DILLON CONSULTING

CITY OF CALGARY

Walden Fire Station and City Facilities Master Plan Climate Risk and Resilience Assessment

Final Report

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Acronyms, Abbreviations, Definitions

2050s	30-year record covering the years 2041 to 2070, collectively referred to as "2050's".
2080s	30-year record covering the years 2071 to 2100, collectively referred to as "2080's".
AC	Alternating Current
BRBS	Bow River Basin Study
CAPE	Convective Available Potential Energy
CFD	Calgary Fire Department
CRRA	Climate Change Risk and Resilience Assessment
CAPE	Convective Available Potential Energy
CDD	Cooling Degree Days
CoC	City of Calgary
DC	Direct Current
ECCC	Environment Climate Change Canada
EV	Electrical Vehicles
F	Functionality
GCM	Global Climate Model
GHG	Greenhouse Gasses
H&S	Health and Safety
HDD	Heating Degree Days
HVAC	Heating, Ventilation, and Air Conditioning
ICLR	Institute for Catastrophic Loss Reduction (PIEVC Framework Host Organization)
IDF	Intensity Duration Frequency
INFC	Infrastructure Canada
LID	Low Impact Development
mm	Millimetre
O&M	Operations and Maintenance
PCIC	Pacific Climate Impacts Consortium
PIEVC	Public Infrastructure Engineering Vulnerability Committee (CCRA Framework)
PIEVC HLSP	PIEVC's High Level Screening Procedure (Modified PIEVC Framework)
PPE	Personal Protection Equipment

RCP	Representative Concentration Pathway
SDHI	Short Duration High Intensity (rainfall)
SI	Structural Integrity
SOP	Standard Operating Procedure
The City	The City of Calgary

Executive Summary

Project Context

The City of Calgary's Walden Fire Station and City Facilities Master Plan CRRA refers to an infrastructure project involving the design, construction (and demolition/removal of a temporary fire station facility), operation, and maintenance of a new multi-use facility housing a new Walden Fire Station and Calgary Public Library, on a site located on 969 Walden Drive SE, in Calgary, Alberta. This Climate Risk and Resilience Assessment (CRRA) assessed the conceptual design plans and objectives for the site as the future location of Walden Fire Station and Library.

CRRA Process

This document reports on the Climate Risk and Resilience Assessment (the Assessment) process conducted for the Walden Fire Station and Library Project. The City of Calgary (the City) conducts CRRAs for its development projects to reduce project risks across an asset's intended life cycle and to provide the decision-support information that fosters improved decision-making during project planning and design phases.

The City has developed a seven-step process (**Figure B3-2**, **Appendix B**) which includes climate risk assessment in alignment with the City's existing Integrated Risk Management Framework to identify, analyse and evaluate risk. The Climate Risk/Resilience Assessment (CRRA) applied for this assessment followed Calgary's prescribed CRRA protocol, which is broadly consistent with the key steps of ISO 31000 (Guide to Risk Management) and considers both current and future projected climate conditions and their potential impacts to elements of the Walden Fire Station and Library Project.

Results from the resilience assessment are intended to identify anticipated climate change risks and recommend opportunities to reduce risks and further enhance resilience to climate hazards for the Walden Fire Station and Library development. The CRRA considered project design choices and anticipated climate risks during the construction (and demolition), operations, and maintenance phases of the project throughout its life cycle.

Through the completion of the Assessment process, the project team worked with the City and its design team to identify and explore potential options for reducing risk and improving climate resilience for the Walden Fire Station and Library Project. Once potential adaptation options were explored, a selection of adaptation options was made to identify only risk reduction measures deemed feasible for additional consideration. This list of adaptation options was provided to the City for their consideration.

Climate Change Impact Survey (eSurvey), Workshops and Validation Process

Following completion of Steps 1 through 4 of the City's Assessment Process (**Figure B3-2, Appendix B**), a two-part, internal, preliminary technical workshop was convened with members of Dillon's assessment team. The internal workshop sessions were held on May 23 and 24, 2023, and resulted in consequence score values applied to the identified assets where climate impacts were anticipated through the team's Yes/No analysis. In Yes/No Analysis, infrastructure elements anticipated to respond to climate changes are indicated with a "Yes", while infrastructure elements that are NOT expected to respond to changes in climate are indicated with a "No". Only the suspected climate interactions ("Yes") are carried forward in the CRRA, with the "No" interactions effectively screened out of the process. Following the two internal sessions, workshop results were assembled and summarised as preliminary risk results. These preliminary risk results were reviewed internally and either validated or adjusted based on the inputs processed from the climate hazard eSurvey with stakeholders. The eSurvey provided an opportunity for invited participants to offer details on their perceptions and knowledge regarding climate change impacts to the proposed Calgary Fire Station and City Library facility, operations and staff/users.

Opportunities to Enhance Resilience

A resilience workshop was scheduled on Wednesday, May 31, 2023, to explore potential Adaptation/Resilience options for the Walden Fire Station and Library Project. A two-hour, virtual session was convened via Microsoft TEAMS and MURAL, where workshop participants from the City, Calgary Fire Department, Calgary Public Libraries and its design team engaged with Dillon's assessment team to identify and explore existing resilience measures inherent in the Walden Fire Station and Library Project's current design concept.

While it was understood in the workshop that the Walden Fire Station and Library design project schedule is such that a preliminary design was not completed by the design team prior to the workshop session, (workshops concluded on May 31, 2023), some resilience measures were already anticipated for inclusion in the project.

Final Reporting

After the assembled adaptation options were reviewed, draft CRRA reporting was submitted to the City for review. Following the City's review, reviewer comments were processed and a Final CRRA Report issued to the City.

The reporting phase included identification of existing resilience measures already considered for the preliminary design as well as recommendations on additional resilience measures that have not yet been considered but could significantly enhance the Project's resilience under a changing climate. These

potential climate resilience risk reduction options have been identified based on participant inputs in the Resilience Options Workshops, while others have been added based on further research and experience. Many of the *existing* resilience measures will offer benefits under the current climate and also provide "no regrets" benefits into the future under climate change. Some existing resilience measures included in the design concept are tailored to support the 24/7 and uninterrupted service needs of the fire station or to address specific vulnerabilities of the library using evidence of weather and climate vulnerabilities found for other Calgary libraries. Due to the shared site and building footprint for this Project, some of the existing resilience measures for the fire station design could offer additional or new resilience benefits for the library. In other cases, *additional* resilience measures will benefit the shared site, the fire station and the library due to their shared footprint. The reporting phase also includes a brief discussion on changing and likely increasing demands for fire emergency response services under future climate change. Similarly, the report includes examples of experiences from other jurisdictions on the potential for libraries to act as community emergency response assets and "information first responders".

1.0 Calgary's Climate Profile

Calgary's climate is expected to change in the coming decades (*Climate Atlas of Canada, City of Calgary Climate Risk and Resilience Assessment – Public Infrastructure Projects, October 2022*) and these changes create potential for impacts to City of Calgary (the City) assets, infrastructure, services, and maintenance programs. The nature and extent of these changes are provided in more detail under the City of Calgary Climate Profile provided in **Appendix A**.

2.0 Project Context

2.1 Project Overview

This Climate Change Risk and Resilience Assessment (CRRA) was completed for the City of Calgary's Walden Fire Station and Library Project. The project can be generally described as a multi-use building and supporting infrastructure development project.

Calgary's fire departments are tasked with All Hazards emergency responses, which means that their services are on the front-end of severe weather events. Fire services need to remain operational 24/7, regardless of external weather conditions and emergencies. In general, as severe weather events become more frequent and intense under climate change, the impacts will increase along with demands for the Fire Department's All Hazards emergency responses. For example, climate change implies that Calgary likely will be exposed to warmer winters with potential for more intense and mixed winter storms, longer warm and dry seasons, more smoke events, more severe weather and flooding events, increases in responses to more weather-related incidents and increased emergency declarations with longer recovery phases. The CFD will need to be prepared for changing demands while supporting fire stations will need to remain resilient to the impacts of climate change. Fire station designs will incorporate flexibility to meet changing fire service demands while also supporting the ongoing health and safety needs of its occupants.

In 2011, the City issued its "Engineering Design Guidelines for City of Calgary Fire Stations". These Fire Station Guidelines exceed typical building Code design requirements and are needed to support increased resilience to today's climate and flexibility for changing uses over time. Under the 2011 Guidelines, the building and its materials specifications are required to support long lifespans, reduced maintenance, redundancy, energy efficiency and health and safety. In the event of a power, gas, and water utility supply failure to the station, the Guidelines intend that the building should operate for 7 days under normal operating conditions with the same internal temperatures, stove usage as experienced during regular operations. Fire stations also need to put their occupants first, which implies that the stations and their grounds need to be low maintenance and durable or alternatively, be able to reduce the operational disruptions associated with repairs.

But, resilience to today's climate is not sufficient for new designs and construction. This study considers the changing climate, the additional climate change risks for the Walden Fire Station and requirements for added resilience. Since the Fire Station is attached to the community library, the study also considers the additional climate risks for the attached library. In addition to its public services, the library is intended to serve as a community cooling center during extreme heat incidents.

2.2 Project Scope

The scope of the Walden Fire Station and Library project includes the design, construction, operation and maintenance of the building and its site. The new fire station and library branch will be built at the same site as the temporary fire station at 969 Walden Drive SE. Once the new fire station is operational, the temporary station will be decommissioned.

This report focuses on the results drawn from the City's Public Infrastructure Climate Risk Assessment Process and its accompanying Climate Risk Assessment Worksheet (v4) following multiple internal and client workshops. Specifically, a preliminary, internal consequence scoring workshop was held with the Dillon project team May 23, 24 and 26, 2023, followed by inclusion of information gathered from an eSurvey that was developed and distributed by Dillon to 8 invited representatives of the Calgary Fire Department (CFD) and the Calgary Public Library to obtain their first-hand knowledge on prior and anticipated climate change impacts on municipal Fire Stations and Libraries in Calgary. The eSurvey was designed to gather information for use in refining the results obtained from Dillon's internal preliminary assessment of climate impacts and consequences for the project. Results of the eSurvey informed the Project Team on prior climate change related impacts and severe weather impacts at the proposed site and at similar Calgary facilities. Following the survey engagement, a Climate Change Impact Survey Results Memo was circulated to the City of Calgary for review and comment. On Wednesday, May 31, 2023, a final Resilience Options Workshop was convened with City project staff, Calgary Fire Department and Public Library representatives, and with Calgary's design consultant (ISL Engineering). The Workshop intended to explore both current resilience measures that are anticipated for inclusion in the early preliminary design and *resilience measures that could potentially be added to further enhance climate resilience* for the Walden Fire Station and Library project.

This CRRA evaluated the risks towards all human-made and natural infrastructure within the project boundary (**Figure 2-1**) over its service life, as well as the occupants/users of the Walden Fire Station and Library and Fire department-specific activities. This CRRA also considers climate risks to construction and demolition personnel and activities during the demolition and construction processes.

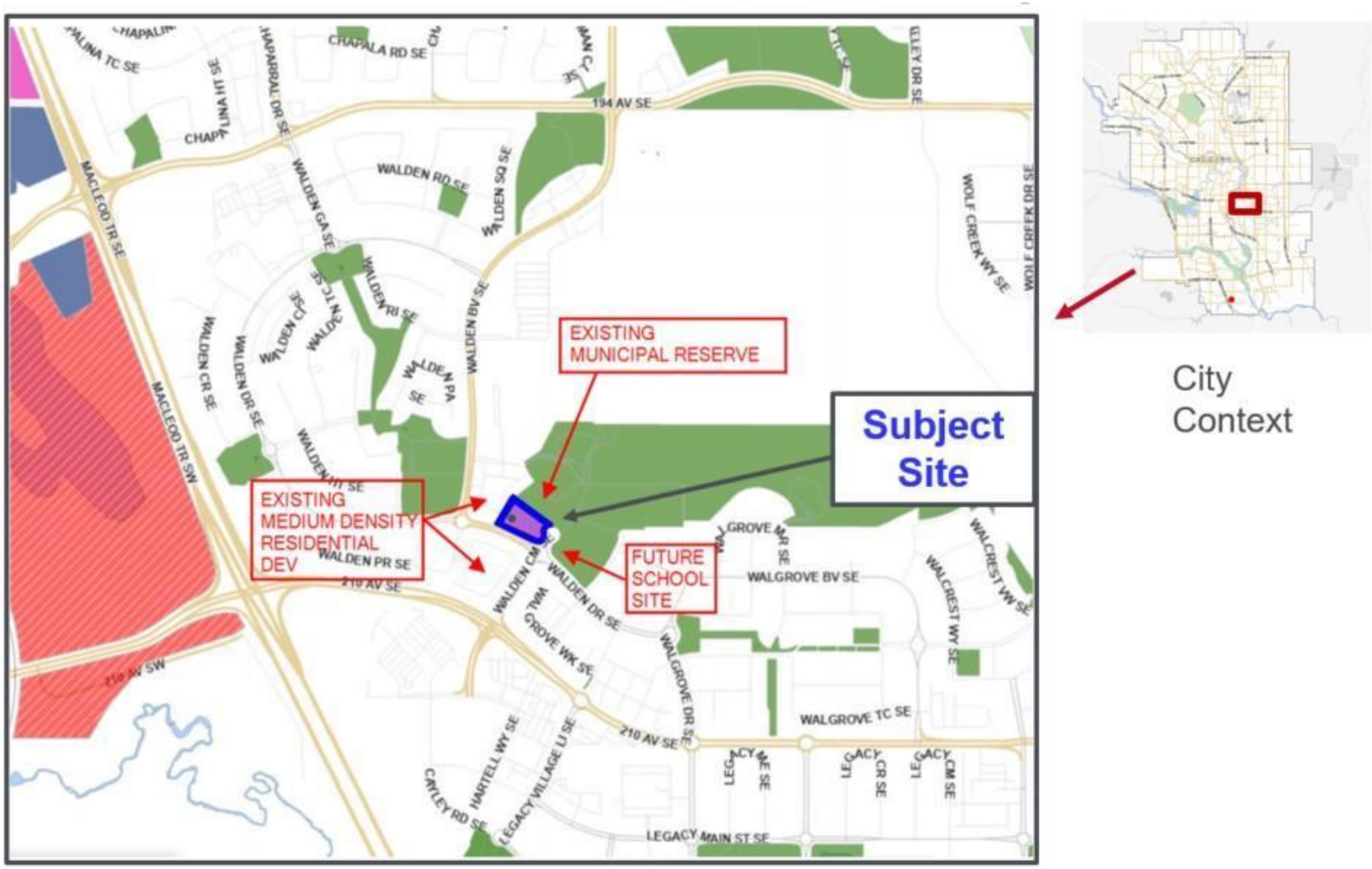

Figure 2-1: Walden Fire Station and Library Project Study Area

SITE PLAN LEGEND	
	PROPERTY LINE
	SETBACK
	UTILITY RIGHT OF WAY
	MAIN ENTRANCE
	SOFT LANDSCAPE AREA
	HARD LANDSCAPE
	ASPHALT AREA

SITE PLAN KEYNOTES	
01	SOFT LANDSCAPE AREA
02	POSSIBLE HARD LANDSCAPE AREA FOR OUTDOOR LEARNING SPACES
03	EXISTING SIDEWALK TO REMAIN
04	PROPOSED WASTE & RECYCLING STAGING AREA, SHARED WITH BOTH FACILITIES (3 STREAMS)
05	PROPOSED RAISED CROSSWALK, FLUSH WITH CURB
06	PROPOSED PAINTED CROSSWALK
07	PROPOSED PAINTED PAVEMENT MARKINGS
08	PROPOSED CLASS 2 BIKE RACKS
09	APPROXIMATE EXTENT OF BOULEVARD MODIFICATION, TBC AT TIME OF DP APPLICATION.
10	PROPOSED ASPHALT
11	PROPOSED CURB CUT TO CITY OF CALGARY STANDARDS
12	CALGARY FIRE DEPARTMENT APRON AND CURB CUT
13	TEMPORARY CALGARY FIRE DEPARTMENT FACILITY TO BE REMOVED
14	CALGARY FIRE DEPARTMENT OUTDOOR TERRACE AREA
15	REHABILITATE CURB CUT FROM TEMPORARY FIRE HALL TO CITY STANDARDS
16	NEW LANDSCAPE MEDIAN
17	LOCKABLE CFD HAZMAT ENCLOSURE

Figure 2-2: Conceptual Drawing of Walden Fire Station and Library (Draft from June 30, 2023)

This assessment is informed by the City's Public Infrastructure Climate Risk and Resilience Assessment (*City of Calgary, 2022*) and the Walden Fire Station and Library project conceptual design plans and objectives.

2.3 Areas of Assessment

The CRRA process was set up and completed with an approach to define project elements into six key impact areas:

1. **Human Well-Being:** Health and safety considerations involving demolition personnel, construction personnel, operations/maintenance staff, staff of Walden Fire Station and Library as well as the general public;
2. **Natural Environment and Infrastructure:** Urban tree canopy, landscaping elements: planters, grasses, xeriscaping, ecosystem and diversity etc.;
3. **Built Infrastructure:** Building superstructure and substructure, roof, cladding, windows and doors, heating, ventilation, and air conditioning (HVAC) systems, pavements, fencing, outdoor light posts, drainage etc.;
4. **Decommissioning, Construction, Operations and Maintenance Phases and CFD Specific Activities:** Activities relating to the removal of buildings decommissioned elements; construction activities related to the building project; post-construction O&M activities; and CFD unique activities, e.g., response to emergencies, 24/7 operation etc.;
5. **Site Supporting Infrastructure:** Assets that affect the building's energy efficiency, water management and overall environmental impact; and
6. **Critical Third-Party Infrastructure:** Critical public infrastructure systems including electrical utility connection, domestic water supply utility connection, sanitary sewer connection and communications/data utility connections.

Each of these six impact areas are discussed in the following sub-sections.

2.3.1 Human Well-being

In addition to infrastructure considerations, human well-being of occupants, operators and the public users were considered when assessing climate change risks for the Project. **Table 2-1** outlines human well-being considerations for this assessment, based on the City of Calgary's framework.

