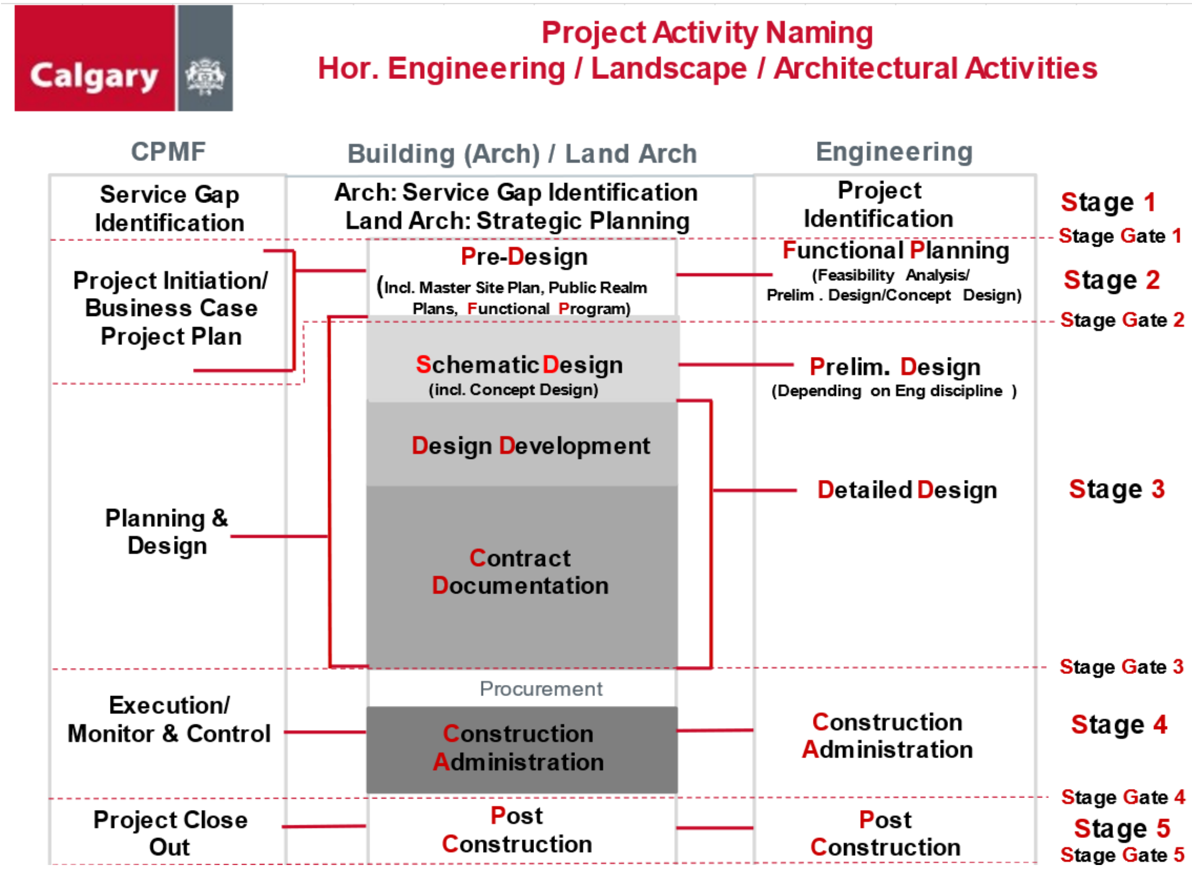
[9] Climate Lens: The Climate Lens is a horizontal requirement applicable to Infrastructure Canada's Investing in Canada Infrastructure Program (ICIP), Disaster Mitigation and Adaptation Fund (DMAF) and Smart Cities Challenge (Infrastructure Canada, 2019).

[10] The Policy applies to the planning, design, construction, operations, maintenance, renovation, and de-commissioning of all buildings that are City-owned and/or City-financed where The City provides a minimum funding contribution of 33 per cent of total project costs and The City contribution is equal to $1,000,000 or more (not including project development costs, design costs, and land).

Figure 2: Design stages of a project



Stage 1

Project Managers can incorporate climate risk reduction language within a Request for Proposal, and a CRRA or CRSA is recommended at later stages in the design depending on the project type.

Stage 2 & 3

Depending on the assignment of budget, a CRRA or CRSA can be completed at either Stage 2 or 3. If there has been a previously completed CRRA for a similar project (see website for completion list), then a CRSA is recommended as the previously completed CRRA can be referenced for the CRSA.

If the proposed project is of a type where a CRRA has not been completed, then a CRRA is recommended (and required if completing as part of the SBP or federal funding requirements).

Examples of projects in different stages of design and project types:

- a **new fire hall project** is at Stage 3 in the design and meets the requirements of the SBP. A CRRA was previouslycompleted for another fire hall. A CRSA is required (as per the SBP).
- a **new recreation facility** is at Stage 2 in the design and meets the requirements of the SBP. There has already been a CRRA completed for another, similar recreation facility in the past; therefore, a CRSA is required (as per the SBP).
- a **new washroom facility** is at Stage 2 in the design but does not meet the requirements of the SBP (under <$10,000,000 in total costs). A CRSA is recommended but not required.

- an **older recreation facility** requires major retrofits and wants to incorporate climate risk reduction measures at the same time. The scale of retrofits would meet the requirements of the SBP, but similar CRRAs have been completed in the past. A CRSA is required (as per the SBP).
- a **mainstreets project** is well into Stage 3 in the design process and wants to incorporate climate risk reduction measures, however the budget has already been assigned for the design. There have already been several CRRAs completed for similar projects, and the project does not meet the requirements of the SBP. A CRSA is recommended.
- a **mainstreets project** is well into Stage 3 in the design process by the time of engagement. There have already been several CRRAs completed for similar sites. As this is not a building, the project does not meet the requirements of the SBP. However, the project manager would like to use the assessment to apply for a relevant federal funding program, which requires the completion of a climate risk assessment or climate lens assessment (equivalent to The City's CRRA process). A CRRA is required (federal funding requirements) regardless of the stage of design.
- a **new Parks project** is being proposed and is at Stage 2 by the time of engagement. There have not been any previous CRRAs completed for similar project types. A CRRA is recommended.

Private projects

For privately owned projects seeking to reduce climate risk, The City recommends completing a CRSA and/or using the recommendations outlined in the SBGD (as part of the SBP). For high profile projects, The City recommends completing a CRSA or CRRA, as directed by the pre-development application process.

