DILLON CONSULTING

CITY OF CALGARY

Marda Loop Climate Change Risk Assessment

Final Report

June 2022 – 22-3553

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The City of Calgary
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Attention: Pippa Cookson-Hills, M.Sc.
Project Manager

Climate Risk/Resilience Assessment for Marda Loop Main Streets Streetscape Master Plan Improvements – DRAFT Final Report

The City of Calgary (the City) intends to execute a Marda Loop Main Streetscape Master Plan intended to provide integration and alignment between public spaces, businesses and people within the 33rd and 34th Avenues SW. This program, referred to in this document as the Marda Loop Project (the Project) will address the need for improved pedestrian environments, safety, community space, connections and enhanced landscaping. Changes in the streetscape will include design changes for pedestrian safety, enhanced interaction between modes of mobility, new place-making opportunities, addition of trees and furnishing for user comfort, design to support local businesses, connections to park spaces and amenities and transit and laneway access improvements.

Dillon Consulting Limited (Dillon) was retained to complete a Climate Risk/Resilience Assessment (CCRA) for the Marda Loop Project. Dillon is pleased to provide this report describing the City of Calgary-prescribed approach applied for the CCRA and a summary of results and recommendations for additional climate adaptation measures for the City's consideration and possible implementation for the Marda Loop Project.

The CCRA process involved multiple rounds of workshop engagement involving staff from the City of Calgary, the City's design consultant for the Marda Loop infrastructure and related elements and staff from the Dillon Climate Resilience Team. We would like to express our gratitude to the staff on the City of Calgary's project team, including the technical workshop participants.

Sincerely,

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Table of Contents

Acronyms, Abbreviations, Definitions

Executive Summary

1.0 Calgary Climate Profile 1

2.0 Project Context 2

2.1 Project Overview 2
2.2 Areas of Assessment 3
2.2.1 Built Infrastructure 4
2.2.2 Natural Environment 4
2.2.3 Human Well-being 5
2.2.4 Critical Third-Party Infrastructure 5
2.3 Validation Workshop 5

3.0 Public Infrastructure Climate Risk Assessment 7

3.1 Hazard Analysis 7
3.1.1 Step 1 – Component Analysis 7
3.1.2 Step 2 – Climate Analysis 8
3.1.3 Step 3 – Impact Analysis 8
3.2 Step 4 – Likelihood Analysis 17
3.3 Step 5 – Consequence Analysis 18
3.4 Step 6 – Risk Analysis 19
3.4.1 Yes/No Analysis 19
3.5 Step 7 – Resilience Analysis 22
3.6 Return on Investment (ROI) for Selected Adaptation Options 29
3.6.1 Identifying and Selecting Adaptation Options: Process 29
3.6.2 Return on Investment Assessment of Selected Adaptation Options 29
3.6.3 High Level ROI Recommendations for Selected Resilience Options 31

Figures

Figure 2-1: Marda Loop Streetscape Project Study Area 3
Figure A3-1: Average convective precipitation events and convective conditions per month at the Calgary International Airport (historical, 2050s and 2080s) 12
Figure B3-2: Climate Resilience Principles 3
Figure B3-3: The Assessment Process 5

Tables

Table 2-1: Built Infrastructure Assets 4
Table 2-3: Natural Environment Assets 5
Table 2-4: Human Well-Being Considerations 5
Table 2-5: Critical Third-Party Infrastructure Assets 5
Table 3-1: Infrastructure under Assessment 7
Table 3-2: Potential Climate Related Impacts (H&S: health and safety, SI: structural integrity, F: functionality) 9
Table 3-3: Likelihood of Impact 18
Table 3-4: Climate Hazard Likelihood Rating Summary 18
Table 3-5: Consequence Classification Matrix 19
Table 3-6: Risk Classification Matrix 19
Table 3-7: Yes/No Analysis 21
Table 3-8: Validated Risk Scores: Climate Impacts and Risk Levels across Present and Future Climate Conditions for the Marda Loop Project 22
Table 3-9: Resilience Measures 23
Table 3-10: Summary Listing of Loss Types 31
Table A3-11: Summary of climate hazard trends for the City of Calgary 3
Table A3-12: Summary of extreme climate projected temperature indicators for Calgary 4
Table A3-13: Summary of climate projected temperature indicators for Calgary 6
Table A3-14: Wildfire Occurrences 7
Table A3-15: Indicators of Meteorological Drought Driven by Climate Projections for Calgary 8
Table A3-16: Baseline IDF of Rainfall Estimates (mm) for the Calgary International Airport 10
Table A3-17: 2050s Climate Adjusted IDF of Rainfall Estimates (mm) for the Calgary International Airport 10
Table A3-18: 2080s Climate Adjusted IDF of Rainfall Estimates (mm) for the Calgary International Airport 10
Table A3-19: Summary of climate projected increase in rainfall IDF for Calgary 11
Table A3-20: Summary of climate projected rainfall for Calgary 11
Table A3-21: Summary of climate projected severe storms for Calgary 12
Table A3-22: Summary of climate projected wind gusts for Calgary 13
Table A3-23: River flooding return periods, flow rates and probability 15
Table A3-24: Summary of climate projected snowfall for Calgary 16