Table 2-1: Human Well-Being Considerations

Asset	Comments
Demolition Personnel	All personnel working to conduct demolition activities associated with the removal of the temporary fire station. It is expected that these personnel will adhere to Standard Operating Procedures (SOPs) regarding safe work practices. (e.g., Extreme Heat Events).
Construction Personnel	All personnel working to construct the new fire station and library facilities. It is expected that these personnel will adhere to SOPs regarding safe work practices. (e.g., Extreme Heat Events).
Operations and Maintenance (O&M) Personnel	All personnel maintaining the project, its site, and operations during and after the construction period is complete. It is expected that these personnel will adhere to SOPs regarding safe work practices. (e.g., Extreme Heat, Wind Events).
Employees and General Public	General users of the project area, including pedestrians, cyclists, motor vehicle drivers, and those who work in both the library and CFD facilities.

2.3.2 Natural Environment and Natural Infrastructure

Climate change will present impacts to the natural environment and natural infrastructure at the Walden Fire Station and Library project site. In the context of a fire station and public library, natural environment and natural infrastructure assets refer to the natural features and resources of the building site and surrounding areas that are essential for maintaining the environmental health and sustainability of the development. Such assets include green infrastructure (parks and gardens), water bodies, wetlands, and other natural habitats. Natural infrastructure assets also include forests, trees and other vegetation on site providing a range of ecosystem services and benefits to the project. Ecosystem services and benefits often include considerations such as water purification, climate regulation and habitat for native species.

Recognizing and valuing the natural environment and natural infrastructure assets of a fire station and public library development supports sustainable and resilient approaches to the built environment. Principles of resilience and sustainability also provide benefits to the health and well-being of both the building's occupants and the surrounding community.

The Walden Fire Station and Library project will incorporate natural infrastructure such as trees, shrubs and other vegetation, planters, and possibly xeriscaping. **Table 2-2** provides a list of natural infrastructure assets within the project area that may interact with climate hazards.

Table 2-2: Natural Environment and Natural Infrastructure Assets

Asset	Comments
Soft Landscaping (Green Infrastructure)	Grassy areas (i.e., library outdoor learning space), trees, and shrubs on the property.
Xeriscaping	Areas that require low amounts of maintenance and irrigation, preference to provide xeriscaping options to avoid need for irrigation.
Ecosystem and Diversity	Changes to the diversity of species in local ecosystems, changes to habitats supporting native species.

2.3.3 Built Infrastructure

ISL Engineering presented the City with design layout options for the Walden Fire Station and Library project. The City selected Layout # 2, a combined fire station and library facility built on a single footprint, sharing an inside structural wall. This option specifies that the fire station will be a two-storey structure with an attached single storey library facility.

Table 2-3 lists the types of building infrastructure assets and elements considered in the Walden CRRA.

Table 2-3: Built Infrastructure Assets

Asset	Comments
Building Substructure	All below ground walls, foundation, and structural components.
Building Superstructure	Above ground structural elements that support building loads.
CFD Terrace/Patio	Outdoor patio for fire station employees.
Roof and Membrane	Roof membrane separating the building superstructure and interior from the outdoor environment.
Exterior Cladding, Sidings	Cladding and siding panel components of building envelope
Windows and Doors	Fenestrations – window and exterior openings to building.
CFD Truck Bay Doors (x2)	Fire Apparatus Bay Doors for CFD.
Exterior Lighting (Fixed on Building)	Standard fixed exterior lighting fixtures.
Electrical Room, Panel Controls	Electrical switches and controls, panels servicing fire station and library building.
Emergency Power System(s)	Independent source of emergency electrical power that supports critical systems in the event of loss of normal power supply.

Asset	Comments
Communications Systems	The set of technologies and protocols designed to facilitate communication among different parties within the building, as well as to the outside world. Provides connectivity among different devices and systems, including voice and data communication, security and surveillance systems, fire alarms, and building automation systems, among others.
Access and Security Systems (FOBs, CCTV)	The set of technologies and procedures designed to control and monitor access to the building and its various areas, as well as to detect and respond to security threats and emergencies. These systems typically include a variety of components, such as access control systems, surveillance cameras, intrusion detection systems, fire alarms, and emergency communication systems, all integrated into a centralized platform.
HVAC – Heating System	HVAC refers to the heating, ventilation, and air conditioning systems designed to maintain a comfortable and healthy indoor environment for occupants. HVAC systems include heating and cooling equipment, air handling units, ductwork, controls, and sensors, all working together to provide heating, cooling, and air circulation throughout the building.
HVAC – Cooling System	
HVAC – Ventilation/Air Handling System	
Plumbing	System of pipes, tanks and fittings required for water supply, sanitation, heating/cooling in a building.
Fire Suppression Systems	Technologies and components designed to detect, suppress, and control fires within a building. These systems typically include fire detection devices, alarm systems, sprinkler systems, and other fire suppression systems.

2.3.4 Construction, Decommissioning, Operations and Maintenance Phases and CFD Specific Functions

Climate change is anticipated to pose impacts to the decommissioning, construction, and O&M Phases of the Walden Fire Station and Library project.

The construction phase of the project is the period during which the permanent Walden Fire Station and Library will be built. During this phase, construction plans are executed, labour allocations are managed, and materials and equipment are brought to the site to support construction activities.

The decommissioning phase is the process of removing the temporary modular building from the site for future use by the City. This process will commence once the new Walden Fire Station is complete and operational. Decommissioning requires careful planning and execution for safe and efficient removal of the building systems, equipment, and materials, including hazardous materials.

The O&M phase occurs post-construction, during the period the building is occupied and in use. O&M includes routine cleaning, repairs, replacements of equipment and systems, and management of resources such as energy, water, and waste.

CFD-specific functions refer to the Fire station's ability to respond to emergency-induced demands for CFD services. Any degradation in the ability to deliver CFD-specific functions could reduce the ability of the fire department to respond to a wide range of emergency situations.

The assets and activities related to the decommissioning, construction and O&M phases as well as CFD-specific functions considered in the assessment are listed in **Table 2-4**.

Table 2-4: Decommissioning, Construction and O&M Phases, and CFD-Specific Functions

Asset	Comments
Construction Phase	Construction plans are executed, labour allocations are managed, and materials and equipment are brought to the site to support construction activities.
Decommissioning Phase	Removal of the decommissioned elements of a buildings systems, equipment, and materials, including hazardous materials.
O&M Phase	Routine cleaning, repairs, replacements of equipment and systems, and management of resources such as energy, water, and waste.
CFD-Specific Functions	Operations unique to CFD – all hazard responses.

2.3.5 Site Supporting Infrastructure

Site supporting infrastructure elements are important considerations in assessing the impacts of climate change to a fire station and library facility. Impacts to site supporting infrastructure can affect a development's energy efficiency, water management, and overall environmental impact. Consideration of these assets can help identify opportunities for sustainable design and management practices that can reduce the building's environmental impact and improve its overall sustainability.

Site supporting infrastructure assets considered in this assessment are listed in **Table 2-5**.

Table 2-5: Site Supporting Infrastructure Assets

Asset	Comments
EV Charging Outlets	Electrical power outlets specifically designed for recharging electric vehicles (EVs).
Outdoor Light Posts	Standard exterior light standards equipped with electrical exterior lighting fixtures.
Grid Power	Lines distributing grid power to a building's main electrical service connection.
Asphalt Pavements	Flexible, asphaltic pavements applied on site in parking areas, pathways, and miscellaneous locations at the building site.
Concrete Pavements	Rigid, concrete pavement installed on site for equipment pads, pathways, and miscellaneous locations at the building site.
Bike Parking Area (Class 2 Bike Racks)	A dedicated area of the Walden Fire Station and Library site allocated for exclusive use of bicycle parking on site.
Benches/Picnic Tables	Site furniture amenity on Walden Fire Station and Library grounds.
Hard Landscaping (Community Spaces)	Non-living elements or features incorporated into a landscape design. It involves the use of hard materials to create structures, surfaces, and decorative elements.
Fencing	Fencing on border of property and surrounding CFD outdoor terrace.
Pavement painted markings (crosswalks etc.)	Road markings to designate parking stalls, crosswalks, etc.
Signage	Standard site signage on site.
Oil & Grit Separator	Underground tanks with chambers designed to remove heavy particles, floating debris and hydrocarbons from stormwater runoff.
Roof Drainage	Components designed to function as a system to manage and control the flow of water off the building's roof. These systems typically include gutters, downspouts, and other components that direct water away from the building and prevent damage to the building's foundation, walls, and other structural elements.
Site Drainage	System and subcomponents designed to manage and control the flow of water on the building's site, including its grounds and surrounding areas. These systems typically include catch basins, pipes, and other components that collect and direct water away from the site and prevent damage to the building's foundation, parking lots, and other outdoor areas.

2.3.6 Critical Third-Party Infrastructure

Another key consideration in assessing climate risks is the potential for secondary impacts due to damage or loss of critical third-party infrastructure. Four third-party infrastructure asset categories were considered in the CRRA, as listed in **Table 2-6**.

Table 2-6: Third-Party Infrastructure Assets

Asset	Comments
Electrical Utility Connection	The connection of a building to the electrical grid, providing a reliable and consistent source of electricity for building occupants and operations. Electrical connections lead to building electrical equipment such as transformers, switchgear, and meters to receive and monitor electricity from the electrical utility.
Domestic Water Supply Utility Connection	Connection of the building to a reliable and safe source of potable water for use by building occupants. Water Utility connections connect to the municipal water supply, distributing water throughout the building.
Sanitary Sewer Connection	The sanitary sewer connection ties the building's internal plumbing systems to the larger municipal sewer network, conveying wastewater away from the building and to a municipal wastewater treatment plant for proper disposal.
Communications/Data utility Connections	Communications and Data Utility connections support reliable and efficient communication and data networks, including telephone, internet, and other communications technologies. These connections typically involve the installation of fibre optic cables, routers, switches, and modems to provide high-speed internet access and connectivity for data and voice communications throughout the building.

2.4 Climate Change Impact Survey (eSurvey), Risk Validation Process

In support of the City of Calgary's Walden Fire and City Library Facilities Master Plan CRRA, Dillon conducted an anonymous Climate Change Impact eSurvey, using the Survey Monkey online platform. Dillon invited eight representatives of the Calgary Fire Department and the Calgary Public Library to provide their first-hand knowledge on prior and anticipated climate change impacts for municipal Fire Stations and Library assets. Each were issued direct email invites to participate in the eSurvey. Over a period of two weeks, the eSurvey provided an opportunity for the invited participants to offer details on their perceptions and knowledge regarding climate change impacts to Fire and Library facilities, their operations and staff/users.

Roger Rempel (Dillon Walden Project Manager) and Liz Pollock (Planner and Designer) developed the eSurvey questions. The eSurvey was then implemented by Dillon's virtual engagement specialist, Spencer Lamirand, and published to the SurveyMonkey platform. The survey included yes/no and multiple-choice questions. The eSurvey was opened to invited respondents (selected by the City) on May 7, 2023. The survey remained open for two weeks, closing on May 24, 2023, at 5:00 PM MDT. Of the eight invited participants, the eSurvey was completed in full by seven of the eight invitees.

After Dillon completed its internal preliminary assessment of climate impacts for Walden Fire Station and Library project, the summarised results and commentary received from eSurvey participants was reviewed, synthesised and applied to inform preliminary risk scores discussed in the Resilience Option Workshop convened on May 31, 2023.

The May 31 Resilience Options Workshop was dedicated to exploring and discussing potential adaptation options (risk reduction measures) to respond to identified climate risks for the Walden site and assets.

2.5 Resilience Options Workshop

On May 31, 2023, Dillon facilitated a Resilience Options Workshop during a two-hour virtual session with invited participants for the Project. The Workshop explored potential additional resilience options for consideration in the Walden Fire and Library City Facilities Master Plan design. Workshop participants included representatives from the City of Calgary's Project Team, the Calgary Fire Department, Calgary Library Services, and Calgary's design consultant, ISL Engineering.

The Resilience Options Workshop's objective was to seek workshop participant inputs to identify potentially feasible adaptation options (i.e., risk reduction measures) in each of the key impact areas for the Walden Fire Station and Library Project. These adaptations are risk reduction measures that could potentially be added to the project design as it moves forward from preliminary concept to detailed design. While preliminary design for the Walden Fire and Library City Facilities Master Plan was not completed at the time of this CRRA, workshop participants reviewed specific climate resilience measures, including those specified in Calgary's *Engineering Guidelines for City of Calgary Fire Stations* (2011). Information provided regarding the City's selected design option, as indicated in ISL Engineering documents as Layout #2, was also considered. The Layout #2 design concept calls for a single 1,983 m^2 (21,340 sq. ft.) building footprint where the fire station and library share a common wall. Conceptual drawings indicate a two-storey fire station, and a single storey library are planned for this development.

The workshop session was hosted in a virtual setting, with project information presented in PowerPoint and participant engagement via MURAL online engagement tools. Dillon facilitated this two-hour session with a focus to review the *medium to highest* climate risks across six key areas of impact:

1. Human Wellbeing;
2. Natural Environmental/Natural Infrastructure;
3. Building Infrastructure;
4. Decommissioning, Construction and O&M Phases, and CFD Specific Functions;
5. Site Supporting Infrastructure; and
6. Critical 3rd Party Infrastructure.

Participants used the online MURAL platform to review six tables that listed medium to highest climate risks anticipated for the Project. Each of the six areas of climate impact was provided with a dedicated MURAL table for workshop participants to add their inputs.

The workshop format allowed for discussion and MURAL inputs from all participants. After a prescribed six to eight-minute comment period for each of the six tables, discussion and focus then moved to the next MURAL table, repeating this process through the remaining MURAL tables.

Workshop participants added their resilience option suggestions into the MURAL platform through facilitated discussions. The allotted time for this workshop was two hours, and unfortunately time was cut short for completion of a thorough discussion on the sixth MURAL board. Participants were invited to add additional comments into the MURAL Activity after the workshop, as the MURAL boards would be kept open by Dillon until the end of the week.

Following discussion of the resilience measures that are already anticipated for inclusion in the concepts described for the design of Layout #2, the workshop participants were then asked to identify further or new options for potential new resilience measures for the City's consideration. Potential new resilience measures are defined in this context as measures that are not currently contemplated but could be considered for addition to the current project design to further enhance climate resilience of the project.

After the Resilience Options Workshop was completed, Dillon assembled the collected inputs from the participants and processed this information to inform recommendations on Resilience Measures (**Section 3.5**). The completed MURAL boards from this workshop are provided in **Appendix E**.

3.0 Public Infrastructure Climate Risk Assessment

Dillon applied the City's Climate Risk Assessment Process (Climate Risk and Resilience Assessment-Public Infrastructure Projects, City of Calgary, 2022), described as in alignment with the Public Infrastructure Engineering Vulnerability Committee (PIEVC) High Level Screening Procedure (Institute for Catastrophic Loss Reduction (ICLR), *ICLR 2016*). The City's process is also consistent with principles described within Infrastructure Canada's Climate Lens Guidance (Infrastructure Canada (INFC) *INFC, 2019*). Full details of this process are provided in **Appendix B**.

3.1 Hazard Analysis

3.1.1 Step 1 – Component Analysis

The first step in creating the assessment is to define the scope, context, infrastructure to be assessed and the timescales of interest. The infrastructure assets identified will eventually be assessed for climate related impacts, with the likelihood and consequence of these impacts determining the risk.

3.1.1.1 Scope of Assessment

The City requires a Climate Risk/Resilience Assessment for an infrastructure project involving the construction of the new Walden Fire Station and Library facility built at the same site as a temporary fire station located at 969 Walden Drive S.E. Calgary. This CRRA considers the design, construction, operation and maintenance of the new facility and its site as well as the decommissioning/removal of the temporary fire station. The climate risk and resilience assessment is required through the City's pilot process of climate assessments for key infrastructure projects, as described in RFSO No. 20-2022 and modelled on Infrastructure Canada requirements for a Climate Lens Assessment. Dillon applied the Calgary CRRA process issued in October 2022.

The geographical extents of the Walden Fire Station and Library project site were presented in **Figure 2-1** as well as the conceptual site design for Layout #2 in **Figure 2-2.**

3.1.1.2 Infrastructure under Assessment

Infrastructure under this assessment was assessed across multiple system categories listed in **Table 3-1**. For each listed System Category, primary considerations are indicated. This assessment evaluated elements anticipated from conceptual Layout #2 details provided by the City and its Design Team, as supplied to Dillon. For the construction phase as an example, primary considerations in the assessment included impacts to construction activities such as construction delays or added burdens in completing construction tasks. For human wellbeing, the assessment considered both construction and demolition personnel impacts and impacts to the O&M personnel, employees, and general public on site.

Table 3-1: Infrastructure under Assessment

System Categories	Considerations
Human Wellbeing	• Construction/demolition personnel; • O&M personnel; and • Staff (CFD and library) and general public.
Natural Environment and Infrastructure	• Natural infrastructure (trees, gardens, and xeriscaping); and • Ecosystem health and biodiversity.
Building Infrastructure Assets	• Building assets as identified by the design team, engineers, operations, etc. (e.g., Substructure, superstructure, envelope, electrical and mechanical systems).
Decommissioning, Construction, O&M Phases and CFD Specific Functions	• Decommissioning activity; • Construction activity; • Operations, maintenance, and inspection activity; and • Operations unique to CFD.
Site Infrastructure Assets	• Site assets as identified by the design team, engineers, operations, etc. (e.g., pavement, fencing, drainage etc.).
Critical Third-Party Infrastructure	• Assets identified as critical by the design/operations team. (e.g., utility connections, sanitary sewer connection).

3.1.1.3 Assessment Timescales

Three-time scales were considered in this assessment: a baseline timescale (1981 to 2010) providing a consideration for the present "baseline" climate conditions, a 2050s timescale (2041 to 2070) representing a near-term future time horizon and a 2080s (2071 to 2100) timescale representing a longer-term future time horizon. As previously mentioned, the baseline timescale refers to the global climate model (GCM) data for the climate normal period (1981 to 2010). The incorporation of two future time periods (the 2050s and 2080s) accounts for the anticipated design life risks across different forms of infrastructure assets, to ensure that short, medium, and long-term risks can be highlighted in the assessment, as per the CSA-S478 Guideline on Durability of Buildings, which indicates the design life of new building structures should be 75 years – or "Long life" (CoC, 2020b).