The Climate Risk and Resilience Assessment (CRRA) process

A CRRA is intended to reduce life cycle climate risk and lead to improved decision-making during project planning and design. CRRAs are to be broadly consistent with the key steps of the ISO 31000 Risk Management Standard and include both current and future climate conditions and impacts in the analysis. The Assessment needs to consider the spectrum of project design choices, climate risks during the construction phase, as well as changing climate risks during the life cycle of the infrastructure into the 2050s and 2080s. Asset-specific adaptation measures must be identified, as well as potential impacts and adaptation measures to support the built infrastructure, environment systems and human well-being of construction personnel and users.

Steps of the process

The following are recommended steps in completing a CRRA based off the PIEVC High Level Screening Guide (HLSG) (ICLR, 2021) guidance.

Step 1 – Scope

The City project team will establish the scope of the assessment from the kick-off meeting, which will include The City project team, the climate adaptation specialist, the design consultants and the climate risk consultant. This is an opportunity for the design and consulting teams to ask each other any questions about climate resilience and gather relevant project documentation.

Step 2 – Select infrastructure elements and climate hazards

Infrastructure elements

In this phase, the climate risk consultant will work with the team to define the built, natural and human asset categories of the project to be included in the CRRA, along with the expected lifecycle of the built elements. Interviews, reviews of site photography, drawings, local knowledge and project plans should be completed and used to define the infrastructure elements. The asset categories of built and natural infrastructure should be broken down into elements (e.g., roadway) and could further be broken down into sub elements (e.g., asphalt, road base, etc.) based on the level of detail required (CRRA dependent). A comprehensive asset table (see Table 1) should be prepared.

Table 1. Infrastructure under assessment

Asset categories	Considerations
Built infrastructure assets	• Elements and sub elements as identified by the design team, engineers, operations, etc. (e.g., Substructure, superstructure, etc.)
Human well-being	• Construction personnel • Operations personnel • Users
Natural environment	• Natural infrastructure • Ecosystem health and biodiversity
Other	*Include any additional components as relevant to your project*

Climate hazards

As per the risk assessment process, climate risk is analyzed as the intersection of the likelihood of a hazard occurring, the consequence should it occur and the exposure of an asset to a climate hazard.

The 2.0 Calgary's Climate Profil includes the likelihoods of the nine main climate hazards that impact Calgary in a baseline climate (1981-2010) compared to the 2050s (2041-2070) and 2080s (2071-2100).

Based on the climate projections for Calgary (COC, 2022b) (version two of the report will be released in February 2024) and employing **Table 2**, climate hazard likelihood ratings were developed and are summarized in **Table 3** (a full table of expanded climate indicators for each hazard are presented in Appendix 1). The standardized probabilities presented in **Table 2** and the middle-baseline method from the High Level Screening Guide (ICLR, 2021) were used to determine most of the climate hazard likelihoods.The likelihood scores were determined by analyzing the evolution of each variable in a changing climate.

Based on the project, additional indicators can be selected from **Appendix 1** beyond what is provided in **Table 3**. Not all relevant hazard indicators may be represented and additional climate analysis may be required.

The exposure[11] of the infrastructure elements to climate hazards should be investigated at a high level and would typically be further investigated in a workshop. Hazards that may not be relevant or likely to occur can be removed from the assessment.

An impacts workshop can be completed to investigate past events that have impacted the project or area, the associated impacts, to review and approve the asset list and to investigate exposure. Alternatively, an online survey or interview process can engage the appropriate subject matter experts to investigate historical impacts.

Table 2. Likelihood of impact

Likelihood rating	Qualitative descriptor	Probability of event occurring in a year (%)	Flooding/SDHI rainfall return period probability	Extreme heat probability
1	Rare	≤ 10	1:200 event (0.5% chance)	< 1 every 10 years
2	Unlikely	11 – 34	1:100 event (1% chance)	Once every 2-10 years
3	Possible	35 – 64	1:70 event (1.4% chance)	Once every 2 years
4	Likely	65 – 89	1: 50 event (2% chance)	More than 1 x every year
5	Almost Certain	≥ 90	1:25 event (4% chance)	More than 3 x every year

Table 3. Climate hazard likelihood ratings summary

Climate related hazard	Projected climate hazard trend	Baseline	Future (2050s)	Future (2080s)
Extreme heat	↑	3	5	5
Increased air temperature	↑	3	4	4
Wildfire	↑	2	4	4

[11] Exposure reflects the presence of something of human value (within a built, natural or human system) in a place and/or setting that could be impacted by a hazard (i.e., people, livelihoods, ecosystems, environmental functions, services, resources, infrastructure, or economic, social, or cultural assets) (WaterSMART Solutions Inc, 2017). Exposure is quantified as a 0 (not exposed) or 1 (exposed).

Drought	Likely ↑	3	4	4
Short duration high intensity (SDHI) rainfall	↑	3	4	5
Severe storms	Likely ↑	3	4	5
High winds	Likely Stable	3	3	2
River flooding	Likely ↑	2	3	3
Heavy snowfall	Likely ↓	3	3	2

Step 3 – Risk assessment

Establishing consequences

Once climate likelihood is established, the consequence of the interaction (impact) is established to assess the climate risk to the infrastructure elements. The consultant will determine relevant consequence scores, which can be assigned to the interactions identified by the subject matter experts. Consequences are assigned from 1-5, based on the consequence table provided in **Table 4**. The cost type consequence is to be determined by the consultant depending on the project type and should be completed in consultation with the project team. The environmental impacts should be assessed on a project-by-project basis and should consider how the surrounding environment will be affected by the project (e.g., if trees are removed, this will amplify the urban heat effect and could increase the consequence of impact). If the consequence types receive different scores, the highest scored consequence type will be used in the evaluation of risk, however, all consequence types should be considered in the identification of resilience recommendations. The following table of consequences should be referenced to develop the assessment.

Table 4. Consequence classification matrix

Consequence Types						
Score	**Classification**	**Health & safety**	**Structural integrity**	**Functionality**	**Cost**	**Environmental impacts**
1	Very Low	First aid injury	No permanent damage	No/minimal service disruption	TBD	No/minimal short term environmental impacts.
2	Low	Medical treatment for a minor injury	Minor asset or system damage, minor repairs or restoration	Minor service disruption may occur	TBD	Localized effect or impact to an already impacted environmental resources(s)/ecosystem(s) **on site**; no sensitive environmental asset or area impacted.
3	Medium	Bodily injury/illness with work restrictions	Moderate damage to asset or system. Minor repairs and some equipment replacement or restoration	Brief service disruption may occur	TBD	Localized adverse effect or impact to an already impacted environmental resource(s)/ ecosystems **off-site**; no sensitive environmental asset or area impacted.
4	High	Permanent disabling injury or multiple people injured	May result in significant damage, loss, or require complete replacement	Lengthy service disruptions may occur	TBD	Substantial impacts requiring emergency management <30 days with the potential for distrupting off-site ecosystem components. Sensitive environmental asset or area impacted with potential for recovery.