Appendices

A Calgary Climate Profile

B Calgary's Climate Risk Assessment Process

C City of Calgary Climate Indicators and Likelihood Scores

D Workshop-Validated Summary Risk Scores, CRRA Summary Worksheet

References

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".
BRBS	Bow River Basin Study
CBA	Cost Benefit Analysis
CCRA	Climate Change Risk/Resilience Assessment
CoC	The City of Calgary
CAPE	Convective Available Potential Energy
CDD	Cooling Degree Days
ECCC	Environment Climate Change Canada
F	Functionality
GCM	Global Climate Model
GHG	Greenhouse Gasses
H & S	Health and Safety
HDD	Heating Degree Days
ICLR	Institute for Catastrophic Loss Reduction (PIEVC framework owner)
IDF	Intensity Duration Frequency
LID	Low Impact Development
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)
SWBRT	Southwest Bus Rapid Transit
SI	Structural Integrity
SOP	Standard Operating Procedure

Executive Summary

Project Context

The City of Calgary's Marda Loop Streetscape Project refers to the transportation project involving the design, construction, operation and maintenance of updates to the Marda Loop Main Streets, 33rd Avenue and 34th Avenue (the Project) from Crowchild Trail to 14th Street SW. The project includes two (2) zones: the 33rd Avenue portion of the project which is at 60% design and the 34th Avenue portion of the project which is in an earlier design stage.

CCRA Process

This document reports on the Climate Risk and Resilience Assessment (the Assessment) process conducted for of the Marda Loop Streetscape Project and is a process commissioned by the City of Calgary (the City) for its development projects with goals of reducing life cycle project risk and providing the decision-support information that fosters improved decision-making during project planning and design phases.

The City has developed a seven (7) step process (Figure B3-3, Section 0) which includes climate risk assessment in alignment with the City's existing Integrated Risk Management Framework to identify, analyse and evaluate risk. The Climate Change Risk/Resilience Assessment (CCRA) documented within this report followed Calgary's prescribed CCRA 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 Marda Loop Streetscape Project.

Results from the resilience assessment are intended to identify and recommend opportunities to reduce risk and enhance resilience to climate hazards for features proposed within the Marda Loop Streetscape development. The CCRA considered project design choices and climate risks during the construction, 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 Marda Loop Project's community infrastructure. Once potential adaptation options were explored, a selection of adaptations options was made to identify only risk reduction measures deemed feasible for additional consideration. This list of recommended adaptation options was provided to the City for their consideration and for selection of preferred options for Return-On-Investment Analysis. Adaptation options approved for further consideration then were to undergo assessment for economic feasibility through a high-level analysis. The Return-On-Investment Analysis was to be developed using costing data provided by the City and its design consultant for the Marda Loop improvements. Following the City's approval of selected options, the City's staff and design team sought costing details identified

by Dillon Consulting Limited (Dillon) for each selected adaptation option. In early June, the City indicated that while data is being assembled to describe avoided loss costs (losses avoided from applying an adaptation option), this effort will not be complete this year. Data required for the ROI analysis would be available, but not until 2023. Due to this data limitation, the City asked Dillon to develop a high-level, qualitative evaluation of ROI. In response, Dillon has prepared a discussion that compares Potential Return-On-Investment between the six (6) adaptation options selected by the City.

Workshops and Validation Process

Following completion of Steps 1 through 4 of the City's Assessment Process (Figure B3-3, Section 0), a set of internal, preliminary technical workshops were convened with members of Dillon's assessment team. The internal workshops were held on March 11 and March 16, 2022. Following the two (2) internal workshop sessions, the workshop results were assembled and summarised as preliminary results to review and discuss in the Validation Workshop process with the City and its design consultants. A summary information package was developed to provide Validation Workshop participants with details on the Marda Loop project elements, Calgary's climate, Marda Loop's infrastructure and related project elements, the risk assessment criteria and preliminary risk level scores for Marda Loop project elements. The Validation Workshop Participant Information Package was issued in PDF format on
Friday, April 1, 2022, in advance of the two (2) hour Validation Workshop session held on Tuesday, April 5, 2022. In the Validation Workshop, each climate hazard was reviewed, and its scored risk levels discussed for validation. In this process, workshop participants provided inputs that both confirmed and modified some preliminary scoring of impacts. A two (2) hour workshop session was dedicated to the validation of risk scores for identified impacts. At the end of the Validation Process, all inputs received were factored into the final rating assigned to each climate/infrastructure interaction, leading to a consensus score achieved for each impact driven by applicable climate hazards specified within the City's CCRA Process documentation.