3.1.2 Step 2 – Climate Analysis

The vulnerability to climate related hazards is influenced by project location, sensitivity to the potential hazards and the response capacity that is built into the project. Likelihood scores were based on the values furnished in the City of Calgary's prescribed CRRA process (Climate Risk and Resilience – Public Infrastructure Projects, 2022).

The climate hazard data applied in this assessment is provided in **Appendix A**.

3.1.3 Step 3 – Impact Analysis

Climate-related impacts are the adverse and/or beneficial effects of climate-related hazards on the construction/demolition/O&M phases of the project including CFD specific operations, the built infrastructure, natural environment, human well-being, and critical third-party infrastructure. The magnitude of impact(s) is dictated by the hazard, as well as the vulnerability and exposure within the system. A summary of the Project's climate hazards, assets affected, and potential climate-related impacts is presented in **Table 3-2**.

Table 3-2: Potential Climate Related Impacts – Health and Safety, Structural Integrity and Functionality

Human Well-Being		
Climate Hazard	**Affected Personnel**	**Potential Climate Related Impacts affecting Human Well-Being Examples**
Extreme Heat	• Staff (CFD and library) and General Public • Decommissioning Personnel • Construction Personnel • O&M Personnel	**Health and Safety (H&S):** risk of heat-related illnesses (e.g., heat stroke).
Wildfire Smoke		**H&S:** Risk of smoke inhalation (exacerbate respiratory problems), risk of reduced visibility.
SDHI Rainfall		**Functionality (F):** Minor impacts to tasks and site accessibility, delays in maintenance and construction/demolition tasks.

Human Well-Being		
Climate Hazard	**Affected Personnel**	**Potential Climate Related Impacts affecting Human Well-Being Examples**
Severe Storms		**H&S:** Increased risk of injury. Hailstorms can injure people and severe storms can expose them to higher risk of slips/trips/falls. Wind-blown debris and falling debris e.g. trees can pose risks in severe storms.
High Winds		**H&S:** Windswept debris can injure people leading to a need for medical treatment, potential access issues. **SI:** Risks for wind, large hail and snowload damages affecting wellbeing of occupants and users.
Heavy Snowfall		**H&S:** Increased risk of slips, trips, and falls, and reduced access for occupants and users.

Natural Environment and Natural Infrastructure		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
Extreme Heat	Soft Landscaping (Green Infrastructure)	**Structural Integrity (SI):** Damage to lawns, trees, and plants
	Ecosystem and Diversity	**SI:** Potential for reduced diversity and ecosystem impacts (e.g., invasive species)
Increased Air Temperature	Soft Landscaping (Green Infrastructure)	**F:** Higher maintenance and higher irrigation demand
	Ecosystem and Diversity	**F:** Unless the plant species selected for higher ranges in temp, potential for reduced diversity and ecosystem impacts (e.g., invasive species)
Drought	Soft Landscaping (Green Infrastructure)	**SI:** Extended periods of drought can lead to tree health decline and increase in tree mortality

Natural Environment and Natural Infrastructure		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
	Ecosystem and Diversity	**SI:** Unless the plant species selected for higher ranges in temp, potential for reduced diversity and ecosystem impacts (e.g., invasive species)
SDHI Rainfall	Soft Landscaping (Green Infrastructure)	**SI:** Minor impacts to vegetation, erosion, and maintenance
Severe Storms	Soft Landscaping (Green Infrastructure)	**SI:** Erosion, hail damage, increased maintenance post event
High Winds	Soft Landscaping (Green Infrastructure)	**F:** Increased maintenance to restore green infra after wind events
Heavy Snowfall	Soft Landscaping (Green Infrastructure)	**SI:** Impacts only arise if the snow is unseasonal

Building Infrastructure		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
Extreme Heat	Envelope – roof and membranes, cladding/siding, windows, and doors	**SI:** Heat and UV induced weathering; deterioration of materials
	Electrical Systems – Emergency power, communication, electric panel/controls and access/security systems	**F:** Under extreme heat, components may fail (dependent on climate control in system location?)
	Mechanical Systems – HVAC A/C Cooling System	**F:** Under high heat, expect high operating costs
Increased Air Temperature	Mechanical Systems – HVAC A/C Cooling System	**F:** HVAC Cooling capacity may be exceeded leading to health impacts, cooling cost impacts, higher energy demand, and increased maintenance. Costly retrofits to increase cooling capacity.
	Mechanical System – HVAC Heating	**Potential Benefit – Cost savings**

Building Infrastructure		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
Wildfire Smoke	Electrical Systems – Access and Security Systems	**F:** Potential impact of smoke, particularly the haze on CCTV outside the building
	Mechanical Systems – HVAC Ventilation/Air Handling System	**F:** Risk of smoke inhalation causing reduced efficiency and higher maintenance
SDHI Rainfall	Structural – Substructure	**SI:** Potential for impacts if the water is ponding along the foundation, minor damage, requires maintenance inspection
	Structural – Superstructure	**SI:** Minimal superstructure impacts are anticipated unless water is not allowed to drain from roof surfaces
	Envelope - Roof and Membrane	**SI:** Potential for water infiltration and damage to seals, decreased service life, increased maintenance
	Envelope - Exterior Cladding/Siding, Windows and Doors, CFD truck bay doors	**SI:** Potential for wind-driven rain intrusion, decreased service life, increased maintenance
	Electrical Systems – Emergency Power System/Communication systems, Access & security	**F:** Low risk of rain and water intrusion, potential for minor disruption. Requires inspection and maintenance
	Mechanical Systems - Plumbing	**F:** Minor disruption in function
Severe Storms	Envelope – Roof and Membranes, Cladding/Siding, Windows and Doors, CFD truck bay doors	**SI:** Potential for wind and debris driven damage; Hail damage, increased maintenance inspection for wind damage. replacement programs for damaged panels
	Electrical Systems – Exterior Lights, Communication and Access/Security Systems	**F:** Potential for damage due to debris; subject to power outages

Building Infrastructure		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
High Winds	Structural – Superstructure	**SI:** Assumes that the current design accommodated wind ranges
	Envelope – Roof and Membranes, Cladding/Siding, Windows and Doors,	**SI:** Potential for wind and debris damage
	Envelope – CFD truck bay doors	**F:** Potential for wind damage or inability to operate in high winds
	Electrical Systems – Communication Systems and exterior lights on building	**F:** Potential for wind and debris damage
	Mechanical Systems – HVAC – Ventilation/Air Handling System	**F:** Potential wind-induced minor damages to exhaust fans and exterior vents – from debris to physical damages
Drought	Structural – Substructure/Superstructure	**SI:** Erosion/cracks
Heavy Snowfall	Structural – Super Structure	**SI:** Snow loads may increase with more snow and rain on snow resulting in higher snow loads
	Structural – CFD Terrace/patio	**F:** Maintenance to access and use
	Envelope – Roof and Membrane	**SI:** Warmer snow seasons and rain on snow events may increase loads to roof and membrane. Roof damages and repair, interior damages
	Electrical Systems – Communication systems	**F:** Temporary loss of service possible
	Mechanical Systems – HVAC – Ventilation/Air Handling System	**F:** Increased maintenance and inspection to ensure operability of exterior vents

Decommissioning Phase*		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
Extreme Heat	Demolition Activities	**F:** Delay in work
SDHI Rainfall		**F:** Site drainage impacts and temporary disruptions to demolition process
Severe Storms		**F:** Potential for delays or disruptions until the storm passes
High Winds		**F:** Potential for delays or disruptions. Demolition activities suspended during high winds. These events are short duration events
Heavy Snowfall		**F:** Delays to some demolition tasks, increased maintenance to clear site

*Includes removal of temporary, modular fire station on site.

Construction Phase		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
Extreme Heat	Construction Activities	**F:** Delay in work
Wildfire Smoke		**F:** Temporary work restrictions
SDHI Rainfall		**F:** Potential for some brief delay in construction – rain induced delay, pump out etc.
Severe Storms		**F:** Delay to construction activities
High Winds		**F:** Delay to construction activities

Operations and Maintenance Phase		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
Extreme Heat	Operation, Maintenance, and Inspection Activities	**F:** Delay in work
Wildfire Smoke		**F:** Delays/restrictions in work – reduced visibility
Drought		**F:** Minor increase in maintenance due to prolonged drought

Operations and Maintenance Phase		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
SDHI Rainfall	Operation, Maintenance, and Inspection Activities	**F:** Increased maintenance on pre and post maintenance efforts
Severe Storms		**F:** Potential for increased maintenance post event
High Winds		**F:** Increase in time required to complete O&M tasks, also triggers additional O&M burdens to respond/maintain
Heavy Snowfall		**F:** Increased maintenance and op delays

CFD (Calgary Fire Department) Specific Functions		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
Extreme Heat	Operations Unique to CFD	**F:** Disruption in work due to heat stress; health considerations
Drought		**F:** Response to increased brush fires/grass fires
SDHI Rainfall		**F:** Task delays
Severe Storms		**F:** Increased demand for CFD services (All-hazards emergency responses)
High Winds		**F:** Increase in time required to complete tasks, also triggers increased demand for CFD services (All-hazards emergency responses)
River Flooding		**F:** Increased demand for CFD services (All-hazards emergency responses)
Heavy Snowfall		**F:** Delays in response and increased demand for CFD services (All-hazards emergency response)

Site Infrastructure		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
Extreme Heat	Site Access – Asphalt and Concrete Pavements	**SI:** Deformations such as softening of surfaces and rutting **F:** Deformations can create hazards and accessibility concerns
	Site Features – Hard landscaping (Community Spaces)	**F:** Potential temporary disruption in ability to use the space under highest heat days.
Increased Air Temperature	Stormwater Management – Site Drainage	**F:** Blockage of drainage assets. Potential vegetation growth, more maintenance efforts to clear drainage inlets
Wildfire	Electrical – Grid Power	**F:** Potential wildfire impact to grid/loss of power (includes third party supplies)
SDHI Rainfall	Site Access – Asphalt and Concrete Pavements	**F:** Potential flooding of pavements
	Site Features – Hard Landscaping (Community Spaces)	**F:** Temporary loss of use under SDHI event
	Stormwater Management – Oil and Grit separators	**F:** Maintenance required
	Stormwater Management – Roof Drainage	**SI:** Potential for stored water on the roof, intrusion damages
	Stormwater Management – Site Drainage	**F:** Blockage of drainage assets
Severe Storms	Electrical –Grid Power	**F:** Potential loss of power to grid
	Site Access – Asphalt and concrete pavements	**SI:** Potential for localised ponding, accessibility, safety with respect to pedestrians
	Site Features – Hard landscaping (Community Spaces)	**F:** Maintenance post storm
	Site Features – Class 2 bike racks, fencing, erected signage, pavement painted markings	**SI:** Response to address potential minor damage

Site Infrastructure		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
	Stormwater Management – Oil and Grit Separators	**F:** Maintenance required
	Stormwater Management – Roof Drainage	**SI:** Potential for drainage blockages due to debris and hail
	Stormwater Management – Site Drainage	**F:** Functionality is impaired as it can block drainage assets
High Winds	Electrical – Outdoor Light Posts	**Si:** Subject to wind or debris damage
	Electrical – Grid Power	**F:** Subject to wind or debris damage. Prevents power from entering the building
	Site Access – Asphalt and Concrete pavements, Site Features	**F:** Increased maintenance to clear wind-swept debris
	Site Features – Class 2 bike racks, fencing, erected signage, pavement painted markings, hard landscaping (community spaces)	**F:** Increased maintenance to clear debris
	Stormwater Management – Roof Drainage and Site Drainage	**F:** Increased maintenance to maintain drainage from debris
Heavy Snowfall	Site Access – Asphalt and Concrete pavements, Bike Parking Area	**F:** Increased maintenance for snow removal/access
	Stormwater Management –Roof and Site Drainage	**F:** Increased maintenance for snow removal/keep drainage clear

Critical Third-Party Infrastructure		
Climate Hazard	**Asset Affected**	**Potential Climate Related Impacts**
Extreme Heat	Electrical Utility Connection and Communications/Data Utility Connections	**F:** No impacts to electrical connection, but potential impacts to the grid are likely; potential for heat-induced failure if the communications room is not climate controlled
SDHI Rainfall	Sanitary Sewer Connection	**F:** Heavy rain has a possibility to overwhelm area drainage assets
	Communications/Data Utility Connections	**F:** Water intrusion, underground infrastructure
Severe Storms	Electrical Utility Connection	**F:** If power connection is exposed, there is high potential for disruption, more likely impacts to library, as CFD has an Emergency Power System (EPS)
	Communications/Data Utility Connections	**F:** Potential impacts due to hail, lightning, wind, and water
High Winds	Electrical Utility Connection	**F:** If the power connection is exposed, there is high potential for disruption, more likely impacts to library where CFD has EPS
	Communications/Data Utility Connections	**F:** Only exposed infrastructure to winds will be affected
River Flooding	Electrical Utility Connection, Domestic Water Supply Utility Connection, Sanitary Sewer Connection and Communications/Data Utility Connections	**F:** Service disruptions expected during flood events, some restoration efforts may be required. This assumes that the project site and services will be indirectly affected by flood events elsewhere. CFD emergency response volumes likely increased for responses elsewhere.

3.2 Step 4 – Likelihood Analysis

Climate hazard likelihoods were analyzed and developed for the City and these climate analytics were prescribed by the City for application in the CRRA process for the baseline and projected time horizons. The climate data and associated probabilities of events have been translated into likelihood of impact using relevant indicators and thresholds for those indicators (e.g., the hazard could be extreme heat, the indicator could be heat waves, and the threshold could be the number of heat waves per year compared to historical or baseline events). The likelihood scores were determined by the City of Calgary by analyzing the evolution of each variable under a changing climate.

Based on the climate projections for Calgary and employing **Table 3-3,** Likelihood Ratings were developed for each climate hazard and are summarized with their projected trends in **Table 3-4** (a full table of expanded climate indicators for each hazard are presented in **Appendix C**). **Table 3-4** uses climate indicators relevant to the assessed Walden Fire and City Library Facilities Master Plan elements for application in this CRRA. The standardized probabilities presented in **Table 3-3** were used for most of the climate hazards. The likelihood scores were determined by the City of Calgary by analyzing the evolution of each variable in a changing climate.

Table 3-3: Likelihood of Impact

Likelihood Rating	Qualitative Descriptor	Probability of Event Occurring in a Year (%)	Flooding/SHI Rainfall Return Period Probability	Extreme Heat Probability
1	Rare	≤ 10	1:200 event (0.5% chance)	< 1 every 10 years
2	Unlikely	11 to 34	1:100 event (1% chance)	Once every 2 to 10 years
3	Possible	35 to 64	1:70 event (1.4% chance)	Once every 2 years
4	Likely	65 to 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 3-4: Climate Hazard Likelihood Rating Summary

Climate Related Hazard	Climate Indicator	Projected Climate Hazard Trend	Baseline	Future (2050s)	Future (2080s)
Extreme Heat	Heatwaves (number of heatwaves per year)	↑	3	5	5
Increased Air Temperature	Cooling Degree Days (CDD)	↑	3	5	5
Wildfires	Fire Spread Days	↑	2	4	4
Drought	2 Week Drought	Likely ↑	4	5	5

Climate Related Hazard	Climate Indicator	Projected Climate Hazard Trend	Baseline	Future (2050s)	Future (2080s)
Short Duration High Intensity (SDHI) Rainfall	24 hr Rainfall > 103 mm	↑	2	4	5
Severe Storms	Days with Convective Events(thunderstorms)	Likely ↑	3	4	5
High Winds	Days Where Max Wind Gusts > 90 km/h	Likely Stable	3	3	2
River Flooding	1:100 Year Flooding	Likely ↑	2	3	3
Heavy Snowfall	Mean Winter Snowfall	Likely ↓	3	3	2

3.3 Step 5 – Consequence Analysis

The City's climate risk assessment process defines a five-point rating scale to describe Climate Impact Consequence Severities ranging from the lowest rating of "Very Low" to a maximum severity of "Extreme" for a given impact consequence. Definitions to characterise each consequence level magnitude were set for considerations across three consequence types: **1)** Health and Safety**, 2)** Structural Integrity and **3)** Functionality. Scale Factor definitions from the City's CRRA process and are listed in **Table 3-5**.

Table 3-5: Consequence Classification Matrix

Rating	Consequence Classification	Consequence Types		
		H&S	Structural Integrity	Functionality
1	Very Low	First Aid Injury	No permanent damage	No/minimal service disruption
2	Low	Medical Treatment for a Minor Injury	Minor asset or system damage, minor repairs, or restoration	Minor service disruption may occur
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

Rating	Consequence Classification	Consequence Types		
		H&S	Structural Integrity	Functionality
4	High	Permanent Disabling Injury or Multiple People Injured	May result in significant damage, loss, or require complete replacement	Lengthy service disruptions may occur
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

3.4 Step 6 – Risk Analysis

With a likelihood scale factor and an impact consequence scale factor score, the Risk Level can be determined as the product of ***(Likelihood) * (Impact Severity) = Risk Level***. Calgary's risk level definitions are shown in **Table 3-6**.

Table 3-6:Risk Classification Matrix

Risk Classification	Rating	Recommended Risk Treatment
Very Low	**1 to 2**	**Tolerable:** Risks do not require further consideration
Low	**3, 4, and 6**	**Monitor:** Controls or coping strategies recommended
Medium	**5*, 7 to 9**	**Requires Some Attention**: Some controls required to reduce risk levels. Monitor risk for changes over time.
High	**10 to 16**	**Requires Much Attention:** High priority control measures required.
Extreme	**20 to 25**	**Not acceptable:** significant controls required.

Notes:

*Risks with a score of 5 are considered medium-level risks due to either the high consequence-low likelihood or low consequence-high likelihood nature of these risks.

Appendix D contains summary tables with extreme, high, and medium risk scores from the Validation Workshop.