5	Extreme	Fatality or significant irreversible disability	May result in significant damage, loss, or require complete replacement	Lengthy service disruptions may occur, alternate service delivery may be required	TBD	Substantial impacts requiring emergency management >30 days distrupting off-site ecosystem components on a community scale. Permanent destruction of key ecosystem component.

Risk analysis

Once the exposures, likelihoods and consequences are determined, risks scores can be calculated for each interaction:

$$Risk = Exposure\ x\ Consequence\ x\ Likelihood$$

A consequence workshop can be completed to finalize and revise the consequence scores identified and review and confirm the associated risk scores. The report will provide a table including the likelihoods, consequences and calculated risk scores for each relevant infrastructure element in a baseline, 2050s and 2080s climate.

Table 5. Risk classification matrix

Risk classification	Rating	Recommended risk treatment
Very low	1-2	Tolerable: risks do not require further consideration.
Low	3, 4 and 6	Monitor: controls or coping strategies recommended.
Medium	5, 7-9	Requires some attention: some controls required to reduce risk levels. Monitor risk for changes over time.
High	10-16	Requires much attention: high priority control measures required.
Extreme	20-25	Not acceptable: significant controls required.

Step 4 – Resilience analysis

Resilience analysis

Once the risks are determined, the consultant will create preliminary resilience recommendations for all medium to extreme risk scores for the baseline, the 2050s and the 2080s.

The analysis should include all resilience measures that have been incorporated into project design already. Recommendations to address identified risks should be provided to improve the resilience of the built infrastructure, natural environment and the human well-being systems that are interconnected with the infrastructure project. The impacts of climate hazards may not be isolated to a single system, instead there may be primary and cascading impacts on multiple systems. Similarly, risk reduction measures may improve resilience across multiple systems.

A resilience workshop can be completed at this stage to explore the preliminary resilience recommendations, engaging project teams to discuss feasibility of implementation.

Following the resilience workshop, the resilience recommendations should be ranked by feasibility of implementation using a variety of indicators determined in the workshop and by the consultant team internally, provided in table format. Some indicators could be practicality, equity, synergy (with mitigation measures), effectiveness, cost efficiency, funding, etc., with a total feasibility indicator provided. The resilience measures provided should be specific enough to constitute action as The City will use this table to prioritize implementation efforts.

Cost benefit analysis

Once the most feasible and highest priority adaptation measures are identified, the consultant should conduct a high-level Cost-Benefit Analysis to support the implementation of the most feasible climate adaptation measures. This analysis should include the present value of costs (both operating and capital, tangible costs), the present value of benefits (such as avoided losses) and associated implementation risks where possible.

Step 5 – Reporting and next steps

A final report will include the requirements from Steps 1- 4, detailed tables, and the summarized results detailing the elements, hazard, baseline, 2050s and 2080s medium, high and extreme risks, impacts, and associated resilience recommendations (as shown in **Table 6**). The project team will be requested to provide an implementation plan, which will provide futher details about the integration of recommended measures.

Table 6. Example final reporting table

Elements	Hazard	Baseline	2050s	2080s	Impact	Resilience recommendations
Substructure	SDHI rainfall	Medium	High	High	Water pooling next to foundation causing structural problems over time	Prioritize efficient drainage and site grading in design

The Climate Risk Screening Assessment (CRSA) process

A Climate Risk Screening Assessment (CRSA) serves to identify climate hazards relevant to a project, and to determine climate risks and provide resilience measures to be used to reduce risk in planning, designing and operating infrastructure. The CRSA process is less time intensive than a CRRA and is intended to be applied to project types with some baseline understanding of climate risk, at a later stage in design, or to better understand how to assess and reduce climate risk. This is a simplified process which requires less engagement and results in a shorter summary report.

While workshop engagement is not necessary for a CRSA, an investigation into the site history of impacts should still be explored. This can take the form of a survey or interviews with relevant staff (e.g., operations and maintenance) to ascertain the history of impacts, which will be used to inform the consequence scoring. For example, is there a history of overland flooding at this site, and if so what kind of damage has occurred? The answer to this question will inform the assignment of consequence and associated risk.

CRSA overview

- A relevant project is identified.
- The project team undertakes the CRSA using the following tools (both available online: Calgary.ca/ClimateRiskAssessmentFramework):
    - The screening tool Excel document (crsa_worksheet.xlsx)
    - Referencing CRRAs that have been completed for similar infrastructure types (in the 'Past Assessments' tab in the crsa_worksheet.xlsx screening tool)
- A summary report (1-3 pages) detailing the highest climate risks and adaptation recommendations.
- The project manager/project team will complete an implementation plan ('Step 4-Implementation Tab' in the screening tool) for the identified adaptation recommendations that are most feasible to integrate into the design of the project.
- The project manager/project team will update the status of the implementation plan as necessary.

Screening tool

The screening tool is part of the Climate Risk Screening Assessment (CRSA) process for city-owned infrastructure. It is designed to apply to infrastructure types of varying size and complexity. The screening tool is intended to provide a structured approach to examine and prioritize the climate risks to a project, enabling project teams tomake climate and risk-informed decisions about the project. This screening tool also aims to build capacity and knowledge in the local design and construction industry to advance the understanding of climate hazard risks and available risk mitigation strategies. The worksheet includes step-by-step instructions within the different tabs (Steps 1-4) explaining how to utilize the screening tool. The screening tool uses the same climate hazard likelihood ratings, consequence classification matrix, and risk matrix, as presented in **Table 3**, **Table 4** and **Table 5**, respectively. For additional context, these tables should be referenced.

CRRA and CRSA comparison

The main milestones in a CRRA and CRSA are presented in Table 7.

Table 7: CRRA and CRSA milestones

Process	CRRA	CRSA
Kick off meeting with design consultant, project team, climate adaptation specialist	✓	
Data gathering (e.g., survey, interviews, gap analysis)	✓	✓
Workshops	✓	
Screening tool		✓
Final report	✓	
1-3 page summary report		✓
Implementation plan	✓	✓

2.0 Calgary's Climate Profile

Climate change is a global and local challenge that will increasingly impact environmental, social and built systems. The City has a responsibility to respond to, prepare for and adapt to the impacts of climate change on Calgarians and the global community.

The changing climate poses evolving risk to all communities in Calgary, and decisions made today on urban form have long term consequences that strongly affect a city's capacity to respond to climate hazards over time. Thus, community planning and design have a critical role to play in The City's response to climate change. Actions that reduce risk from climate hazards should be integrated at all urban scales.