Opportunities to Enhance Resilience

A third workshop hour was scheduled on April 20, 2022, to cover the Adaptation/Resilience option considerations for the Marda Loop project. In this hour-long virtual session convened via ZOOM and MURAL, workshop participants from the City and its design team engaged with Dillon's assessment team to identify and explore existing resilience measures inherent in the Marda Loop Project's current design and new adaptation measures that could be considered for implementation to enhance climate resilience for the project. Following this final workshop session, the assessment team processed the received inputs from participants and developed recommendations for adaptation options for the City's consideration.

ROI and Final Reporting

After high-level Return-On-Investment considerations for the selected adaptation options were completed, CCRA reporting was completed and submitted to City for review. Following the City's review, this report will be finalised after reviewer inputs are processed.

1.0 Calgary Climate Profile

Calgary's climate is expected to change in the coming decades (Climate Atlas of Canada, City of Calgary Summary Report, 2019) 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 detail within Appendix A.

2.0 Project Context

2.1 Project Overview

This climate change impact assessment is for the 33rd and 34th Avenues SW (Marda Loop) Streetscape Project, defined by the 33rd and 34th Avenues SW from Crowchild Trail SW to 14th Street SW. This redevelopment project is a component of the City's "Main Streets Program", focused on improved accessibility, safety and beautification.

The study area currently services the neighborhoods of South Calgary, Marda Loop, Garrison Woods, Altadore and Richmond/Knob Hill but is quickly becoming a regional destination. Since the redevelopment of Garrison Woods in 2004, the community has intensified with a growing number of infill housing units, duplexes, small condos (four (4) to six (6) stories) and row housing. With most of the residents of the surrounding areas finding their daily needs within the commercial offerings of the project boundary; Marda Loop has begun to define itself as a trendy destination that offers a vibrant retail and commercial environment and a diversity of options to live and work in the community. These diverse housing and retail types have attracted new residents to the community, including young families, business professionals and university students. In response to changing demographics and the efforts of the Business Improvement Area (BIA), new retail opportunities have been established on 33rd and 34th Avenues SW and plans for future development expansion continues within the area. This has made the area one of the most popular locations in Calgary and as a result, the Marda Loop area is seeing a resurgence of both residential and commercial development.

The five (5) goals of the Marda Loop Streetscape Project are to:

1. Prioritize the pedestrian;
2. Enhance landscaping to support pedestrian comfort;
3. Develop unique streetscape elements that clearly announce the Marda Loop Main Street as a destination within Calgary;
4. Provide new opportunities for community gathering space; and
5. Improve mobility by providing safe circulation of all modes.

To accomplish these goals, several structural changes will be implemented including the creation of a street hierarchy controlling vehicle movement, the creation of designated bike lanes/pathways, greater transportation corridors for all transportation modes connecting the Marda Loop Streetscape to other neighbourhoods and a connection to the new Southwest Bus Rapid Transit (SWBRT) Station located on Crowchild Trail SW at 33rd Avenue SW. Construction for this project is slated to begin in 2023 and will likely extend to 2025. Design plans have not been finalized, and therefore the results of this assessment should be considered high level and generally applicable.