3.4.1 Yes/No Analysis

A Yes/No Analysis was conducted to establish which elements of the Walden Fire Station and Library Project are potentially climate sensitive, and which will not respond to shifts in the operating environment conditions. Where a climate hazard/project element interaction does not exist, or where an impact response occurs but it results in virtually NO impact, these interactions fall within the NO category and would be screened out of additional consideration in the risk assessment. For interactions where a YES is indicated, these denote interactions that could result in a more significant impact and consequently require additional consideration and assessment in the climate risk assessment process. For climate interactions that are considered to create positive benefits (in contrast to impacts detrimental to the project), these are designated in the table as Opportunities, and denoted by the letter "O".

Table 3-7 provides the completed Yes/No Analysis matrix results.

Following the Yes/No Analysis, the Likelihood data is assembled for each climate hazard relevant to the project elements in a Risk Assessment Worksheet which the City refers to as "F3 Climate Risk Assessment Worksheet". As described in **Appendix B** (Calgary's CRRA Process), this worksheet follows the classic PIEVC worksheet structure and lists a project's systems and subcomponents with a set of climate hazard events listed across the horizontal axis of the worksheet. For each column indicating one of the climate hazards, sub columns are provided to indicate the likelihood of the climate hazard, the consequence score assigned to reflect the impact severity and the resulting Risk Level scores obtained as the product of: ***(Likelihood) * (Impact Consequence Severity) = Risk Level***. Definitions for consequence severity scoring and likelihood scoring are also presented in the appended worksheet.

Table 3-7: Yes/No Analysis

System		Asset Component	Climate-Related Hazard								
			Extreme Heat	Increased Air Temperature	Wildfire	Drought	SDHI Rainfall	Severe Storms	High Winds	River Flooding	Heavy Snowfall
Site Infrastructure	Electrical	EV Charging Outlets	N	N	N	N	N	N	N	N	N
		Outdoor Light Posts	N	N	N	N	N	N	N	N	N
		Grid Power	N	N	Y	N	N	Y	Y	N	N
	Site Access	Asphalt Pavements	Y	N	N	N	Y	Y	N	N	Y
		Concrete Pavements	Y	N	N	N	Y	Y	N	N	Y
	Site Features	Benches	N	N	N	N	N	N	N	N	N
		Class 2 Bike Racks	N	N	N	N	N	Y	Y	N	Y
		Fencing	N	N	N	N	N	Y	Y	N	N
		Pavement Painted Markings (Xwalks, etc.)	N	N	N	N	N	Y	N	N	N
		Hard Landscaping (Community Spaces)	Y	N	N	N	Y	Y	Y	N	N
		Erected Signage	N	N	N	N	N	Y	Y	N	N
	Stormwater Management	Roof Drainage	N	N	N	N	Y	Y	Y	N	Y
		Oil & Grit Separator	N	N	N	N	Y	Y	N	N	N
		Site Drainage	N	Y	N	N	Y	Y	Y	N	Y
Natural Infrastructure		Soft Landscaping (Green Infra)	Y	Y	N	Y	Y	Y	Y	N	N
		Xeriscaping (if implemented)	N	N	N	N	N	N	N	N	N
		Ecosystem and Diversity	Y	Y	N	Y	N	N	N	N	N
Human wellbeing		Construction Personnel	Y	N	Y	N	Y	Y	Y	N	Y
		Maintenance Personnel	Y	N	Y	N	Y	Y	Y	N	Y
		Staff (CFD and Libraries), Library Patrons, contractors, etc.	Y	N	Y	N	Y	Y	Y	N	Y
Critical 3rd Party Infrastructure		Electrical Utility Connection	Y	N	N	N	N	Y	Y	Y	N
		Domestic Water Supply Utility Connection	N	N	N	N	N	N	N	Y	N
		Sanitary Sewer Connection	N	N	N	N	Y	N	N	Y	N
		Communications/Data Utility Connections	Y	N	N	N	Y	Y	Y	Y	N

The likelihood values for climate hazards under the current and projected climate are provided by the City's prescribed climate hazard information for use in their CRRA process. Once likelihood scale factors are indicated for each current and projected future climate hazard in each of the systems and subcomponents, the assessment team developed a score to describe the corresponding consequences of each anticipated impact (response) should that climate hazard occur. The Consequence Severity Impact uses a 5-Point Scale also defined and prescribed by the City. The completed CRRA Worksheet listing all severity scores, likelihoods and risk levels for the elements assessed for the Walden Fire Station and Library Project is provided in **Appendix D**.

A summary table is provided in **Table 3-8**, listing the number of climate interactions identified for the Walden Fire Station and Library Project within each of the five levels of risk defined by Calgary's CRRA process. Risk totals shown in each column are specific to each climate period indicated, i.e., the baseline climate and two projected future climate time horizons (2050s, 2080s). The highest risk interactions across all the assessed climate hazards for the Walden Fire Station and Library Project are also tabulated and provided in **Appendix D**.

Table 3-8: Validated Risk Scores – Numbers of Climate Impacts and Risk Levels across Present and Future Climate Conditions for the Walden Fire Station and Library Project

Risk Classification	Rating	Present	2050s	2080s	Total
Very Low	1 to 2	9	0	8	17
Low	3,4 and 6	113	41	33	187
Medium	5, 7 to 9	22	61	23	106
High	10 to 16	0	42	80	122
Extreme	20 to 25	0	0	0	0

3.5 Step 7 – Risk and Resilience Analysis

An internal workshop was held by Dillon to establish preliminary risk scores in the resilience analysis of the assets included in the Walden Fire Station and City Library Facilities Master Plan Climate Risk and Resilience Assessment. The scores were refined by results from a Climate Change Impact Survey where invited participants (representatives of the Calgary Fire Department and the Calgary Public Library) were provided an opportunity to offer details on their perceptions and knowledge of climate change impacts to fire station and library facilities. A final Resilience Options Workshop focused on resilience measures for the project, with focused engagement on two main adaptation measure categories:

1. Adaptation measures already incorporated (inherent) in the current *concept* intended for eventual design; and
2. Adaptation measures that could be considered for addition to the project *design* to achieve additional resilience.

While preliminary design for the Walden Fire and Library City Facilities Master Plan had not yet been completed at the time of this CRRA, workshop participants reviewed specific climate resilience measures specified in the City of Calgary document "*Engineering Guidelines for City of Calgary Fire Stations"* (2011) as well as information provided regarding the City's selected design concept option, referred to in ISL Engineering documents as Layout #2. This design concept option calls for a single 21,340 sq. ft. (1,983 m^2) building footprint where the fire station and library share a common wall. Conceptual drawings specify a two-storey fire station, and a single storey library are planned for this development.

This section outlines adaptation measures corresponding to the two adaptation measure categories above. Project design beyond ISL's site layout concepts for the Walden Fire Station and Library Project was not complete at the time of this risk assessment, providing an opportunity for this assessment to explore risk reduction recommendations that could further enhance the project's climate resilience in the future.

Areas where additional adaptation measures or recommendations were generated were determined based on specified required actions for each Risk Level within the City's Risk Treatment Guidelines, as summarised in **Table 3-6**. Resilience option recommendations were made for assets where risks were identified as medium to high, given that no extreme risks were identified in this assessment. Recommendations generally focused on options to modify aspects of design or modifications to operations and maintenance programs for added climate resilience.

The risk levels summarised in **Table 3-8** indicate the number of identified risks at Extreme, High, Medium, Low and Very Low levels in this CRRA process.

In **Table 3-9** through to **Table 3-14**, high risk levels were highlighted in orange and medium risk levels were highlighted in yellow. In situations where high, and medium risks both exist for an asset, the overall risk was identified as high to ensure a conservative approach. Low and Very Low Risk Levels are not included in the table. Also, within the tables, one column provides detail on resilience measures that are already inherent in the project's design concept while a second column indicates options for additional resilience measures that are not currently incorporated into the project but could be considered for addition to the project to further enhance the project's climate resilience.

Colours in **Table 3-9** indicate **extreme**, **high**, and **medium** risk scores.

Table 3-9: Resilience Measures for Anticipated Climate Impacts: 2050s, 2080s – Human Well-Being

Human Wellbeing

Consider the health, wellness, and safety of construction staff, maintenance staff, CFD and Library staff, and general public as well as the resilience of all of them to climate hazards.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
Construction & Decommissioning Personnel **Operations and Maintenance Personnel** **Staff (CFD & Library)**	High risks from **Extreme Heat, Wildfire**	• Maintenance staff are supplied with bottled water and Personal Protective Equipment (PPE) (N95 masks). • Facility design will account for sustainability, safety, and structural guidelines established in the CoC Engineering Design Guidelines for City of Calgary Fire Stations (2011). • Dust transport and exposure from construction sites are to be taken into account. • High quality air handling system with Merv 13 filters as a standard going forward will help prevent airborne contaminants (e.g., cement dust) from entering the facility.	• Enhanced SOPs (standard operating procedures) for occupational health in extreme conditions. • Consider SOP of sheltering equipment and personnel in advance of forecasted extreme events. • Supply staff with water fountains in addition to bottled water to maintain reliable access to water, especially under extreme heat conditions. • Develop Emergency Response Plan (ERP) for extreme heat events. • Provide sunshades above windows on the outside and window screens on the inside. • Glazing specifications that can be sourced effectively (i.e., not a custom build). • Secure 'cooling centre' type areas in library to provide people with shelter during extreme events. • Staff engagement/education on effectively managing extreme weather conditions. • Building envelope to provide adequate insulation from outdoor temperatures to ensure thermal comfort of people indoors as keeping the indoor climate cooler can reduce risks of heat-borne illnesses. • Planting trees on the south side of the building.

Human Wellbeing

Consider the health, wellness, and safety of construction staff, maintenance staff, CFD and Library staff, and general public as well as the resilience of all of them to climate hazards.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
			• Merv 13 filters as a standard going forward will help prevent airborne contaminants (e.g. cement dust) from entering the facility and impact human well-being.
	High risk from **Severe Storms** Medium risk from **High Winds** and **SDHI Rainfall**	• Facility design will account for sustainability, safety, and structural guidelines established in the CoC Engineering Design Guidelines for City of Calgary Fire Stations (2011). • CoC Stormwater Design guidelines minimum standard is to size to 1:100 system. • Design of roof drainage system account for impacts from hail and debris from storm events. • Stormwater retention ponds are present in the community which will allow avenues for stormwater to be collected and prevent inland flooding. • Site context has lower river flood risk (outside inundation area, high elevation).	• Enhanced SOPs (standard operating procedures) for occupational health in extreme conditions. • Consider SOP of sheltering equipment and personnel in advance of forecasted extreme events. • Supply staff with water fountains in addition to bottled water to maintain reliable access to water, especially under extreme heat conditions. • Secure 'cooling centre' type areas in library to provide people with shelter during extreme events. • Staff engagement/education on effectively managing extreme weather conditions. • Planting trees on the west and south side of the building.

Table 3-10: Resilience Measures for Anticipated Climate Impacts: 2050s, 2080s – Natural Environment and Infrastructure

Natural Environment and Infrastructure

What resilience measures could be built into the project that would increase the coping capacity of the natural environment to climate hazards?

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
Soft Landscaping	High risks from **Drought**, **Increased Temperature**, **Extreme Heat**	• Drought tolerant plants and grasses.	• Drought tolerant plants and grasses native to area. • Xeriscaping for high traffic areas to reduce irrigation needs during periods of drought and extreme heat. • Plant additional trees for natural protection against extreme heat and storms on west and south facing exterior walls (e.g., resilient trees) – It is notably easier to replace trees than repair infrastructure.
	High risks from **Severe Storms** Medium risks from **High Winds** and **SDHI Rainfall**	• There are several structures and trees in the immediate area that help slightly reduce the impact of west and south winds.	• Rain barrels and rainwater harvesting to use for landscaping as well as to reduce local peak runoff flow during a heavy rainfall event • Deep rooting plants to minimize impacts of high wind and storms. • Plant additional trees for natural protection against extreme heat and storms on west and south facing exterior walls (e.g., resilient trees) – It is notably easier to replace trees than repair infrastructure.
Ecosystem and Diversity	High risks from **Drought** and **Extreme Heat**. Medium risks from **Increased Air Temperature**	• No specific resilience measures identified.	• Water Management practices through rainwater harvesting and water efficient irrigation. • Green infrastructure such as rain gardens and more shade trees to reduce impacts of higher temperatures and drought.

Table 3-11: Resilience Measures for Anticipated Climate Impacts: 2050s, 2080s – Building Infrastructure

Building Infrastructure

Resilience measures may include changes to project design, management or response related recovery actions, or measures that may be implemented at a future date to address increasing risk.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
Building Substructure and Superstructure	High Risks from **SDHI Rainfall**.	• Post-disaster design (for fire station). • The multi-residential building to the West may provide the location with some shelter. • Low areas on the parking lots will spill before the depth gets to 300mm, so the risk of building flooding is limited. • The site is about 50m above the river. It will not likely ever be flooded by the river.	• Adequate egress for occupants in case of emergencies. • Sustainable infrastructure – what is included needs to withstand climate hazards over time with limited interruptions or closures for repairs (i.e. risks for 24/7 operations). • All-hazards emergency response capability for CFD and for library assets. • Increase the elevation of the site to reduce flooding and water infiltration risks; install critical equipment in elevated locations.
	Medium to High risks from **Drought**.	• The multi-residential building to the West may provide the location with some shelter.	• Drought can impact foundations through soil shrinkage and cracking, hence inspections should be completed throughout hot summer months. If cracks are identified, structure wall repair should follow. • Installing a retaining can also help hold back the soil and prevent it from shrinking and cracking.

Building Infrastructure

Resilience measures may include changes to project design, management or response related recovery actions, or measures that may be implemented at a future date to address increasing risk.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
Envelope – Roof and Membrane, Exterior Cladding/ Siding, Windows and Doors, and CFD Truck Bay Doors	High risk from **SDHI Rainfall, Severe Storms**	• No specific resilience measures identified beyond design engineering requirements.	• Note that Calgary's Engineering Guidelines for City of Calgary Fire Stations (2011) require resilience measures and design specifications well above usual Codes, Standards and By-law requirements to support (reduce risks) for CFD emergency responses. • A few requirements under the 2011 Engineering Guidelines for City of Calgary Fire Stations (2011) require updating (to reflect "lessons learned" for emergency backup power, incorporation of renewable energy sources, etc.). • Instate a standard O&M procedure to check debris or snow accumulation on roof following a storm or heavy snowfall event. • Incorporate waterproofing rather than damp-proofing materials and systems

Building Infrastructure

Resilience measures may include changes to project design, management or response related recovery actions, or measures that may be implemented at a future date to address increasing risk.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
	High risk from **Extreme Heat** (except CFD Truck Bay Doors)	• No specific resilience measures identified beyond design engineering requirements.	• Note that Calgary's Engineering Guidelines for City of Calgary Fire Stations (2011) require resilience measures and design specifications well above usual Codes, Standards and By-law requirements to support (reduce risks) for CFD emergency responses. • A few requirements under the 2011 Engineering Guidelines for City of Calgary Fire Stations (2011) require updating (to reflect "lessons learned" for emergency backup power, incorporation of renewable energy sources, etc.). • Optimizing selection of exterior colours and surface finishes to account for increasing temperatures • Optimizing the window-to-wall ratio and solar heat gain coefficients for glazing • Incorporate operable windows, where appropriate, to allow for passive ventilation

Building Infrastructure

Resilience measures may include changes to project design, management or response related recovery actions, or measures that may be implemented at a future date to address increasing risk.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
	High risk from **Heavy Snowfall** (Roof and Membrane only).	• No specific resilience measures identified beyond design engineering requirements.	• Note that Calgary's Engineering Guidelines for City of Calgary Fire Stations (2011) require resilience measures and design specifications well above usual Codes, Standards and By-law requirements to support (reduce risks) for CFD emergency responses. • A few requirements under the 2011 Engineering Guidelines for City of Calgary Fire Stations (2011) require updating (to reflect "lessons learned" for emergency backup power, incorporation of renewable energy sources, etc.). • Instate a standard O&M procedure to check debris or snow accumulation on roof following a storm or heavy snowfall event. • Hail resilient roofing/siding.
Electrical Systems – Exterior Lights	Medium to High risks from **Severe Storms**	• Solar modules that are mounted on the shear wall at an angle to increase the likelihood of self-cleaning (included in options analysis of feasibility study).	• Solar technologies to be integrated with other options to meet peak demands (e.g. water heating).

Building Infrastructure

Resilience measures may include changes to project design, management or response related recovery actions, or measures that may be implemented at a future date to address increasing risk.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
Electrical Systems – Communication Systems, Access and Security Systems (FOB, CCTV)	High risk from **Extreme Heat**, **SDHI Rainfall** Medium to High risk from **Severe Storms** Medium risk **Wildfire** (Access and security only).	• No specific resilience measures identified. Discussion on other fire stations with potential ground water infiltration and risks to electrical and communications systems – for further discussion on design, inspections, maintenance considerations.	• No specific resilience measures identified.

Electrical Systems - Electric Panel, Emergency Power System(s)	High risks from **Extreme Heat**	• EPS located indoors in air-conditioned setting for fire station only.	• Increased generator maintenance as hot weather can impact generator life and performance. Examples include:
			  ○ Regularly lubricate bearings throughout summer months;
			  ○ Maintain battery health through weekly visual checks of fluid level;
			  ○ Regular filter cleaning; and
			  ○ Increased cooling of area.

	Medium risk from **SDHI Rainfall** (EPS)	• No specific resilience measures identified.	• Consider raised platform for electrical backup generator to further mitigate risk of flooding from leaks.

Building Infrastructure

Resilience measures may include changes to project design, management or response related recovery actions, or measures that may be implemented at a future date to address increasing risk.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations

HVAC Cooling System	High risks from **Extreme Heat**, **Increased Average Air Temperature**	• Sizing of high efficiency HVAC systems.	• Ensure that the library has sufficient cooling capacity or shares specifications for the fire station cooling. Library is intended for use as a public cooling center.
			• Explore passive cooling measures such as:
			  ○ using energy-efficient enclosure assemblies;
			  ○ reducing thermal bridging at building enclosure interface details;
			  ○ improving building air tightness;
			  ○ optimizing building form and solar shading; and
			  ○ optimizing glazing systems (e.g., window-to-wall ratio, solar heat gain coefficient, orientations).