Greenhouse gas reduction (known as mitigation), and adaptation are complementary approaches for reducing the risks of climate change impacts over different time scales. Mitigation, in the near term and through the next half-century, can substantially reduce climate change impacts in the latter decades of the 21st century and beyond. Climate change adaptation is a risk management strategy to reduce the negative impacts of climate change that cannot be avoided. Guided by local and global policy and specific climate mitigation and adaptation actions, the Calgary Climate Strategy (COC, 2022) aims to reduce climate risk to Calgarians and build the resilience of the City to a changing climate.

The intent of this document is to help project teams and consultants understand which climate hazards, and how climate risk, may affect their project area and its users.

Climate projections

Calgary experiences a multitude of climate hazards, most of which are expected to increase in frequency, intensity and duration in a changing climate. To better understand the climate hazards in Calgary's changing future, The City of Calgary partnered with the Calgary Airport Authority to develop Calgary-specific climate projections for the 2050s and 2080s (GHD, 2020), which are summarized in the Climate Projections for Calgary report (COC, 2022b). All data presented is based on the RCP8.5 emissions scenario, as directed by the Pacific Climate Impacts Consortium (PCIC) for long life span infrastructure (PCIC, 2021). Global policy to date has not significantly reduced GHG emissions, which are currently tracking between RCP6.0 and RCP8.5. RCP8.5 is therefore the most prudent and conservative choice for planning for infrastructure with a long service life (PCIC, 2021; GHD, 2020).

Historical weather data (1960-2014) was sourced from the Environment and Climate Change Canada (ECCC) station at the Calgary International Airport, with quality assurance/quality control conducted by The City. Observed precipitation, air temperature, wind speed and direction data were collected from the airport. The historical data was then perturbed to the 2050s (2041-2070) and 2080s (2071-2100) climates using global climate models (GCMs). The climate profile data analysis utilized the Canadian climate normals period (1981-2010) as the baseline period (historical adjusted) to compare against the 2050s and 2080s GCM projections. The Climate Projections for Calgary Report should be referenced for more information on time periods and bias correction methods.

There are several types of uncertainty that exist within climate projections, including that of the climate models themselves, emissions scenarios, and natural climate variability (ENSO patterns, sunspot cycle, volcanic eruptions, etc.). The greatest amount of uncertainty in projections arises from emissions scenarios and not knowing what emission concentrations will be in the future. Therefore, given uncertainty is a normal characteristic of the modelling process, it is expected that reports provide a range of projected changes. For example, a stated range of mean daily maximum air temperature from the 10 to 90 % range in modeling results shows there is a 10 % chance that the mean daily maximum air temperature will be less than 24.8°C by the 2080s and a 90 % change that it will be less than 30.9°C. Uncertainties are further quantified by the likelihood of the expressed probability range and the confidence in the validity of the reported results.

Confidence relates to the ability of the climate models to reproduce observed features of the current and future climate. Greater confidence exists in broader scale projections, mid-century rather than late, and some variables over others (temperature versus precipitation). For example, experts are highly confident that average temperatures will increase as GHG emissions increase; however, for every compounding variable in the climate problem, less confidence exists. For example, with higher temperatures, more moisture exists in the atmosphere which can lead to higher rainfall, in turn leading to more intense short duration high intensity rainfall. These extreme rainfall projections have less confidence as the magnitude depends on more contributing factors and assumptions than only an increase in temperature.

For some hazards, due to limitations of the model or the nature of the hazard, projections cannot be used. Therefore, literature was used to determine future trends. In some cases, both literature and projections were utilized.

This climate profile utilizes the ensemble of the CMIP5 global climate models for RCP8.5. The most current global climate data for CMIP6 and the shared socioeconomic pathways (SSPs) is now available but not included in either this climate profile or the Climate Projections for Calgary Report. The CMIP5 and CMIP6 future climate simulations are qualitatively similar for Canada, however CMIP6 simulations exhibit larger temperature and precipitation extremes by the end of the century (climatedata, 2023) and have limited temporal availability compared to the available CMIP5 projections. Therefore, The City will continue to utilize the available CMIP5 projections.

Calgary's top climate hazards

Projected climate hazard trends for Calgary are presented in **Table 8** along with associated references.

Table 8. Summary of climate hazard trends for Calgary

Climate hazard	Projected climate hazard trends (2050s and 2080s)	References
Extreme heat	↑	Projections used: GHD, 2020
Higher average temperatures	↑	Projections used: GHD, 2020
Wildfire (smoke)	↑	Literature used: Flannigan, 2016; Wotton, 2017; Wang, 2017; WSP, 2021
Drought	Likely ↑	Projections used: GHD, 2020
Short duration high intensity (SDHI) rainfall	↑	Projections used: GHD, 2020, Trenberth, 2011
Severe storms (i.e., hail, tornadoes)	Likely ↑	Literature and projections used: GHD, 2020; Etkin, 2018; Brimelow, 2017; Romps, D. M. et. al., 2014; ECCC, 2021
High winds	Likely Stable	Literature and projections used: GHD, 2020; Zeng, 2019; Vautard, 2010; Greene, 2010
River flooding	Likely ↑	Literature used: Rajulapati et. al., 2020; Tesemma, et. al., 2020; Pomeroy, 2015

Heavy snowfall	Likely ↓ (in all seasons but winter)	GHD, 2020; DeBeer, 2016

Extreme heat

Calgary will experience increasingly hot summers with heat waves occurring more often and for longer periods of time (GHD, 2020). ECCC issues heat warnings in Calgary when two or more consecutive days of daytime maximum temperatures are expected to reach 29°C or higher and overnight minimum temperatures are expected to be 14°C or warmer; The City uses the same criteria to define a heat wave. The number of hot days (maximum temperature greater than or equal to 29°C), heat waves, and the length of heat waves are all expected to increase in the future. Warm nights (minimum temperature greater than or equal to 14°C), are projected to increase as well. **Table 9** includes a summary of baseline and projected extreme temperature indicators (e.g., number of hot days) for the City. The low (10th), median (50th) and high (90th) percentiles were calculated for all the GCMs and are presented below in the table for each indicator where available.

Table 9. Summary of extreme climate projected temperature indicators for Calgary

Extreme Heat Indicators	Season[1]	Baseline	2050s			2080s		
			Low[2]	Median[2]	High[2]	Low[2]	Median[2]	High[2]
Mean daily maximum temperature (°C)	Summer[1]	21.4	23.4	25.0	27.0	24.8	27.6	30.9
	Annual	10.3	11.6	13.3	15.4	13.0	15.4	18.0
Mean daily minimum temperature (°C)	Winter[1]	-11.6	-10.1	-7.9	-5.8	-7.9	-5.7	-3.3
	Annual	-1.2	0.5	2.0	3.6	2.1	4.1	6.1
Number of warm nights	Annual	5.3	19.1	32.4	46.8	35.8	65.5	85.6
Annual maximum temperature (°C)	Summer[1]	32.0	34.2	36.0	39.2	35.6	38.4	43.1
Hot days	Annual	6.8	15.2	26.5	42.0	24.3	48.1	71.5
Heatwave length (days)	Annual	0.5	2.5	4.8	7.9	4.9	10.6	17.8
Max heatwave length (days)	Annual	4.0	6.0	16.0	18.0	14.0	24.0	48.0
Mean number of heat waves	Annual	0.2	1.7	3.0	5.1	2.9	7.1	9.5

[1] Spring (March, April May), Summer (June, July, August), Autumn (September, October, November), Winter (December, January, February).
[2] Indicates the 10th (low), 50th (median) and 90th (high) percentiles across the regionally downscaled modelled projections (GHD, 2020).

Higher average temperatures

Local temperatures have steadily increased over the past century and projections strongly indicate that regional warming is expected to continue at an accelerated rate. Greater warming is expected during the cooler seasons (winter, late autumn and early spring) and in nighttime temperatures throughout the year. Winters are getting shorter, spring is arriving earlier, summers are longer and fall is arriving later. Average winter temperatures are projected to increase but remain below 0°C. The intensity of cold spells will likely become less intense as average temperatures are projected to increase. Freeze-thaw cycles are expected to decrease annually, especially during the spring and fall as more of the year will be spent at temperatures above 0°C. **Table 10** includes a summary of seasonal average and projected temperature ranges for the Calgary.

Table 10. Summary of climate projected temperature indicators for Calgary

Increased air temperature indicators	Season[1]	Baseline	2050s			2080s		
			Low[2]	Median[2]	High[2]	Low[2]	Median[2]	High[2]
Mean temperature (°C)	Annual	4.5	6.0	7.7	9.5	7.6	9.8	12.1
	Winter	-6.2	-5.1	-3.0	-0.9	-3.3	-1.0	1.4
	Spring	4.2	5.4	7.0	9.1	6.8	8.8	11.3
	Summer	15.3	17.3	18.7	20.3	18.8	21.3	23.7
	Fall	4.7	6.2	7.7	9.3	7.7	9.7	11.7
Mean number of cooling degree days (CDD)[3]	Annual	46.1	119.1	201.7	327.2	203.4	401.3	657.2
Mean number of heating degree days (HDD)[4]	Annual	4958.7	4491.7	3981.8	3423.4	4014.6	3411.5	2820.0
Mean number of freeze-thaw cycles	Annual	107.4	95.3	83.5	70.3	85.3	64.1	54.6
Mean number of freeze-thaw cycles	Winter	43.5	43.9	43.8	42.1	43.8	39.5	36.3
Mean number of freezing degree days (FDD)[5]	Annual	902.2	768.2	566.4	381.7	587.8	404.1	237.4
Mean growing season length	Annual	123.8	141.9	151.7	172.3	151.6	169.7	200.4
Mean July 2.5% design air temperature[6]	Frequency	28.0	30.4	32.2	34.5	32.5	34.8	39.0
Building zone[7]	-	7A	6			5		

[1] Spring (March, April May), Summer (June, July, August), Autumn (September, October, November), Winter (December, January, February).
[2] Indicates the 10th (low), 50th (median) and 90th (high) percentiles across the regionally downscaled modelled projections (GHD, 2020).
[3] CDD are equal to the number of degrees Celsius a given day's mean temperature is above 18°C (Climate Atlas, 2021).
[4] HDD are the average annual sum of the number of degrees Celsius that each day's mean air temperature is below 18°C. When mean air temperature is ≥18°C the degree day is 0 (Climate Atlas, 2021).
[5] FDD are the annual sum of the number of degrees Celsius that each day's mean temperature is below 0°C. When the average daily temperature is ≥ 0°C, the degree day is 0.
[6] The upper 2.5th percentile of hourly air temperature in July. Calculated from 40,920 July hourly air temperatures over the entire 55-year historical time series.
[7] Building climate zones data examines heating degree days in a future climate by region which can be used by building professionals to specify thermal performance requirements (climatedata, 2023).

Wildfires

With hotter, drier and earlier summers expected in the future, wildfire risks (and associated hazards, such as reduced air quality from wildfire smoke) are expected to increase for Calgary. A research study examined the number of projected wildfire spread days in the Southern Cordillera range (extending from central/interior/southern British Columbia into central/southern Alberta) and found an increase in the expected number of wildfire spread days for this region (Wang, 2017). Additionally, the southern Alberta area will likely have bigger fires and more frequent days of fire growth (Wotton, 2017) towards the end of the century if increases in precipitation due to climate change are not sufficient to offset increases in temperature (Flannigan, 2016). **Table 11** includes a summary of baseline and projected wildfire spread days for the Southern Cordillera range. Given that this is a projection based on literature and the nature of the hazard, the confidence in these projections is low.

Although the physical risk due to wildfire is low within most areas of the City, there is the potential to experience increased wildfire smoke and poor air quality days due to the higher number of wildfire days expected and the prevailing westerly wind direction.

Table 11. Regional wildfire spread

Wildfire indicator	Historical	2050s	2080s
		Median[1]	Median[1]
Median number of wildfire spread days	3	5.5	5.7

[1] Indicates the 50th (median) percentile.
[2] Median number of wildfire spread days for the Southern Cordillera fire region based on realized spread days (depends on the occurrence of an active fire, extensive fuels and extreme fire weather (Wang, 2017)).

Drought

Based on climate modelling availability, only meteorological drought projections are provided but two types of drought are discussed in this guidance document:

- **Meteorological drought** is a result of less precipitation than normal over a prolonged period in a specific region. It is usually the first type of drought to occur. Meteorological drought can be represented by the annual number of dry days (daily precipitation less than 1mm) and dry spells (at least 14 consecutive dry days). Meteorological drought is also represented by drought days, and when the Standard Precipitation Evapotranspiration Index (SPEI) is less than -1 annually. Drought days (days experiencing less than the annual 10th percentile of the daily distribution of precipitation-evapotranspiration) and a two-week drought are also indicators used to represent meteorological drought.
- **Hydrological drought** occurs when surface water or groundwater levels fall below average levels due to a lack of precipitation. It usually occurs more slowly than a meteorological drought.