Mechanical Systems – HVAC Ventilation/Air Handling System	High risk from **Wildfire**	• Sizing of high efficiency HVAC systems.	• Merv 13 filters as a standard going forward will help prevent airborne contaminants (e.g. cement dust) from entering the facility and impact human well-being. • Periodic testing of the overall performance of the air barrier (whole building air barrier testing), as well as providing quality assurance testing (e.g. against CSA and ASTM test standards) of air barrier system details during construction to help confirm efficacy. • Consider using fully adhered air barrier materials, such as self-adhered or liquid applied air barrier products, depending on base structure

Building Infrastructure ***Resilience measures may include changes to project design, management or response related recovery actions, or measures that may be implemented at a future date to address increasing risk.***			
Component	**Risk Level Comments**	**Resilience Measures (Already Included in Design Concept)**	**Additional Measures or Recommendations**
Mechanical System – Plumbing	High risk from **SDHI Rainfall**	• No specific resilience measures identified.	• Ensure backwater valves are implemented to prevent backflow and overflow from blocked public sewers. • Non-potable rainwater catchment systems such as rainwater harvesting barrels can reduce loading on building plumbing systems

Table 3-12: Resilience Measures for Anticipated Climate Impacts: 2050s, 2080s – Decommissioning, Construction, O&M Phases and CFD Specific Functions

Decommissioning, Construction, Operations & Maintenance Phases and CFD Specific Functions ***Consider the resilience of construction/maintenance activities and equipment to climate hazards.***			
Component	**Risk Level Comments**	**Resilience Measures (Already Included in Design Concept)**	**Additional Measures or Recommendations**
Decommissioning/ Construction	High risks for **Wildfire, Extreme Heat**	• Emergency operational practices (heat, smoke). • Sustainable Building Policy.	• Ensure proper PPE (breathing apparatus/particulate masks) for work during elevated AQ index due to wildfire smoke. • Ensure that hazard assessments are completed by contractors and that the filed Public Protection Site Safety Plan includes extreme weather events.
	High risks for **Severe Storms, SDHI Rainfall**	• Stormwater design guidelines.	• Increase the elevation of site; install critical equipment in elevated locations. • Use of temporary wind barriers during construction. • Develop a wind hazard mitigation plan that identifies potential wind hazards on site with measures to reduce impact of winds.

Decommissioning, Construction, Operations & Maintenance Phases and CFD Specific Functions
Consider the resilience of construction/maintenance activities and equipment to climate hazards.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
			• Use equipment designed to withstand high winds and flying debris.
Operations and Maintenance	High risks for **Wildfire, Extreme Heat, Severe Storms, SDHI Rainfall** Medium risks for **High Winds**, and **Drought**	• Follow Public Protection Site Safety Plan submitted to City for wind, snow, and other hazards. • Emergency operational practices for construction, operations and maintenance (heat, smoke). • Sustainable Building Policy. • Stormwater design guidelines.	• Increase the elevation on site/keep critical equipment elevated. • Increase green spaces to accommodate water retention and decrease runoff flow rates. • Ensure that hazard assessments are completed by contractors (HSE Management Plans).
CFD Specific Functions	High Risks from **Severe Storms**, **Wildfire**, **Drought**, **Extreme Heat** and **SDHI Rainfall** Medium risks from **River Flooding**, **Heavy Snowfall**, and **High Winds**	• Emergency operational practices (heat, smoke). • Sustainable Building Policy. • Stormwater design guidelines.	• Emergency Operational practices. • Safety/Adaptation plans for SEVERE (but short duration) storms. • Potential increased demand for emergency services (due to increased weather events) may necessitate increased staff numbers and equipment. Note that fire stations rely on limited repair interruptions or closures (i.e. O&M and sustainable building policies).

Table 3-13: Resilience Measures for Anticipated Climate Impacts: 2050s, 2080s – Site Supporting Infrastructure

Site Supporting Infrastructure

Resilience measures may include changes to project design, management or response related recovery actions, or measures that may be implemented at a future date to address increasing risk.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
Site Access – Asphalt/Concrete Pavements	High risks from **Severe Storms** Medium risk from **Heavy Snowfall** and **SDHI Rainfall**	• No specific resilience measures identified.	• Regular maintenance to seal and repair pavements. • Minimise installation of impervious pavements (use permeable interlocking stones instead, this reduces risk of buckling). • Develop maintenance plan that includes regular cleaning, sealing, and repairing pavements to reduce the potential for damage.
	Medium risk from **Extreme Heat**	• No specific resilience measures identified.	• Reduce asphalt use to reduce urban heat island effect. • Install shade structures over pavements - moor trees or awnings. • Regular maintenance to seal and repair pavements. • Install “cool pavements” that are designed to reflect more sunlight and reduce absorption of heat. • Develop maintenance plan that includes regular cleaning, sealing, and repairing pavements to reduce the potential for damage.
Stormwater Management – Roof Drainage	High risks from **SDHI Rainfall** and **Severe Storms**	• No specific resilience measures identified.	• Use enhanced waterproofing membranes. • Regular maintenance/inspection to keep drains clear of debris. • Drainage routing from roof to reduce ice buildup. • On-site stormwater retention.

Site Supporting Infrastructure

Resilience measures may include changes to project design, management or response related recovery actions, or measures that may be implemented at a future date to address increasing risk.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations

Stormwater Management – Site Drainage	High risks from **SDHI Rainfall** and **Severe Storms**	• Stormwater runoff rate from the site will be restricted and underground retention will be incorporated.	• Planned maintenance for O&M to keep drains/scuppers cleared.
			• Install Low Impact Development solutions such as:
			  ○ Rain gardens;
			  ○ Bioretention areas;
			  ○ Downspout Disconnection (directing roof gutter systems onto permeable landscaped areas instead of impermeable surfaces);
			  ○ Install a rainwater retention system (e.g., rainwater barrels or cistern);
			  ○ Green roofs; and
			  ○ Permeable pavements.
			• Ensure site grading provides adequate slope to allow water to flow away from foundations effectively.
			• Install larger capacity drainpipes.
			• One or more storm drains in the parking lot to support freeze-thaw drainage limitations.

	High risks from **Increased Average Air Temperature** Medium risk from **High Winds**	• No specific resilience measures identified.	• Planned maintenance for O&M to keep natural drains/ scuppers/ditches cleared of debris or overgrown vegetation.

Site Supporting Infrastructure

Resilience measures may include changes to project design, management or response related recovery actions, or measures that may be implemented at a future date to address increasing risk.

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
Stormwater Management – Oil and Grit Separator	High risks from **SDHI Rainfall** and **Severe Storms**	• No specific resilience measures identified.	• Increased regular maintenance/inspection prior to and following an anticipated heavy rainfall or storm event.
Electrical – Grid Power	High risk from **Severe Storms**. Medium risk **from Wildfires**.	• No specific resilience measures identified.	• Develop an emergency response plan that includes procedures to respond to storm damage, including gas and electrical shutdown. • Consider installing solar energy system which includes PV panels and battery storage system to have access to more sustainably sourced EPS. • EPS for library if planned for emergency shelter/cooling facility.
Site Features – Hard Landscaping	High risk from **Extreme Heat**, **Severe Storms**. Medium risk from **SDHI Rainfall**	• No specific resilience measures identified.	• Regular maintenance and Inspection especially following a severe weather event (e.g. heavy rainfall or storm). • Consider using permeable hardscape materials (e.g. pervious concrete or pervious asphalt).
Site Features – Class 2 Bike Racks, Erected Signage, Fencing	Medium to high risk from **Severe Storms**.	• No specific resilience measures identified.	• Regular maintenance and Inspection. • Stronger anchoring of outdoor fixtures such as fence or sign posts.

Table 3-14: Resilience Measures for Anticipated Climate Impacts: 2050s, 2080s – Critical Third-Party Infrastructure

Critical Third-Party Infrastructure

What resilience measures could be built into the project that would increase the coping capacity of critical Third-party infrastructure to climate hazards?

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
Electrical Utility Connection	High risks from **Extreme Heat** and **Severe Storms**.	• Install backup power systems (CFD only). • Building code compliance for lightning surge protection. • Lightning rod installed on the roof to help protect facility from lightning strikes. • Underground electric utility lines to site. • Enclosed generator protected from the elements.	• Install surge protection devices to protect sensitive electrical and electronic equipment from lightning surges. • Measures to prevent water damage such as installing barriers or a raised platform for backup generator to be sited above anticipated major flood events. • Consider Library's potential use as an emergency response asset (the library as an area of refuge/ cooling centre during extreme events). • Develop emergency response plans that include procedures for responding to utility outages and restoring critical services as quickly as possible (library). • Sharing of backup capacity from fire station.
	Medium Risk from **River Flooding** and **High Winds**	• Install backup power systems (CFD only). • Underground electric utility lines to site. • Enclosed generator protected from the elements.	• Measures to prevent water damage such as installing barriers or a raised platform for backup generator to be sited above anticipated major flood events. • Consider Library's potential use as an emergency response asset (the library as an area of refuge/ cooling centre during extreme events). • Develop emergency response plans that include procedures for responding to utility outages and restoring critical services as quickly as possible (library). • Sharing of backup capacity from fire station.

Critical Third-Party Infrastructure

What resilience measures could be built into the project that would increase the coping capacity of critical Third-party infrastructure to climate hazards?

Component	Risk Level Comments	Resilience Measures (Already Included in Design Concept)	Additional Measures or Recommendations
Communication/ Data Utility Connections	High risks from **Extreme Heat** and **Severe Storms**. Medium risk from **SDHI Rainfall** and **River Flooding**	• Buried connections to reduce risk of aboveground interferences (e.g. damage from windswept debris).	• Sharing of backup capacity from fire station.
Domestic Water Supply	Medium risk for **river flooding**	• No specific resilience measures identified.	• Develop a plan to provide an emergency water supply system during a flooding event (e.g. flooding elsewhere that interrupts local supplies).
Sanitary Sewer	Medium risk for **river flooding** and **SDHI Rainfall**	• No specific resilience measures identified.	• Develop an emergency response plan and related procedures to respond to sewer backups and overflow. • Ensure backflow preventers are installed to prevent backflow of sewage.

3.6 Adaptation Option Recommendations and Discussion

A number of potential climate resilience risk reduction options have been identified for the Walden Fire Station and Library Project based on participant inputs in the Resilience Options Workshops, as described in **Section 2.4**. The workshop, which convened on May 31, 2023, identified existing resilience measures but focussed on identifying the potential *additional* resilience measure options for consideration by the City that go beyond those currently in place. The identification of these new, additional climate resilience options that are deemed feasible have the potential to *further enhance climate resilience* over the planned lifespan of the Project.

Many of the *existing* resilience measures outlined in **Table 3-9** through **Table 3-14** were identified from the workshop and will offer benefits for the current climate but also provide "no regrets" benefits into the future under climate change. Many of the *additional* resilience measures that are not already included in the design concept are tailored to support the 24/7 and uninterrupted service needs of the fire station or to address specific vulnerabilities of the library using evidence of issues found for other Calgary libraries. Due to the shared site and building footprint for this Project, some of the existing resilience measures included in City of Calgary fire station designs could offer additional resilience benefits for the library. These existing fire station resilience measures may not be available for other libraries and would include more resilient facade materials, more durable roofing, site flood-proofing and grounds maintenance and management. In other cases, additional resilience measures will benefit both the fire station and the library due to their shared footprint.

3.6.1 Recommendations for Adaptation Options

There are differences and overlaps in the additional resilience needs for the site, the fire station and the library. This makes it challenging to prioritize one set of resilience needs over others, recognizing that the fire service has unique needs, demands and may be facing increasing demands for services. The potential added role of libraries in community emergency support is also changing, as seen in other jurisdictions and discussed in **Section 3.6.2**.

The additional resilience measures recommended below for the grounds, fire station and library can be grouped under six sets or categories of decisions and actions:

1. ***Joint flood-proofing actions*** that reduce changing climate risks for the site, fire station and library include:
    1.1. Flood and water proofing options to reduce risks to the site or grounds and protect both the fire station and library, their contents and access. These site water-proofing measures include rainwater retention systems, use of rain barrels or on a larger scale, added stormwater retention and use of barriers to redirect site flood waters. Other joint options include use of permeable pavers where appropriate, reduction of hard or asphalt surfaces where feasible, the addition of one or more extra drains in the parking lots to reduce blockage and pooling

from increased freeze-thaw cycles or clogging due to storm debris and site grading to increase the elevations of facilities.

1.2. Larger capacity drainage pipes would likely serve both the fire station and library.

1.3. Regular site or grounds inspections after storms to detect and ensure early repair of damages and drainage blockages.

2. ***Enhanced emergency planning*** and backups for potential interruptions to third party electrical, gas, water supplies are essential for the fire station but could also offer some resilience for the library. This emergency preparedness planning also needs to include resilience to sewage backup incidents or interruptions to sewage services. As required in emergency situations, additional emergency planning will help in supporting the fire station to operate under normal loads for periods as long as 7 days during prolonged emergencies, even given potential interruptions to critical services. This Guidance should also include needs and best practices for gas and electrical shutdown procedures. In the worst cases, planning may need to consider adequate protection or egress for the occupants of the fire station and library e.g. tornado hit.

   The library would also benefit from the added emergency planning. If emergency power and other utilities needed for the fire station were shared, the library could offer some services in a role as a public or community emergency response asset (see Section 3.6.2). The library will currently offer refuge to vulnerable community members as a cooling centre under extreme heat incidents and may also be offering refuge to vulnerable community members under extreme cold winter conditions.

3. Additional resilience design consideration for the ***fire station*** includes enhanced ventilation and air filtering to deal with increasing wildfire and local smoke conditions (e.g. merv 13 filters as a minimum) along with the flood-proofing measures identified under joint flood-proofing actions. Enhanced exterior waterproofing membranes and even more resilient facade materials for the fire station likely could be applied to the library portion of the exterior building footprint, adding to the library's resilience. Supplementary solar power options also would reduce energy use while adding some redundancy options during power interruptions. The use of enhanced filtering in the air handling facilities, at least during wildfire smoke season, would reduce the additional background smoke exposure. Other additional measures included the raising of platforms used to support interior backup power equipment and use of enhanced electrical and communications surge protection.

   A few components of the City's 2011 E*ngineering Guidelines for Calgary Fire Stations* were identified by workshop participants as being in need of review and updating (e.g. solar hot water heating, dual fuel backup power generation). These Guidelines are important in supporting enhanced resilience of new and retrofitted fire stations and require ongoing updates.

4. The enhanced exterior waterproofing membranes and more hail and weather resilient facade materials required for the fire station should be considered for the ***library*** portion of the exterior building footprint. The use of enhanced air filters (e.g. *merv 13*) in air handling facilities would also be beneficial for times when vulnerable members of the community require respite from increased and elevated background wildfire smoke conditions. Additional design requirements for the new library include increased air conditioning capacity beyond the specifications provided for many existing City libraries, especially given that the library is intended to serve as a public cooling center. Other libraries have experienced insufficient cooling capacities and hail damage to exterior facades under current climate conditions. Due to its co-location and particularly should the role of the library increase as a community emergency asset, the library building could "share" the enhanced cooling and backup power capacities needed for the fire station. The library would also benefit from the enhanced insulation required for the fire station.

5. Measures to enhance resilience for the ***site and grounds*** already include flood-proofing options for fire services. Additional resilience measures for the site would include use of drought tolerant plants and trees on the grounds, addition of deep-rooted plants near buildings and outdoor facilities that are more resistant to high winds, severe storms and snow or ice loads, natural protection to shelter the northern and western slopes and shade trees and other green infrastructure for southern exposures. Attention to regular maintenance practices for drains, pavements, permeable surfaces and other hard horizontal surfaces as well as water routing to permeable surfaces and winter redirection of storm and melt water would reduce potential risks from ponding and ice buildups. As indicated, raising the elevation of the building and critical facilities also would reduce building and parking lot ponding and flooding risks.

6. The City of Calgary has policies and many Standard Operating Practices (SOPs) in place to reduce risks to workers and occupants during building ***decommissioning, construction*** and ongoing operations and maintenance. Any decommissioning will be undertaken at the end of the project and would consist of a careful dismantling and packing of the current temporary fire station. Existing measures to be implemented to protect health, safety and failure risks during the construction phase would include use of a Calgary wind warning App with forecasts and guidance to prepare for upcoming high wind events, requirements for the bracing of building components, site perimeter fencing and construction site hoarding requirements along with adherence to the initial filing of the Public Protection Site Safety Plan with the City that should include extreme weather events. Additional resilience measures should include enhanced Standard Operating Procedures (SOPs) for occupational health and safety under extreme weather and high heat conditions, sheltering of equipment and personnel in advance of forecast extreme weather (not just high winds), use of equipment that is more resistant to high winds and flying debris and use of proper PPE for work during elevated air quality index conditions due to wildfire smoke.

3.6.2 Changing Needs of Fire Stations and Library Facilities under Climate Change

Under a changing climate, it is likely that demands on Calgary's Fire Department will increase as the numbers and intensities of extreme weather events and their impacts on communities grow. Community fire stations currently provide a range of emergency and non-emergency services beyond firefighting responses and fire prevention. These include responses to emergency medical and heat wave incidents, waterway rescues, collapsed building and confined space rescues, chemical and hazardous materials releases and motor vehicle collisions. While the Walden fire station is outside of the high-risk region for riverine flooding, it could be called upon more often in future to respond to any increases in flooding for higher risk communities in the vicinity. Being on the front lines of the all-hazards response team, Calgary's fire stations will need to become even more resilient to meet potentially growing demands.