Under the influence of climate change, counter-acting effects will influence the evolution of drought episodes (e.g., more precipitation at certain times of the year or with discrete storm events, with higher temperatures and decreasing precipitation in the summer months). Climate projections indicate the frequency of occurrence for dry days and dry spells will remain similar, however, once evapotranspiration is considered, drought conditions are expected to become more frequent (see **Table 12**).

Due to data availability, only the median of the ensemble is presented for some of the indicators in **Table 12**; the confidence is considered medium.

Table 12. Indicators of drought driven by climate projections for Calgary.

Drought indicators	Baseline	2050s			2080s		
		Low[1]	Median[1]	High[1]	Low[1]	Median[1]	High[1]
Number of dry days	296.2	301.2	296.7	295.7	301.1	296.8	295.7
Number of dry spells	5.9	6.3	6.0	5.9	6.3	6.0	5.9
Drought days [2]	63.9	-	75.6	-	-	83.8	-
Return period of 2-week drought (years) [2]	55.0	-	27.5	-	-	18.3	-
Return period of 12-monthly Standard Precipitation – Evapotranspiration Index (SPEI-12) <-1 (annual) [2]	<1:100	-	1:10	-	-	1:1.4	-

[1] Indicates the 10th (low), 50th (median) and 90th (high) percentiles across the regionally downscaled modelled projections (GHD, 2020).
[2] Considers only the mean of the model ensemble.

Short duration high intensity (SDHI) rainfall

Precipitation observations and climate modelling indicates an upward trend in extreme precipitation events for Calgary, and research indicates an increase in convective storms (i.e. thunderstorms, lightning, hail) (Brimelow, 2017; Romps, D. M., et. al., 2014). Severe, convective storms can produce lightning, high winds, hail, and short duration high-intensity rainfall events (SDHI), potentially leading to overland flooding.

The intensity, duration, and frequency (IDF) of rainfall are used to relate rainfall intensity with its duration and frequency of occurrence, and are used in hydrology, flood forecasting, and civil engineering for urban design. Calgary-specific IDF of rainfall were developed by GHD for The City in partnership with The Calgary Airport Authority using data from the Calgary International Airport (GHD, 2020). **Table 13** -**Table 15** are the IDF rainfall estimates for the City for the baseline, 2050s and 2080s, respectively. **Table 16** includes a summary of average projected IDF of rainfall across all frequencies for the City. IDF of rainfall is anticipated to increase across short duration (less than 24 hours, typically 1-2 hour events) and long duration (24 hours or longer) events. The projected increase in rainfall volumes can be described by employing the Clausius-Clapeyron relationship, which predicts an increase in the saturation vapour pressure of air by 7% for every 1°C increase in surface temperature (Trenberth, 2011), a hypothesis further supported by GCM analysis for The City.

Projections indicate the degree of change will be greater by the 2080s than it will be in the 2050s. At higher return periods (i.e., less likely storms, e.g., 1:100 year event) there is a greater degree of rainfall volume increase than at lower return periods (i.e., more likely storms, e.g., 1:5 year event). Significant increases in rainfall amounts are expected during discrete storm events (**Table 16**); and in the seasonal precipitation projections (**Table 17**).

Table 13. Baseline IDF of rainfall estimates (mm) for the Calgary International Airport

Time	2 yrs	5 yrs	10 yrs	25 yrs	50 yrs	100 yrs	200 yrs	500 yrs
5 min	5.1	7.2	8.6	10.4	11.7	13	14.3	16.1
10 min	7.7	11.2	13.4	16.3	18.4	20.5	22.6	25.4
15 min	9.6	13.9	16.8	20.4	23.1	25.8	28.5	32
30 min	12.2	18.4	22.5	27.6	31.4	35.2	39	44
1 hr	14.6	21.8	26.6	32.7	37.1	41.6	46	51.9
2 hr	17.5	24.9	29.8	36	40.6	45.1	49.7	55.6
6 hr	24.6	32.9	38.4	45.3	50.4	55.5	60.6	67.3
12 hr	31.1	42.1	49.4	58.5	65.4	72.1	78.9	87.8
24 hr	39.5	54	63.6	75.7	84.7	93.7	102.6	114.3

Table 14. 2050s Climate adjusted IDF of rainfall estimates (mm) for the Calgary International Airport

Time	2 yrs	5 yrs	10 yrs	25 yrs	50 yrs	100 yrs	200 yrs	500 yrs
5 min	6.5	9.2	11	13.3	15	16.7	18.4	20.6
10 min	9.9	14.3	17.2	20.9	23.6	26.3	29.0	32.5
15 min	12.2	17.8	21.5	26.2	29.6	33.1	36.5	41.0
30 min	15.7	23.5	28.7	35.3	40.2	45.1	49.9	56.3
1 hr	18.7	27.9	34.1	41.8	47.5	53.2	58.9	66.4
2 hr	22.5	31.9	38.2	46.1	51.9	57.8	63.6	71.2

6 hr	31.5	42.1	49.1	58	64.6	71.1	77.6	86.2
12 hr	39.8	53.9	63.2	74.9	83.7	92.3	101.0	112.4
24 hr	50.6	69.2	81.4	97	108.5	119.9	131.3	146.3

Table 15. 2080s Climate Adjusted IDF of rainfall estimates (mm) for the Calgary International Airport

Time	2 yrs	5 yrs	10 yrs	25 yrs	50 yrs	100 yrs	200 yrs	500 yrs
5 min	7.7	10.9	13.1	15.8	17.8	19.8	21.8	24.4
10 min	11.7	17.0	20.4	24.8	28.0	31.2	34.4	38.6
15 min	14.5	21.2	25.5	31.1	35.2	39.3	43.3	48.7
30 min	18.6	28.0	34.1	42.0	47.8	53.5	59.3	66.8
1 hr	22.2	33.2	40.5	49.6	56.4	63.2	69.9	78.8
2 hr	26.7	37.9	45.3	54.7	61.7	68.6	75.5	84.6
6 hr	37.4	50.0	58.4	68.9	76.7	84.4	92.2	102.3
12 hr	47.3	64.0	75.0	89.0	99.4	109.7	119.9	133.4
24 hr	60.1	82.1	96.7	115.1	128.8	142.4	155.9	173.7

Table 16. Summary of climate projected increase in rainfall IDF for Calgary.

Precipitation event	2050s	2080s
Short duration (<24 hours)	28% increase [1]	52% increase [1]
Long duration (≥ 24 hours)	10-15% increase [1]	10-20% increase [1]
[1] Averaged over all return periods.		

Table 17. Summary of climate projected precipitation for Calgary.

Climate indicator	Season	Baseline (mm)	2050s (mm)			2080s (mm)		
			Low[1]	Median[1]	High[1]	Low[1]	Median[1]	High[1]
Mean precipitation totals	Annual	418.2	362.6	440.1	533.2	360.6	451.8	558.2
	Winter	29.0	26.1	30.7	36.5	27.1	32.1	38.4
	Spring	99.3	91.6	110.1	135.1	95.2	118.3	144.4
	Summer	216.4	182.8	219.0	265.0	172.4	219.8	274.7
	Fall	73.5	62.0	80.4	96.6	65.8	81.6	100.7

[1] Indicates the 10th (low), 50th (median) and 90th (high) percentiles across the regionally downscaled modelled projections (GHD, 2020).

Severe storms

As surface temperatures and associated convective available potential energy (CAPE) increases with climate change, the number of days per year with severe weather potential are projected to increase (Brimelow, 2017). July is the most active month for convective conditions and events in Calgary, however, as seasons shift, convective events are projected to occur in more months than previously observed with more days having favourable conditions for severe storms development.

Although hail cannot be explicitly modelled by global and regional climate models due to limitations in resolution, in a changing climate, hail stones are expected to increase in size due to increasing atmospheric energy (and associated updraft). Conversely, the frequency of smaller sized hail events occurring are expected to decrease due to a rising melting level in a warming atmosphere (Brimelow, 2017). The longer convective storm season (**Table 18**) will likely contribute to Calgary experiencing more hail events in total (Etkin, 2018).

The frequency and duration of severe storms is likely to increase in the future, increasing risk to property owners. Buildings will increasingly be impacted by severe storm hazards such as heavy rain, lightning (Romps, D. M., et. al., 2014) and hail. Given the nature of the climate hazard and the methodology used, the confidence in the projections is low (GHD, 2020).

Table 18. Summary of climate projected severe storms for Calgary

Severe storms indicators	Season	Baseline	2050s			2080s		
			Low[1]	Median[1]	High[1]	Low[1]	Median[1]	High[1]
Mean number of days with convective events (thunderstorms)[2]	Annual	22.9	26.1	34.7	41.9	25.3	39.9	48.6

[1] Indicates the 10th (low), 50th (median) and 90th (high) percentiles across the regionally downscaled modelled projections (GHD, 2020).
[2] Thunderstorm designation was determined by specific GHD methodology and a weather typing model to identify potential convective precipitation events (which could consist of funnel clouds, hail, heavy rainfall, thunderstorms) based on historical data (GHD, 2020).

High winds

Projections provided by GHD align with recent research studies that suggest global wind speeds were decreasing from the 1970s to 2010 and have been increasing since 2010 (Zeng, 2019). Research is still ongoing to understand this trend. Given the nature of the climate hazard and uncertainty surrounding future wind changes with increasing temperature, the confidence in the projections is low. **Table 19** includes a summary of baseline and projected wind gust days for the City.

Table 19. Summary of climate projected wind gusts for Calgary

Climate indicator	Season	Baseline	2050s			2080s		
			Low[1]	Median[1]	High[1]	Low[1]	Median[1]	High[1]
Mean number of days with maximum wind gusts ≥ 90 km/hr[2]	Annual	2.0	0.6	1.8	4.3	0.7	1.6	3.8

[1] Indicates the 10th (low), 50th (median) and 90th (high) percentiles across the regionally downscaled modelled projections (GHD, 2020).
[2] The wind threshold of 90km/hr was chosen based on ECCC's warning criteria for wind warnings (ECCC, 2021), and the lower bound for 1-4 Storey buildings on the 'Enhanced Fujita scale damage indicators and degress of damage, chapter 17' (ECCC, 2014).

River flooding

The hydrological processes that most commonly contribute to flooding in the Bow River Basin include snow melt runoff and rainfall runoff (and associated rain-on-snow events). Larger, less frequent floods (with return periods greater than 15 years) are generally driven by rain-on-snow events, while smaller, more frequent floods (with return periods of less than 15 years) are typically driven by snowmelt and rainfall runoff (Pomeroy, 2015). Climate change is expected to shift temperature and precipitation patterns that can potentially exacerbate the conditions that lead to river flooding; however, these conditions are complex and not well resolved by modelling approaches. To improve these uncertainties, a large-scale two-part extensive research project – the Bow River Basin Study (BRBS) – was recently carried out by Tesemma et al., (2020) (Part 1) and Rajulapati et al., (2020) (Part 2) in collaboration with The City, Alberta Environment and Parks, ECCC and the Global Water Futures program. Their results highlight the need for continued observation, additional studies and furthered flood river mitigation work. There has been substantial flood river mitigation work already completed in Calgary since the 2013 floods, including changes to upstream water management operations, extensive flood barriers particularly to protect the downtown core, and significant lot-level risk reduction practices have been implemented in many locations.

To further the work done by the BRBS, WSP conducted a research study for The City to better understand how flooding will affect Calgary communities in a changing climate (WSP, 2021). A 1:100-year river flood was selected as the threshold event to demonstrate how river flooding may evolve. The 1:100-year event reflects many provincial and municipal regulations, current design standards for much of The City's infrastructure and is aligned with recent and ongoing flood initiatives led by The City. The baseline, present magnitude of a 1:100-year flood event was determined by the existing flood mapping and studies completed by Alberta Environment and Parks and The City. The baseline river flow rates are based on the state of flood mitigation in 2015 and do not account for mitigation measures taken after 2015.

Based on the BRBS and using **Table 20** below (WSP, 2021), The City expects the 1:100 year flooding events for the baseline period to equal about 2000 m^3/s (roughly equivalent to the 2013 flood flow rate) and are expecting that amount to increase by 20% by 2050 in the Bow River Basin (WSP, 2021). Therefore, the volume associated with a 1:100 year flood historically could become the volume of a 1:80 year flood by 2050; however, the confidence in this projection is low given the nature of the climate hazard.

Table 20. River flow rates that would flood the study area and probability

Flow rate upstream of the Elbow River (m^3/s)	Flow rate downstream of the Elbow River (m^3/s)	Flow rate in the Elbow River downstream of Glenmore Dam (m^3/s)	Natural chance of a property within the study area flooding in any given year without mitigation - given as % chance of flood occurring in any year, as a 1:X probability flood
839	1040	201	12.5 % (1:8)
927	1160	234	10–12.5 % (1:8–1:10)
1230	1500	275	5–10% (1:10–1:20)
1660	2150	494	2–5% (1:20–1:50)
2020	2820	803	1–5% (1:50–1:100)
3340	5610	2270	0.1–1% (1:100–1:1000)

Heavy snowfall

As average winter temperatures continue to approach the 0°C threshold, Calgary will continue to experience winter storm hazards and could experience more freezing rain, rain-on-snow events and a wetter, heavier snowpack. Calgary's climate will remain cold enough for snowfall events, particularly through the months of December, January and February. Some research suggests lighter events may be decreasing, while heavier events are increasing in western Canada (Zhang, 2001). Total snow amounts are still likely to decrease annually as temperatures increase and precipitation shifts from snow to rain in the spring (e.g., April, May). As precipitation shifts to more rainfall events, annual snowfall totals are expected to decrease (DeBeer, 2016) as shown in **Table 21**, especially in the 2080s.