In many jurisdictions, the role of the community library system is also being recognized as important to community emergency responses. For example, the U.S. Federal Emergency Management Agency (FEMA) in 2010 formally designated public libraries as essential community organizations, adding to other critical services such as fire, police, emergency services, medical care, education, and utilities. FEMA is still in the process of identifying and defining the specific roles that different libraries can address. After Superstorm Sandy, for example, one of the Public Libraries in New Jersey provided the affected public with a place to charge devices, gather or contact loved ones or even just watch movies and keep their children engaged. Libraries in some U.S. States are often regarded as community partners during emergencies and even have been known to transform into shelters when needed. Nor surprising, the State of New Jersey referred to libraries as "I*nformation First Responders*" (Paton, 2020; Young, 2020).

Since libraries are often designated as community cooling centres during heat waves, as will be the case for the Walden library, they could potentially play larger roles in the community during emergencies in future. In Toronto, for example, librarians in some neighbourhoods have been trained in sighting and emergency treating of drug overdoses among patrons, or are sometimes used by the community as shelters during heat waves, extreme cold, snow storms, hail, and other extreme weather conditions (Hawco, 2019). In Australia, carefully selected air-conditioned public buildings with good ventilation and higher capacity air filtering, such as libraries, have been used as a cleaner indoor air shelters during episodes of elevated smoke emissions (Wheeler, et al, 2021). Given the expected changes to and impacts from extreme weather in future, it is likely emergency responses will require "all these hands on the deck".

Appendix A

Calgary Climate Profile

Calgary 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 Resilience Strategy (*COC, 2020*) 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 understand which climate hazards, and how climate risk, may affect their project area and its users.

Calgary's Top Climate Hazards

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 partnered with the Calgary Airport Authority to develop Calgary-specific climate projections for the 2050s and 2080s (*GHD, 2020*); all data presented is based on the Representative Concentration Pathway (RCP) 8.5 scenario, as directed by the Pacific Climate Impacts Consortium (PCIC) for long life span infrastructure (*PCIC, 2021).* The historical time horizon for the City consists of Environment and Climate Change Canada (*ECCC*) data from 1960 to 2014 as observed at the Calgary Airport, and the baseline period refers to an ensemble of GCM data for the climate normal period (1981 to 2010). The 50th (median), 10th (low) and the 90th (high) percentiles were calculated across the baseline for all of the GCMs when available (*GHD, 2020*).

The climate data and probabilities used for the assessment were provided by the City and the Calgary Airport Authority. The climate probabilities were based on climate observations from the Calgary International Airport, while the climate change projections were based on standard variables available from the PCIC. These available climate variables reflect the 10th percentile low, the median and the

90th percentile high values (but not representative of extremes typically used for infrastructure design). Such variables are typically used in international climate change research and are recommended by the IPCC for climate model intercomparisons and climate science studies. On the other hand, the engineering and planning communities, who are concerned with flooding and infrastructure design for example, focus on very low probability of occurrence events (e.g., >99th percentile high) with very long "return periods". The 90th percentile high climate variable used in climate research generally can be expected to occur at least once, if not several times each year.

Given that the climate research community's definitions of extreme climate events have been established for a different purpose (i.e., studies needing at least one "extreme" event per year), it is not surprising that they typically do not correspond to the amounts and intensities used in engineering risk assessments.

The Calgary Airport data was further analyzed by the City's adaptation team to assess Calgary's changing climate and associated trends were determined. Sometimes projections were unavailable for a given hazard, and in those cases, literature was used to determine trends, in some cases both literature and projections were utilized. Projected climate hazard trends for the City are presented in **Table A-1** along with associated references.

Table A-1: Summary of Climate Hazard Trends for the City of Calgary

Climate Hazard	Projected Climate Hazard Trend	References
Extreme Heat	↑	*(GHD, 2020)*
High Average Temperatures	↑	*(GHD, 2020)*
Wildfire	↑	*(Flannigan, 2016), (Wotton, 2017), (Wang, 2017), (WSP, 2021)*
Drought	Likely ↑	*(GHD, 2020)*
Short Duration High Intensity (SDHI) Rainfall	↑	*(GHD, 2020), (Trenberth, 2011)*
Severe Storms (I.E. Hail, Tornadoes)	Likely ↑	*(GHD, 2020), (Etkin, 2018), (Brimelow, 2017), (Romps, D. M., Seeley, J. T., Vollaro, D., & Molinari, J., 2014), (GHD, 2020), (ECCC, 2021)*
High Winds	Likely Stable	*(GHD, 2020), (Zeng, 2019), (Vautard, 2010) (Greene, 2010)*
River Flooding	Likely ↑	*(Rajulapati, Tesemma, Shook, Paplexiou, & Pomeroy, 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 warmer than 14°C. The number of hot days with maximum temperatures equal to or greater than 29°C, number of heat waves and the length of heat waves are all expected to increase in the future. **Table A-2** includes a summary of baseline (1980s to 2010) and projected (2050s (2041 to 2070), 2080s (2071 to 2100) extreme temperature indicators (e.g., number of hot days) for the City. The low (10^{th}), median (50^{th}) and high (90^{th}) percentiles were calculated across the baseline for all of the GCMs and are presented below in the table for each indicator where available.

Extreme heat can impact built infrastructure, the natural environment and particularly people's health and wellbeing. This has implications for building heating and cooling system design, thermal comfort and the health and safety of site users and staff. Extreme heat can lead to heat-related illnesses, including heat stroke, and increase morbidity and mortality in vulnerable individuals, such as outdoor workers, the elderly and those with pre-existing health conditions. It can also contribute to less than optimal performance of HVAC and mechanical systems.

Table A-2: Summary of Extreme Climate Projected Temperature Indicators for Calgary

Extreme Heat Indicators	Season[1]	Baseline	2050s			2080s		
			Median[2]	Low[2]	High[2]	Median[2]	Low[2]	High[2]
Mean Daily Maximum Temperature (°C)	Summer[1]	21.4	25.0	23.4	27.0	27.6	24.8	30.9
	Annual	10.3	13.3	11.6	15.4	15.4	13.0	18.0
Mean Daily Minimum Temperature (°C)	Winter[1]	-11.6	-7.9	-10.1	-5.8	-5.7	-7.9	-3.3
	Annual	-1.2	2.0	0.5	3.6	4.1	2.1	6.1
Warm Nights	Annual	5.3	32.4	19.1	46.8	65.5	35.8	85.6
Annual Maximum Temperature (°C)	Summer[1]	32.0	36.0	34.2	39.2	38.4	35.6	43.1
Mean Number of Hot Days[3]	Annual	6.8	26.5	15.2	42.0	48.1	24.3	71.5
Longest Heat Wave (Days)	Annual	4.0	16.0	4.0	16.0	24.0	16.0	24.0
Mean Number of Heat Waves	Annual	0.2	3.0	1.7	5.1	7.1	2.9	9.5

Notes:

[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 Temperature

Local temperatures have steadily increased over the past century and projections strongly indicate that regional warming is expected to continue at an accelerated rate (*GHD, 2020*). Greater warming is expected during the cooler seasons (winter, late autumn, and early spring) and in nighttime temperatures throughout the year. Changes in temperature extremes (e.g., heat waves and hot days) are significantly more pronounced than seasonal or annual averages. Winters are getting shorter, spring is arriving earlier, summers are longer, and fall is arriving later; average winter temperatures are projected to increase but are projected to remain below 0°C. Freeze-thaw cycles are expected to decrease, especially during the spring and fall, as more of the year will be spent at temperatures above 0°C. **Table A-3** includes a summary of seasonal average and projected temperature ranges for the City. Increased annual temperatures, a longer season of cooling degree days (CDD) and higher extreme warm temperatures impact air conditioning needs and costs for buildings to maintain thermal comfort. While

there may be less energy expended for heating in a warming climate, increased cooling needs should be considered.

Table A-3: Summary of Climate Projected Temperature Indicators for Calgary

Increased Air Temperature Indicators	Season[1]	Baseline	2050s			2080s		
			Median[2]	Low[2]	High[2]	Median[2]	Low[2]	High[2]
Mean Temperature (°C)	Annual	4.5	7.7	6.0	9.5	9.8	7.6	12.1
	Winter	-6.2	-3.0	-5.1	-0.9	-1.0	-3.3	1.4
	Spring	4.2	7.0	5.4	9.1	8.8	6.8	11.3
	Summer	15.3	18.7	17.3	20.3	21.3	18.8	23.7
	Fall	4.7	7.7	6.2	9.3	9.7	7.7	11.7
Mean Number of Cooling Degree Days[3]	Annual	46.1	201.7	119.1	327.2	401.3	203.4	657.2
Mean Number of Heating Degree Days[4]	Annual	4,958.7	3981.8	4491.7	3423.4	3411.5	4014.6	2820.0
Mean Number of Freezing-Thaw Cycles	Annual	107.4	83.5	95.3	70.3	64.1	85.3	54.6
	Winter	43.5	43.8	43.9	42.1	39.5	43.8	36.3
Mean Number of Freezing Degree Days5	Annual	902.2	566.4	768.2	381.7	404.1	587.8	237.4
Mean Growing Season Length	Annual	123.8	151.7	141.9	172.3	169.7	151.6	200.4
Mean July 2.5% Design Air Temperature[6]	Frequency	28.0	32.2	30.4	34.5	34.8	32.5	39.0

Notes:

[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] Cooling Degree Day (CDD) are equal to the number of degree Celsius a given day's mean temperature is above 18°C *(Climate Atlas, 2021).*

[4] Heating Degree Days (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] Freezing degree days 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 (55 years) per series.

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 the City. A recent research study examined the number of 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 should increases in precipitation due to climate change is not enough to offset increases in temperature (*Flannigan, 2016*). **Table A-4** includes a summary of baseline and projected wildfire spread days for the Southern Cordillera range.

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. As future climate conditions increase the projected number of wildfire spread days for the Southern Cordillera region, there is likely to be an increase in poor air quality due to smoke in the Calgary region. Wildfire smoke and poor air quality have had significant impacts on Calgarians' health, well-being, and enjoyment of outdoor activities in the recent past.

Table A-4: Wildfire Occurrences

Increased Air Temperature Indicators	Baseline	2050s			2080s		
		Median[1]	Low[1]	High[1]	Median[1]	Low[1]	High[1]
Median Number of Wildfire Spread Days[2]	3	5.5	-	-	5.7	-	-

Notes:

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

[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

Drought is a current climate hazard affecting the Calgary region that will likely be exacerbated by climate change. There are four main types of drought, reflecting the different impacts associated with each:

1. Meteorological drought is a result of less precipitation than normal over a prolonged period in a specific region. It usually is the first type of drought to occur;
2. Agricultural drought occurs when there is not enough soil moisture to meet the needs of crops and pastures. It usually occurs next after a meteorological drought;
3. Hydrological drought occurs when surface water or groundwater levels fall to below average levels due to a lack of precipitation. It usually occurs more slowly than a meteorological or agricultural drought; and

4. Socio-economic drought occurs when the prolonged absence of water in a region begins to impact people and the economy.

At the City, the corporate drought vulnerability and risk assessment focuses mainly on hydrological drought whereby: “drought conditions are defined on a watershed basis wherein the sum of the projected water demands for The City and other water users including agricultural users and instream flow needs are less the available surface water supply available in the Bow and Elbow Rivers”. This highlights the importance of the watershed scale surface water availability, water supply for various uses and water use demand. Hydrological drought drives the City four stage drought response plan *(COC, 2021)*.

Within climate adaptation, the City has been using an understanding of drought that aligns more closely with meteorological drought, while recognizing that hydrological drought will likely be amplified by climate change as well.

Under the influence of climate change, counter-acting effects will influence the evolution of drought episodes (more precipitation at certain times of the year, but higher temperatures and decreasing precipitation in the summer months). Typical climate modelling processes indicate that the number of dry days, dry spells and the longest dry spell are likely to remain similar, while the return period of a two-week drought is expected to decrease (become more frequent). Inter-annual variability in precipitation regimes is anticipated to increase due to climate change; therefore, drought could increase during extreme years. **Table A-5** presents many of the indicators that have been investigated through climate projections as contributing to meteorological drought. Extreme heat (number of hot days, heat waves) and precipitation (mean annual precipitation) are also indicators of drought and can be referenced in **Table A-2** and **Table A-10**, respectively.

Drought can impact infrastructure through its effects on soil moisture, compaction, and can lead to shifting and instability in foundations and roadbeds which could cause issues during infrastructure development.

Table A-5: Indicators of Meteorological Drought Driven by Climate Projections for Calgary

Increased Air Temperature Indicators	Baseline	2050s			2080s		
		Median[1]	Low[1]	High[1]	Median[1]	Low[1]	High[1]
Mean Number of Dry Days[2]	296.2	296.7	301.2	295.7	296.8	301.1	295.7
Mean Number of Dry Spells[2,3]	5.9	6.0	6.3	5.9	6.0	6.3	5.9
Longest Dry Spell[2] (Days)	35.9	35.9	40.9	35.4	35.9	40.9	35.4
Drought Days	63.9	75.6	-	-	83.8	-	-
Return Period of Two-Week Drought (Years)[4]	55	27.5	-	-	18.3	-	-

Notes:

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

[2] Dry day is defined as daily precipitation below 1 millimetre (mm).

[3] Dry spell is defined as a daily precipitation below 1 mm for a minimum of 14 days.

[4] 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 (e.g., thunderstorms, lightning, hail) (*Brimelow, 2017; Romps, D. M., Seeley, J. T., Vollaro, D., & Molinari, J., 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 A-6** to **Table A-8** are the IDF rainfall estimates for the City for the baseline, 2050s and 2080s, respectively. The future projections for IDF of rainfall were derived for the 2050s and 2080s. **Table A-9** 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 one to two-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; the confidence in the SDHI rainfall increases is medium-low.

Projections indicate the degree of change will be greater by the 2080s than it will be in the 2050s. At higher return periods (e.g., large storms with a lower frequency of occurrence, e.g., 1:100-year event) there is a greater degree of rainfall volume increase than at lower return periods (e.g., more frequent storms, e.g., 1:5-year event). Significant increases in rainfall amounts are expected during discrete storm events (**Table A-6**), the events for which systems should be designed to accommodate safely and efficiently; the confidence in the seasonal precipitation projections (**Table A-7**) is medium-high. The overall recommendation is to consider the future IDF curve and precipitation estimates in the design of stormwater systems, including traditional hard infrastructure stormwater design, as well as in the design and implementation of green stormwater infrastructure/low impact development (LID) practices. Green stormwater infrastructure can provide a multi-benefit solution to multiple climate challenges, while also existing as a community attraction.

Table A-6: Baseline IDF of Rainfall Estimates (mm) for the Calgary International Airport

Time	2 Years	5 Years	10 Years	25 Years	50 Years	100 Years	200 Years	500 Years
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 A-7: 2050s Climate Adjusted IDF of Rainfall Estimates (mm) for the Calgary International Airport

Time	2 Years	5 Years	10 Years	25 Years	50 Years	100 Years	200 Years	500 Years
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	29.8	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 A-8: 2080s Climate Adjusted IDF of Rainfall Estimates (mm) for the Calgary International Airport

Time	2 Years	5 Years	10 Years	25 Years	50 Years	100 Years	200 Years	500 Years
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 A-9: Summary of Climate Projected Increase in Rainfall IDF for Calgary

Precipitation Event	2050s	2080s
Short Duration (< 25 Hours)	28% increase [1]	52% increase [1]
Long Duration (≥ 24 Hours)	10 to 15% increase [1]	10 to 20% increase [1]

Notes:

[1] Averaged over all return periods.

Table A-10: Summary of Climate Projected Precipitation for Calgary

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

Notes:

[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 events and favourable conditions 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 (**Table A-11**).

Although hail cannot be explicitly modelled by global and regional climate models due to limitations in resolution, large hail events are projected to increase, with the hail stones increasing in size, due to increasing atmospheric energy (and associated updraft). Conversely, smaller hail events are expected to decrease due to a rising melting level in a warming atmosphere (*Brimelow, 2017*). However, the longer convective storm season (**Table A-11**) will likely contribute to Calgary experiencing more hail events in total (*Etkin, 2018*). Given the nature of the climate hazard and the methodology used, the confidence in the projections for the number of days with convective events are low.

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., Seeley, J. T., Vollaro, D., & Molinari, J., 2014*) and hail with the potential for physical damage to the building envelope and water damage to its contents (e.g., below and at grade flooding). It is therefore recommended that buildings be designed with hail-resistant exteriors to prevent costly damage as it may reduce long-term operational, repair, maintenance, and insurance costs. Physical health and safety concerns also must be considered, as hail, lightning and heavy rain can contribute to injuries as well as property and vehicle damage.

Table A-11: Summary of Climate Projected Severe Storms for Calgary

Severe Storms Indicators	Season	Baseline	2050s			2080s		
			Median[1]	Low[1]	High[1]	Median[1]	Low[1]	High[1]
Mean Number of Days with Convective Events (Thunderstorms)[2]	Annual	23	35	26	42	40	25	49

Notes:

[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 based on historical data (*GHD, 2020*).

[5] Hail projections for 2050 and 2080 used a linear regression (*Etkin, 2018*).

High Winds

How wind will be affected by climate change is not as well understood as variables such as temperature. Data provided by GHD shows a slight reduction in high wind events, which agrees with recent larger scale research studies that suggest global wind speeds have been decreasing since the 1980s, and increasing since 2010 (*Zeng, 2019*). As temperatures increase with climate change, the temperature gradient between the equator and the poles is reduced, and concomitantly the pressure gradient, and synoptic weather system intensity (*Vautard, 2010*). The relaxation of a pressure gradient could therefore be partially responsible for a decrease in wind speeds (*Greene, 2010*). **Table A-12** includes a summary of baseline and projected wind gust days for the City. Note that there are significant uncertainties associated with analysis of recent historical wind data and with their climate change projections.

Table A-12: Summary of Climate Projected Wind Gusts for Calgary

Severe Storms Indicators	Season	Baseline	2050s			2080s		
			Median[1]	Low[1]	High[1]	Median[1]	Low[1]	High[1]
Mean Number of Days with Maximum Wind Gusts ≥ 90 Km/Hr [2]	Annual	2.0	1.8	0.6	4.3	1.6	0.7	3.8

Notes:

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

[2] The wind threshold of 90 km/hr was chosen based on ECCC's warning criteria for wind warnings (ECCC, 2021), and the lower bound for 1 to 4 storey buildings on the 'Enhanced Fujita scale damage indicators and degrees 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 run off and rainfall runoff (and associated rain-on-snow events). Larger, less frequent floods (with return periods greater than 15 years events) 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 precipitations 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, Tesemma, Shook, Paplexiou, & Pomeroy (2020) (Part 2) in collaboration with the City, Alberta Environment and Parks, ECCC and the Global Water Futures program to better understand the future of flooding in Calgary. 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 the City since 2013, 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 historical/baseline river flood projections 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 A-13** below (*WSP, 2021*), the City expects the 1:100-year flooding events for the baseline period to equal about 2,000 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*) (the same assumption was applied to 2080s). Therefore, the volume associated with a 1:100-year flood historically could become the volume of a 1:70-year flood by 2050.

Table A-13: River Flooding Return Periods, Flow Rates and Probability

Upstream of the Elbow River (m^3/s)	Downstream of the Elbow River	Elbow River Downstream of Glenmore Dam	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	1,040	201	12.5% (1:8)
927	1,160	234	10 to 12.5% (1:8 to 1:10)
1,230	1,500	275	5 to 10% (1:10 to 1:20)
1,660	2,150	494	2 to 5% (1:20 to 1:50)
2,020	2,820	803	1 to 5% (1:50 to 1:100)
3,340	5,610	2,270	0.1 to 1% (1:100 to 1:1,000)

Heavy Snowfall

As average winter temperatures continue to approach the 0°C threshold, Calgary will continue to experience winter storm hazards but could experience more freezing rain and rain-on-snow events. Calgary's climate will remain cold enough to be subject to 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*); however, snow amounts are still likely to decrease on average annually as temperatures warm and precipitation shifts from snow to rain in the spring (e.g., April, May). As winters become warmer and precipitation shifts to more rainfall events, annual snowfall totals over a shorter winter are expected to decrease (*DeBeer, 2016*) as shown in **Table A-14**.

Snow events which do occur may be heavier in nature due to increased moisture content and accompanied or followed by rainfall, resulting in extremely heavy loading on trees and overhead infrastructure, including roofs and powerlines. Winter snow loading and moisture content of snow events should continue to be analyzed and considered for roof and overhead infrastructure (e.g., powerlines) design.

Table A-14: Summary of Climate Projected Snowfall for Calgary

Climate Indicator	Season	Baseline	2050s			2080s		
			Median[1]	Low[1]	High[1]	Median[1]	Low[1]	High[1]
Mean Number of Heavy Snowfall Days [2]	Annual	0.9	0.20	0.1	1.0	0.2	0.0	0.7
Winter Snowfall Total	Winter	28.7	27.1	21.9	34.3	25.6	19.6	33.7
Mean snowfall total (cm)	Annual	0.9	0.20	0.1	1.0	0.2	0.0	0.7
1:50 year storm event[3] (cm)	Annual	0.9	0.20	0.1	1.0	0.2	0.0	0.7

Notes:

[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 12 hours, based on ECCC's warning criteria for a snowfall warning *(ECCC, 2021).*

[3] 1:50 years ground snow load as per the National Building Code – 2019 Alberta Edition (NRC, 2019).

Appendix B

Calgary's Climate Risk Assessment Process

Calgary's Climate Risk Assessment Process

The Risk Assessment Process

The objective of a Public Infrastructure Climate Risk and Resilience Assessment (the Assessment) is to identify and evaluate the risk that climate-related hazards may have on infrastructure (capital assets), the natural environment and the human users of the asset over its lifetime, and to recommend resilience measures to decrease the impact of these hazards. The risk assessment process was developed in alignment with the Public Infrastructure Engineering Vulnerability Committee (PIEVC) High Level Screening Procedure (*ICLR, 2016*), the City Risk Matrix and requirements for the Federal Infrastructure Canada Climate Lens Resilience Assessment (*GOC, 2019*). The risk assessment process is informed by the City's "Climate Change Adaptation Technical Report" (The City of Calgary, 2017) and the City's Integrated Risk Management Process. There is a Greenhouse Gas (GHG) Mitigation Assessment that accompanies the risk assessment which is not included in the scope for this assessment. An accompanying spreadsheet "Public Infrastructure Climate Risk Assessment Worksheet V4" was provided by the City as a template with predetermined climate hazards for use with the assessment.

Definitions and Principles

Climate hazard is 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. Climate indicators are metrics used to assess the climate hazard changing over time (e.g., number of hot days per year).

The climate hazards applicable to the City in this assessment were furnished by the City for application in its prescribed CRRA process and is presented in **Appendix A**.

Climate hazard likelihood is the probability of the climate hazard occurring, considering the influence of climate change.

Climate risk is the interaction of climate hazard likelihood, community exposure to each climate hazard and community vulnerability to each hazard. These three components can be used to estimate overall climate risk. We can manage climate risk by taking actions to reduce exposure and vulnerability.

Exposure reflects the presence of people, built assets or natural assets in a place or setting that could be impacted by a hazard. In the case of some climate hazards, such as river flooding and wildfires, exposure can be reduced through moving people, built and natural assets away from a physical boundary that has potential to be impacted (e.g., moving away from a floodplain to avoid being exposed to river flooding). In the case of other climate hazards, exposure is reasonably similar across all areas (e.g., wildfire smoke, severe storms, extreme heat).

Vulnerability reflects the propensity or predisposition of people, built infrastructure or natural assets to be adversely affected by a climate hazard. Vulnerability is based on sensitivity and adaptive capacity:

- **Sensitivity** is the degree to which a social, built, or natural system is affected by climate change, and is determined by the predisposition of systems to suffer harm because of intrinsic and/or contextual conditions; and
- **Adaptive capacity** is the ability of social, built, or natural systems to adjust to potential damage, to take advantage of opportunities or to respond to consequences.

Vulnerability can be reduced by implementing targeted measures that lessen the degree to which people, built and natural systems are affected by climate impacts, or by providing support that helps improve the ability to cope and adapt to changes. Addressing vulnerability differs depending on the system, e.g., providing care and support for vulnerable populations, maintenance, or upgrades to built assets, protection measures for natural areas, etc.

In cases where hazard exposure cannot be reduced, managing climate risk is accomplished primarily through reducing vulnerability (e.g., reducing sensitivity or increasing adaptive capacity). The federal government utilizes the following high-level resilience principles for the integration of climate resilience considerations to projects of all scales, as shown in **Figure B-1**.

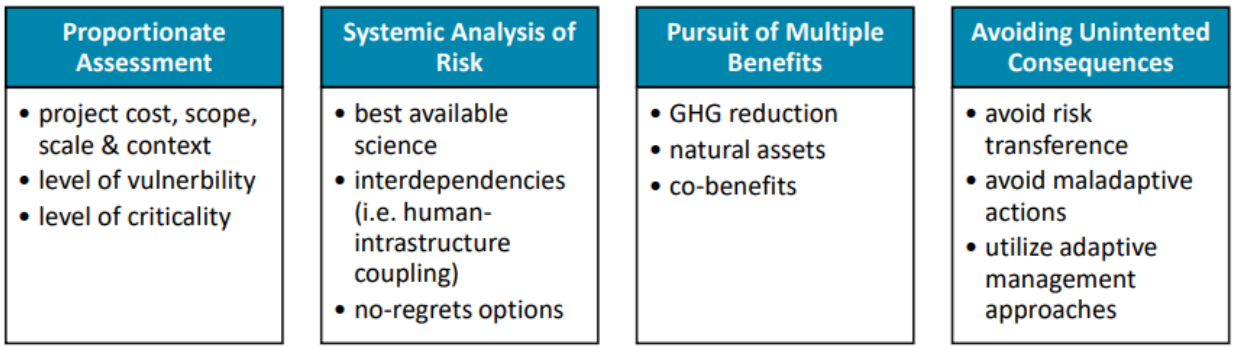

Figure B-1: Climate Resilience Principles

The Process

Practitioners of the risk assessment process ask the following questions and follow the step-by-step process below to complete a climate risk and resilience (ICLR, 2016), as shown in **Figure B3-2**.

What can happen? Hazard Analysis

- **Step 1: Define Infrastructure –** The project team reviewed the assets which make up the infrastructure relevant to the project (**The Risk Assessment Process**);
- **Step 2: Hazard Identification –** This step considers potential climate hazards that are pertinent to the project, all of which have been identified in **Appendix A** by the City's provided climate

profile data. These hazards are the interactions between the climatic events and components of infrastructure (**Section 3.1.2**); and

- **Step 3: Interaction Analysis –** Once the climate and component analyses have been completed, a list of interactions between the climatic events and infrastructure components was developed by the Assessment Team (**Section 3.1.3**). At this stage, as part of this process, several hazards will fall into a category that is considered non-applicable or are deemed unlikely to occur. For these climate hazard/component interactions pairings where an impact response is not expected to occur (the component is not sensitive to climate), these items are then screened out of further consideration in the risk assessment. In this way, only the interactions anticipated to generate a climate response are carried forward for further analysis.

How is it likely to happen? Likelihood Analysis

- **Step 4:** For each climate hazard, the likelihood of occurrence is defined in the City's supplied climate hazard data as an input to the equation to determine risk level for assessed impacts. Likelihoods can be assigned per infrastructure element (e.g., a major stormwater management system would be overwhelmed by a different amount of water than minor stormwater management system) or applied on a broad scale across the various infrastructure pieces. A summary of the likelihood of events for climate hazards occurring in Calgary is provided in **Table A-1**, and a full likelihood analysis for various climate indicators is provided in **Appendix C** with likelihoods specified by the City across its adopted five-point Likelihood Scale (1 to 5).

Given what occurred, what are the consequences of the impact? Consequence Analysis

- **Step 5:** Once the hazard and likelihood analyses are completed, severity of impact consequences can be assessed, scored, and assigned to the interactions based on historical data, statistics, guidance, or professional judgement. Consequences were assigned using a five-point rating scale defined by the City's process, based on the consequence table scoring framework provided in **Table 3-5**. In accordance with Best Practice (ISO 31000), the Assessment Team considered the consequence of events occurring to be independent from the likelihood scores (also defined by a five-point rating scale developed by the City).

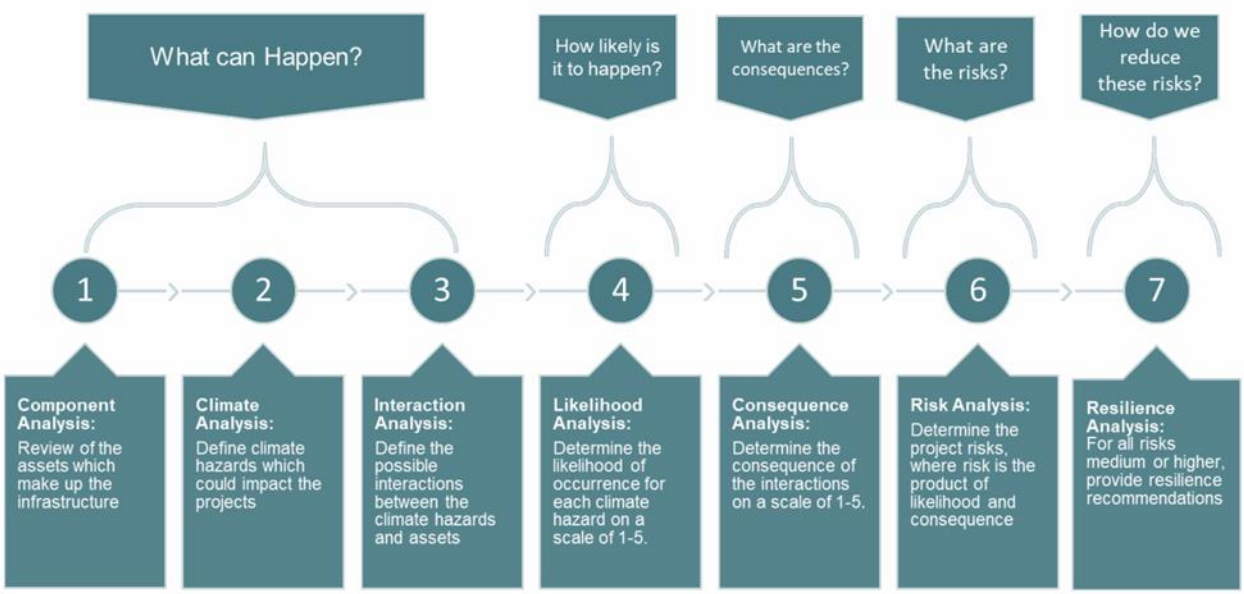

Figure B-2: The Assessment Process

Appendix C

City of Calgary Climate Indicators and Likelihood Scores

Climate Hazard	Climate Indicator	Time Period	Likelihood			Occurrences		
			Baseline	2050s	2080s	Baseline	2050s	2080s
Extreme Heat	Heatwaves [1,2]	Annual	3	5	5	0.2	3.0	7.1
	July 2.5% Design Temperature [3]	Annual	3	4	4	28.0	32.2	34.8
	Hot days[4]	Annual	3	5	5	6.8	26.5	48.1
Increased Air Temperature	Heating degree days (HDD) > 5000 [5,6]	Annual	3	2	2	4,958.7	3981.8	3411.5
	Cooling degree days (CDD) [7]	Annual	3	5	5	46.1	201.7	401.3
	Freeze-thaw cycles	Annual	3	2	2	107.4	83.5	64.1
	Freeze-thaw cycles	Winter	3	3	3	43.5	43.8	39.5
Wildfires	Fire spread days [8]	Annual	2	4	4	3.0	5.5	5.7
Drought	Dry spells [9,10]	Annual	3	3	3	5.9	6.0	6.0
	Dry days [9]	Annual	3	3	3	296.2	296.7	296.8
	Drought days [11]	Annual	3	4	4	63.9	75.6	83.8
	2-week drought [12]	Annual	4	5	5	0.7	0.9	1.0
	Longest dry spell	Annual	3	3	3	36	36	36
SDHI Summer Rainfall	15 min rainfall > 23 mm [6,13]	Annual	4	5	5	0.8	1.0	1.0
	50 mm/1hr [2,13]	Annual	1	4	5	0.1	0.8	1.0
	24 hr rainfall > 103 mm [13,14]	Annual	2	4	5	0.3	0.8	1.0
Severe Storms (Hail, Tornadoes)	Days with convective events (thunderstorms) [15]	Annual	3	4	5	22.9	34.7	39.9
High Winds	Days where max wind gust > 90 km/hr [2]	Annual	3	3	2	2.0	1.8	1.6
River Flooding	1:100-year flooding [16]	Annual	2	3	3	-	-	-
Heavy Snowfall	10 cm of snow in 12 hours or less [2]	Annual	3	1	1	0.90	0.20	0.20
	Mean winter snowfall	Winter	3	3	2	28.7	27.1	25.6
	Mean annual snowfall	Annual	3	2	2	93.6	62.0	51.8
	Annual maximum snow load (cm) exceeding 1:50 year storm for ground snow [6,17]	Annual	2	1	1	32.5	17.20	13.2

Notes:

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 entire 55-year historical time series.
4. Hot days are defined as maximum temperature ≥ 29°C.
5. Heating Degree Days (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. Cooling Degree Days (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 (*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 to 2010).

Appendix D

Summary Risk Scores, CRRA Summary Worksheets

Table D1: Extreme Heat (Heat Waves)

ASSET AFFECTED			IMPACT DESCRIPTION	CONSEQUENCE TYPE	RISK SCORE		
					Present	2050s	2080s
CFD Specific Functions		*Operations Unique to CFD*	Minor Delay in work	Functionality	6	10	10
Construction Activities		*Construction Activities*	Minor Delay in work	Functionality	6	10	10
Decommissioning Phase		*Demolition*	Minor Delay in work	Functionality	6	10	10
Operations and Maintenance Phase		*Operations, Maintenance, and Inspection*	Minor Delay in work	Functionality	6	10	10
Building Infrastructure	**Mechanical Systems**	*HVAC – Cooling System*	HVAC Cooling capacity may be exceeded leading to health impacts, cooling cost impacts, higher energy demand, increased maintenance.	Functionality	9	15	15
	Envelope	*Roof and Membrane*	Additional weathering stress – wear and tear	Structural Integrity	6	10	10
		Exterior Cladding/Siding	Weathering, impacts to seals	Structural Integrity	6	10	10
		Windows and Doors	Weathering, impacts to seals	Structural Integrity	6	10	10
	Electrical Systems	*Electric Panel, Controls*	Under extreme heat, components in access systems can fail	Functionality	6	10	10
		Emergency Power System(s)	High heat and poor airflow can lead to generator overheating. EPS located inside on ground floor in Floorplan – assuming adequate ventilation for heat exhaust.	Functionality	6	10	10
		Communications Systems	Under extreme heat, components in communications infrastructure may be damaged	Functionality	6	10	10
		Access and Security Systems (FOBs, access, CCTV)	Under extreme heat, components in access systems can fail	Functionality	6	10	10
Human Wellbeing		*Construction Personnel*	Risk of heat-related illnesses (e.g., heat stroke)	Health & Safety	9	15	15
		Staff (CFD's and Library's), Library Patrons, Contractors, etc.	Risk of heat-related illnesses (e.g., heat stroke)	Health & Safety	9	15	15
		O&M Personnel	Risk of heat-related illnesses (e.g., heat stroke)	Health & Safety	6	10	10
Natural Infrastructure		*Soft Landscaping (Green Infrastructure)*	Damage to lawns and trees	Structural Integrity	6	10	10
		Ecosystem and Diversity	Decreased survivability of plants and animals	Structural Integrity	6	10	10
Site Infrastructure	**Site Access**	*Asphalt Pavements*	Increased maintenance - softening of surfaces - can lead to deformation and ponding	Structural Integrity	6	10	10
			Deformations, rutting lead to safety issues	Functionality	6	10	10
		Concrete Pavements	Buckling of concrete pavements – "Heat Explosion"	Structural Integrity	6	10	10
			Buckling of sidewalks can pose a hazard for accessibility.	Functionality	3	5	5
	Site Features	*Hard Landscaping (Community Spaces)*	Increased maintenance – softening of surfaces – can lead to deformation and ponding	Functionality	6	10	10
Critical Third Party		*Electrical Utility Connection*	No impacts from heat due to connection but potential impacts to the grid are likely	Functionality	6	10	10
		Communications/ Data Utility Connections	Potential for heat-induced failure if the room is not climate controlled	Functionality	6	10	10