Table 21. Summary of climate projected snowfall for Calgary

Climate indicator	Season	Baseline	2050s			2080s		
			Low[1]	Median[1]	High[1]	Low[1]	Median[1]	High[1]
Mean number of heavy snowfall days [2]	Annual	0.9	0.1	0.2	1.0	0.0	0.2	0.7
Winter snowfall total (cm)	Winter	28.7	21.9	27.1	34.3	19.6	25.6	33.7
Snowfall total (cm)	Annual	93.6	43.1	62.0	90.2	34.1	51.8	75.2
1:50 year storm event (cm) [3]	Annual	32.5	12.4	17.2	26.6	13.2	18.8	27.3

[1] Indicates the 10th (low), 50th (median) and 90th (high) percentiles across the regionally downscaled modelled projections (GHD, 2020).
[2] Heavy snowfall is indicated by more than 10 cm in 24 hours.
[3] Maximum snowfall event as determined from 1961-2010 data.

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Appendix 1

Climate hazard indicators and likelihoods

Climate hazard	Threshold	Likelihood			Median indicator score			Projected trend
		Baseline	2050s	2080s	Baseline	2050s	2080s	
Extreme heat	Heatwaves[1,2–](annual)	3	5	5	0.2	3.0	7.1	Increasing
	July 2.5% design temperature [3](annual)	3	4	4	28.0	32.2	34.8	Increasing
	Hot days [4] (annual)	3	5	5	6.8	26.5	48.1	Increasing
Increased air temperature	HDD > 5000 [5,6](annual)	3	2	2	4958.7	3981.8	3411.5	Decreasing
	CDD [7] (annual)	3	5	5	46.1	201.7	401.3	Increasing
	Freeze-thaw cycles (annual)	3	2	2	107.4	83.5	64.1	Decreasing
	Freeze-thaw cycles (winter)	3	3	3	43.5	43.8	39.5	Steady
Extreme cold	Average number of cold spells (T_{max} < -10°C for 5 days)	5	4	4	4.5	3.1	2.3	Decreasing
Wildfires	Fire spread days (annual)[8]	2	4	4	3.0	5.5	5.7	Increasing
Drought	Dry spells [9,10] (annual)	3	3	3	5.9	6.0	6.0	Increasing
	Drought days [11](annual)	3	4	4	63.9	75.6	83.8	Increasing
	Return period of 2-week drought [12] (annual	4	5	5	55.0	27.5	18.3	Increasing
	Return period of SPEI-12 <-1 (annual)	1	1	4	<1:100	1:10	1:1.4	Increasing
Combined drought and high intensity rainfall	Return period of SPEI-12 <-1 and 85 mm rainfall in 24 hours	1	1	2	<1:100	1:100	1:7	Increasing
SDHI rainfall	40 mm in 2 hours	4	5	5	1:50	1:15	1:5	Increasing
	15 min rainfall > 23 mm [6,13]	4	5	5	0.8	1.0	1.0	Increasing
	50 mm/1hr [2,13]	1	4	5	0.1	0.8	1.0	Increasing
	24 hr rainfall > 103 mm [13,14]	2	4	5	0.3	0.8	1.0	Increasing
	96 mm in 48 hours	4	5	5	1:50	1:25	1:5	Increasing
Severe storms (hail, lightning)	Days with convective events (annual) (thunderstorms) [15]	3	4	5	22.9	34.7	39.9	Increasing
High winds	Days where max wind gust > 90 km/hr [2] (annual)	3	3	2	2	1.8	1.6	Steady
River flooding	1:100 year flooding [16]	2	3	3	–	–	–	Increasing
Heavy snowfall	10 cm of snow in 24 hours or less (annual)	3	1	1	0.9	0.2	0.2	Decreasing

	Winter snowfall total	3	3	2	28.7	27.1	25.6	Decreasing
	Annual snowfall total	3	2	1	93.6	62.0	51.8	Decreasing
	1:50 year storm event [6,17]	2	1	1	32.5	17.2	18.8	Decreasing

[1] Heat waves are defined as the maximum temperature ≥ 29°C and minimum temperature ≥14°C for more than 48 hours (ECCC, 2021)

[2] Threshold chosen based on ECCC's warning criteria (ECCC, 2021)

[3] The upper 2.5th percentile of hourly air temperature in July. Calculated from 40,920 July hourly air temperatures over the 55-year historical time series

[4] Hot days are defined as maximum temperature ≥ 29°C

[5] HDD are the average annual sum of the number of degrees Celsius that each day's mean air temperature is below 18°C When mean air temperature is ≥ 18°C the degree day is 0 (Climate Atlas, 2021)

[6] Threshold chosen based on the National Building Code: 2019 Alberta Edition (NRC, 2019)

[7] CDD are the average annual sum of the number of degrees Celsius that each day's mean air temperature is above 18°C When mean air temperature is ≤ 18°C the degree day is 0 (Climate Atlas, 2021)

[8] Median number of wildfire spread days for the Southern Cordillera fire region based on realized spread days (depends on the occurrence of an active fire, extensive fuels and extreme fire weather (Wang, 2017)

[9] Dry day is defined as daily precipitation below 1 mm

[10] Dry spell is defined as 14 days with daily precipitation below 1 mm

[11] Where Precipitation – Evaporation (P-E) is < 10th percentile

[12] Where Precipitation – Evaporation (P-E) is < 10th percentile for two weeks

[13] Probabilities determined using Calgary specific IDF curves (GHD, 2020). Return periods for the baseline, 2050s and 2080s IDF of rainfall are translated into probabilities using PIEVC probability for return period events (ICLR, 2016) and assuming a 75-year project lifespan

[14] Threshold chosen based on the City of Calgary Stormwater Design Guidelines (COC, 2011)

[15] Thunderstorm designation was determined by specific GHD methodology and a weather typing model to identify potential convective precipitation events based on historical data (GHD, 2020)

[16] Derived from the Community Climate Risk Index report and internal City correspondence (WSP, 2021)

[17] Numbers presented are for the 1:50 year snowfall totals, and not occurrences/time period. Likelihood was inferred from the reduced snowfall totals in a 1:50 year storm (1961-2010)