Table D2: Increased Air Temperature (Cooling Degree Days)

ASSET AFFECTED			IMPACT DESCRIPTION	CONSEQUENCE TYPE	RISK SCORE		
					Present	2050s	2080s
Building Infrastructure	**Mechanical Systems**	HVAC - Cooling System	*Impacts focus on Library, as CFD engineering guidelines call for higher spec AC. Assuming Library is lighter duty AC vs CFD AC (CFD is higher duty AC - designed as post-disaster building, must consider future temp regimes*)	Functionality	9	15	15
Natural Infrastructure		Soft Landscaping (Green Infrastructure)	*Damage to vegetation and reduced tree health (e.g., loss of leaves and shade)*	Functionality	6	10	10
		Ecosystem and Diversity	*Damage to vegetation and reduced tree health (e.g., loss of leaves and shade)*	Functionality	3	5	5
Site Infrastructure	**Stormwater Management**	Site Drainage	*Blockage of drainage assets can lead to localized flooding and would require clearing. Possible increase from regular maintenance*	Functionality	6	10	10

Table D3: Wildfire (Fire Spread Days)

ASSET AFFECTED			IMPACT DESCRIPTION	CONSEQUENCE TYPE	RISK SCORE		
					Present	2050s	2080s
CFD Specific Functions		*Operations Unique to CFD*	*Delays in operations due to risk of smoke inhalation, reduced visibility*	Functionality	6	12	12
Construction Activities		*Construction Activities*	*Delays in operations due to risk of smoke inhalation, reduced visibility*	Functionality	6	12	12
Decommissioning Phase		*Demolition*	*Risk of smoke inhalation, reduced visibility*	Functionality	6	12	12
Operations and Maintenance Phase		*Operations, Maintenance, and Inspection*	*Delays in operations due to risk of smoke inhalation, reduced visibility*	Functionality	6	12	12
Building Infrastructure	**Mechanical Systems**	*HVAC – Ventilation/Air Handling System*	*Risk of smoke inhalation - Reduced efficiency and higher maintenance*	Functionality	6	12	12
	Electrical Systems	*Access & Security Systems (FOBs, CCTV)*	*Potential impact of smoke, particularly the haze on CCTV outside the building*	Functionality	4	8	8
Human Well-Being		*Construction Personnel*	*Risk of smoke inhalation High smoke events can exacerbate respiratory problems for vulnerable populations (e.g., old and young populations, people with pre-existing respiratory conditions)*	Health & Safety	6	12	12
		O&M Personnel	*Risk of smoke inhalation High smoke events can exacerbate respiratory problems for vulnerable populations*	Health & Safety	6	12	12
		Staff (CFD's & Library's), Library Patrons, Contractors, etc.	*Risk of smoke inhalation High smoke events can exacerbate respiratory problems for vulnerable populations*	Health & Safety	6	12	12
Site Infrastructure	**Electrical**	*Grid Power*	*Potential wildfire impact to grid*	Functionality	4	8	8

Table D4: Drought (Two-Week Drought)

ASSET AFFECTED			IMPACT DESCRIPTION	CONSEQUENCE TYPE	RISK SCORE		
					Present	2050s	2080s
CFD Specific Functions		*Operations Unique to CFD*	Water demand and management impacts	Functionality	8	10	10
Operations and Maintenance Phase		*Operations, Maintenance, and Inspection*	Minor increase in maintenance due to prolonged drought	Functionality	4	5	5
Building Infrastructure	**Structural**	*Building Substructure*	Degradation of soil impacting foundations	Structural Integrity	8	10	10
		Building Superstructure	Increased risk of cracks or uneven settling due to soil shrinkage	Structural Integrity	4	5	5
Natural Infrastructure		*Soft Landscaping (Green Infrastructure)*	Extended periods of drought can lead to tree health decline and increase in tree mortality	Structural Integrity	8	10	10
		Ecosystem and Diversity	Unless the plant species are selected for higher ranges in temp, potential for reduced diversity and ecosystem impacts (e.g., invasive species)	Structural Integrity	8	10	10

Table D5: SDHI Rainfall (24 hr Rainfall > 103 mm)

ASSET AFFECTED			IMPACT DESCRIPTION	CONSEQUENCE TYPE	RISK SCORE		
					Present	2050s	2080s
CFD Specific Functions		*Operations Unique to CFD*	Task Delays	Functionality	4	8	10
Construction Activities		*Construction Activities*	Potential for some brief delay in construction - rain induced delay, pump out, etc.	Functionality	4	8	10
Operations and Maintenance Phase		*Operations, Maintenance, and Inspection*	Increased maintenance on pre and post maintenance efforts	Functionality	4	8	10
Decommissioning Phase		*Demolition*	Site drainage impsupersacts and temporary disruptions to demolition process	Functionality	4	8	10
Building Infrastructure	**Electrical Systems**	*Communications Systems*	Experience disruptions due to water intrusion, located indoors.	Functionality	4	8	10
		Access & Security Systems (FOBs, CCTV)	Disruptions from water intrusion	Functionality	4	8	10
		Emergency Power System(s)	Risk driven by location. EPS is located in generator room in CFD Bldg. Library has no EPS requirement.	Functionality	2	4	5
	Envelope	*Roof and Membrane*	Potential for water infiltration and damage to seals	Structural Integrity	6	12	15
		Exterior Cladding/Siding	Potential for wind-driven rain intrusion	Structural Integrity	4	8	10
		Windows & Doors	Potential for wind-driven rain intrusion	Structural Integrity	4	8	10
		CFD Truck Bay Doors (x2)	Potential for wind-driven rain intrusion	Structural Integrity	4	8	10
	Mechanical Systems	*Plumbing*	Minor disruption in function	Functionality	4	8	10
	Structural	*Building Substructure*	Increased potential for damage through water related infiltration and corrosion	Structural Integrity	4	8	10
		Building Superstructure	Minimal superstructure impacts are anticipated unless water is not allowed to drain from roof surfaces	Structural Integrity	4	8	10
Human Well-Being		*Construction Personnel*	Minor impacts to tasks and site access	Functionality	2	4	5
		O&M Personnel	Minor impacts to tasks and site access	Functionality	2	4	5
		Staff (CFD's & Library's), Library Patrons, Contractors, etc.	Impacts to accessibility of site and building	Functionality	2	4	5
Natural Infrastructure		*Soft Landscaping (Green Infrastructure)*	Potential for erosion of soil, some vegetation, and more maintenance	Structural Integrity	2	4	5
Site Infrastructure	**Site Access**	*Asphalt Pavements*	Potential flooding of pavements	Functionality	2	4	5
		Concrete Pavements	Potential flooding of pavements	Functionality	2	4	5
	Site Features	*Hard Landscaping (Community Spaces)*	Potential flooding of pavements	Functionality	2	4	5
	Stormwater Management	*Roof Drainage*	Potential for stored water on the roof, intrusion damages	Structural Integrity	6	12	15
		Oil & Grit Separator	Increased loading may lead to faster rate of overloading or wear and tear	Functionality	4	8	10
		Site Drainage	Blockage of drainage assets	Functionality	4	8	10
Critical Third-Party Infrastructure		*Sanitary Sewer Connection*	Heavy rain has a possibility to overwhelm drainage assets	Functionality	2	4	5
		Communications/ Data Utility Connections	Water intrusion – assuming underground	Functionality	2	4	5

Table D6: Severe Storms (Hail, Tornadoes, Days with Convection Events – Thunderstorms)

ASSET AFFECTED			IMPACT DESCRIPTION	CONSEQUENCE TYPE	RISK SCORE		
					Present	2050s	2080s
CFD Specific Functions		*Operations Unique to CFD*	Task delays	Functionality	9	12	15
Construction Phase		*Construction Activities*	Potential for delays or disruptions until the storms pass	Functionality	6	8	10
Decommissioning Phase		*Demolition*	Potential for delays or disruptions until the storms pass	Functionality	6	8	10
Operations and Maintenance Phase		*Operations, Maintenance, and Inspection*	Potential for delays or disruptions until the storms pass	Functionality	6	8	10
Building Infrastructure	**Electrical Systems**	*Exterior Lighting (fixed on Building)*	Potential for damage due to debris subject to wind power outages	Functionality	6	8	10
		Access & Security Systems (FOBs, CCTV)	Potential for damage due to debris subject to wind power outages	Functionality	6	8	10
		Communications Systems	Subject to wind, power outages – assumes EPS activates	Functionality	3	4	5
	Envelope	*Roof and Membrane*	Potential for wind and debris driven roof damage	Structural Integrity	6	8	10
		Exterior Cladding/Siding	Potential for wind and debris driven damage	Structural Integrity	6	8	10
		Windows & Doors	Potential for wind and debris driven damage	Structural Integrity	6	8	10
		CFD Truck Bay Doors (x2)	Potential for wind and debris driven damage	Structural Integrity	6	8	10
Human Well-being		*Staff (CFD's & Library's), Library Patrons, Contractors, etc.*	Increased risk of injury, delays in task	Health & Safety	6	8	10
		Construction Personnel	Increased risk of injury, delays in task	Health & Safety	6	8	10
		O&M Personnel	Increased risk of injury, delays in task	Health & Safety	6	8	10
Natural Infrastructure		*Soft Landscaping (Green Infrastructure)*	Potential for damage	Structural Integrity	9	12	15
Site Infrastructure	**Electrical**	*Grid Power*	Exposed power lines subject to damage from winds, (tree) limb fall, and debris – assumed buried electrical services	Functionality	6	8	10
	Site Access	*Asphalt Pavements*	Potential for localised ponding, accessibility with respect to pedestrians	Structural Integrity	6	8	10
		Concrete Pavements	Potential for localised ponding, accessibility with respect to pedestrians	Structural Integrity	6	8	10
	Site Features	*Class 2 Bike Racks*	Post storm inspection for any damage or presence of windswept debris	Structural Integrity	6	8	10
		Hard Landscaping (Community Spaces)	Maintenance post storm	Functionality	6	8	10
		Fencing	Post storm inspection for any damage or presence of windswept debris	Structural Integrity	6	8	10
		Erected Signage	Response to address potential minor damage	Structural Integrity	3	4	5
	Stormwater Management	*Roof Drainage*	Potential for drainage blockages due to debris and hail	Structural Integrity	6	8	10
		Oil & Grit Separator	Maintenance	Functionality	6	8	10
		Site Drainage	Maintenance - functionality is impaired as it can block drainage assets	Functionality	6	8	10
Critical Third-Party Infrastructure		*Electrical Utility Connection*	Power connections are buried and CFD building has backup power with 7 day capacity. Library building may see impacts due to loss in power.	Functionality	6	8	10
		Communications/Data Utility Connections	Potential impacts due to hail, lightning, wind, and water	Functionality	6	8	10

Table D7: High Winds (Gusts > 90 km/hr)

IMPACT THEME SYSTEM PROJECT ASSET/COMPONENT			IMPACT DESCRIPTION	CONSEQUENCE TYPE	RISK SCORE		
					Present	2050s	2080s
CFD Specific Functions		*Operations Unique to CFD*	Expected to also trigger increase in demand for CFD services.	Functionality	9	9	6
Construction Activities		*Construction Activities*	Delay to construction activities	Functionality	9	9	6
Decommissioning Phase		*Demolition*	Potential for delays to demolition tasks	Functionality	9	9	6
Operations and Maintenance Phase		*Operations, Maintenance, and Inspection*[1]	Increase in time required to complete O&M tasks, also triggers additional O&M burdens to respond/maintain	Functionality	9	9	6
Human Wellbeing		*Staff (CFD's & Library's), Library Patrons, Contractors, etc.*	Windswept debris can injure people, potential access issues if debris is airborne, cars may be damaged	Health & Safety	9	9	6
		Maintenance Personnel[2]	Windswept debris can injure O&M personnel	Health & Safety	9	9	6
Natural Infrastructure		*Soft Landscaping (Green Infrastructure)*	Increased maintenance to restore green infra after wind events	Functionality	9	9	6
Site Infrastructure	**Stormwater Management**	*Site Drainage*	More prone to blockages through debris or leaves compared to the roof	Functionality	9	9	6
Critical Third-Party Infrastructure		*Electrical Utility Connection*	Power connections are buried and CFD building has EPS (7 Days). Library building may see impacts due to loss in power.	Functionality	9	9	6

Table D8: River Flooding (1:100-year Flood)

ASSET AFFECTED		IMPACT DESCRIPTION	CONSEQUENCE TYPE	RISK SCORE		
				Present	2050s	2080s
CFD Specific Functions	*Operations Unique to CFD*	Highly disruptive if a flood ever affected them at this site	Functionality	6	9	9
Critical Third-Party Infrastructure	*Electrical Utility Connection*	Service disruptions expected during flood events, some restoration effort required	Functionality	6	9	9
	Domestic Water Supply Utility Connection	Service disruptions expected during flood events, some restoration effort required	Functionality	6	9	9
	Sanitary Sewer Connection	Service disruptions expected during flood events, some restoration effort required	Functionality	6	9	9
	Communications/Data Utility Connections	Service disruptions expected during flood events, some restoration effort required	Functionality	6	9	9

Table D9: Heavy Snowfall (Mean Winter Snowfall)

ASSET AFFECTED			IMPACT DESCRIPTION	CONSEQUENCE TYPE	RISK SCORE		
					Present	2050s	2080s
CFD Specific Functions		*Operations Unique to CFD*	Delays in response and increased demand for CFD services (All-hazards response)	Functionality	9	9	6
Building Infrastructure	**Envelope**	*Roof and Membrane*	Warmer snow seasons and rain on snow events may increase loads to roof and membrane. Roof damages and repair, interior damages	Structural Integrity	9	9	6
Human Well-being		*Staff (CFD's & Library's), Library Patrons, Contractors, etc.*	Increased risk of slips, trips, and falls, reduced access	Health & Safety	9	9	6

[1] *"Operations, Maintenance, and Inspection" refers to the services being conducted by the maintenance personnel.*

[2] *"Maintenance Personnel" refers to the health & safety of the people separate of the services or work being completed.*

Appendix E

MURAL Interested Party Inputs

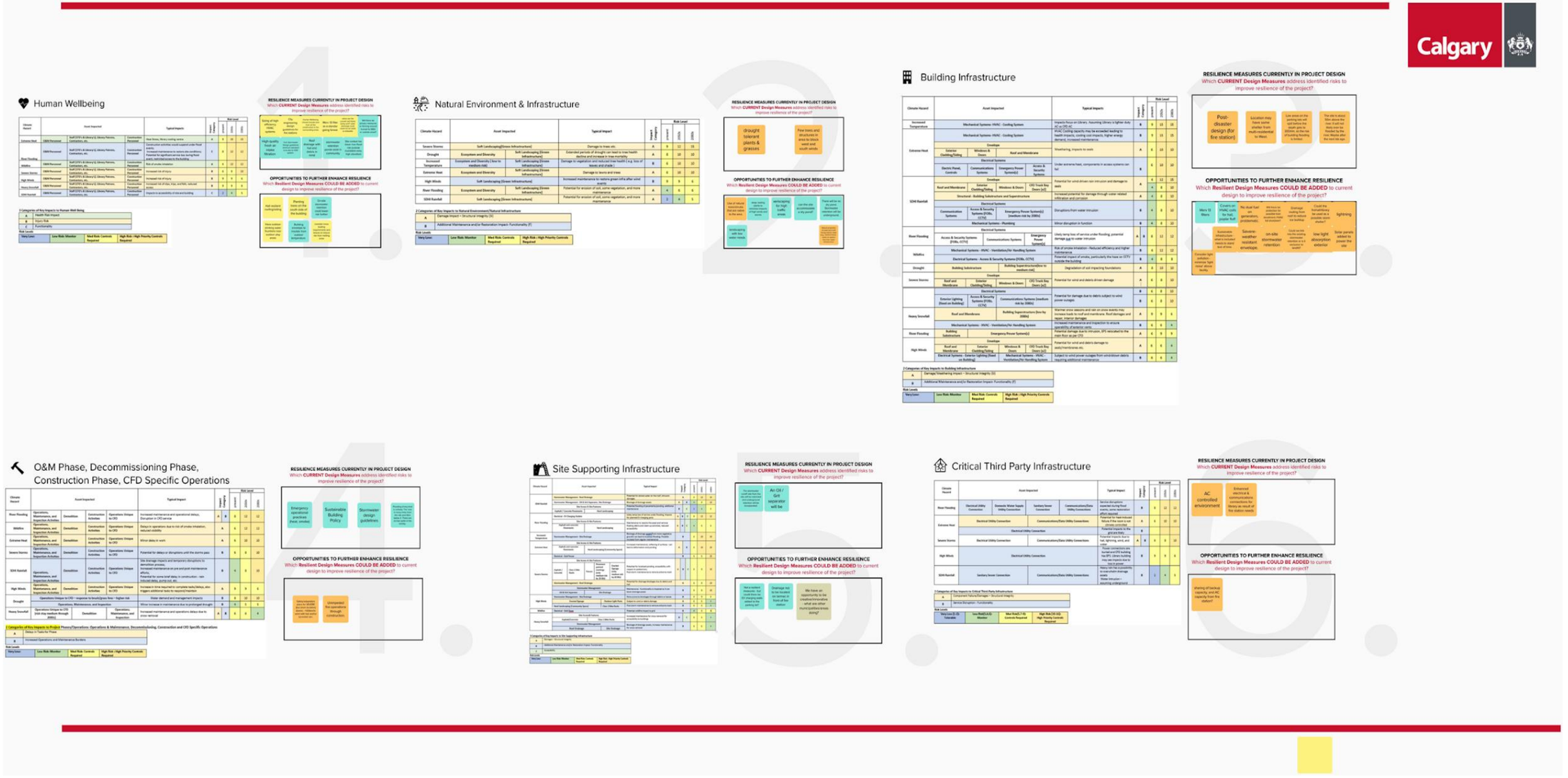

Figure E1: MURAL Board Adaptation Option Workshop Inputs

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