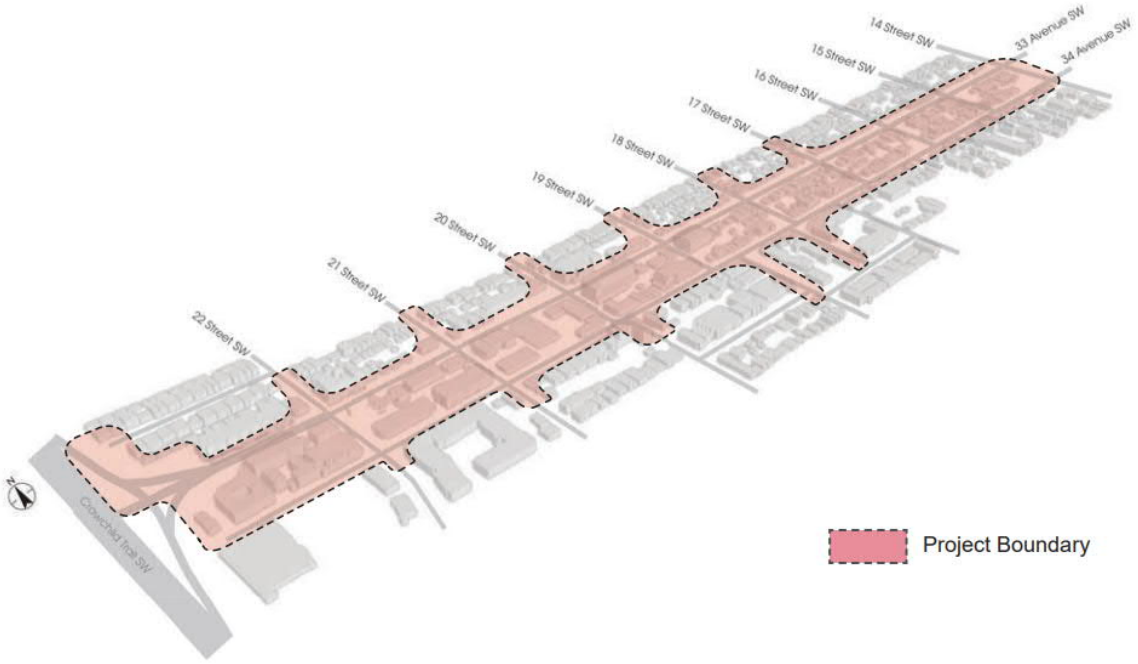

Figure 2-1: Marda Loop Streetscape Project Study Area

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 workshops. Specifically, a preliminary, internal consequence scoring workshop was held with the Dillon project team on March 11, 2022, then Validation Workshop sessions were hosted with the City and its design consultants on April 5, 2022 and April 20, 2022. This assessment 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 users of the Marda Loop Streetscape and operations personnel. This assessment also considers climate risks to construction personnel and equipment during the construction process.

This assessment is informed by the City's Public Infrastructure Climate Risk and Resilience Assessment (City of Calgary, 2021), the South Calgary Community Climate Risk Profile (City of Calgary, 2021), the 33rd and 34th Avenues SW Marda Loop Streetscape Master Plan (City of Calgary, 2019).

2.2 Areas of Assessment

The CCRA process was set up and completed with an approach to define project elements into four (4) key areas:

1. Built Infrastructure (roads, sidewalks, signage, multi-use lanes, lighting, street furnishings, etc.);
2. Natural Infrastructure (urban tree canopy, landscaping elements: planters, grasses and planted areas, etc.);

3. Human Well-being (health and safety considerations involving construction personnel, operations staff, staff working in the Marda Loop district and general users of the streetscape); and
4. Critical Third-Party Infrastructure (critical public infrastructure systems including overhead power lines, underground utilities and stormwater drainage systems).

Each of these four (4) areas are specified in the following sub-sections.

2.2.1 Built Infrastructure

The development of the Marda Loop Streetscape will involve the creation of new essential public infrastructure, along with the refurbishment/modification of existing public infrastructure. Built infrastructure assets (and in some cases asset groupings) within the project boundary that were included in the assessment are listed in Table 2-1.

Table 2-1: Built Infrastructure Assets

Asset	Comments
Construction Equipment	General category for all equipment used during construction phase
Sidewalks, Curbs	Covers all sidewalk pavements and curbs
Bike Lanes	Bike-specific pathways
Pathways	e.g., Multiuse paths
Street Lighting	City-operated Street and pedestrian lighting
Temporary Furnishings	Decorative lighting, heaters, fences, hanging planters
Road – asphalt	Including driving surface, surface drainage
Road – concrete	Driveway ramps, etc.
Utility Access Covers	Manholes, etc.
Signage	Commercial, construction and traffic signage
Traffic Lights	Traffic signals
Bus Stops and Shelters	Designated Calgary Transit Bus Stops and Transit Stop Shelters
Fixed Furnishings	Bicycle racks, benches, water fountains, pay stations
Tree Grates	Cast iron grates to protect tree root bulb zone at surface
Retaining Walls	Boundary elements within Marda streetscape at specific locations
Event Space (Festival Space)	General category for all equipment and purposes of the Festival Space
Fire Hydrants	Standard city-owned hydrant installations

2.2.2 Natural Environment

Climate change will impact both natural systems and existing and future green infrastructure. While no dedicated green space exists within the project boundary, the Marda Loop Main Street project will incorporate natural infrastructure by way of street trees, planters, pathway connections and more. 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 Assets

Asset	Comments
Trees	Street, Ornamental (either grated, in gardens, or in planters)
Landscaping	Lawns, footpaths, garden vegetation, flower beds

2.2.3 Human Well-being

Along with infrastructure, human well-being should be considered when assessing climate change risks, especially when portions of the community population are particularly vulnerable, as is the case in South Calgary (COC, 2021b). Table 2-3 outlines human wellbeing considerations for this assessment, based on the City of Calgary's framework.

Table 2-3: Human Well-Being Considerations

Asset	Comments
Construction Personnel	All personnel working to execute the project. It is expected that these personnel will have safe work practices in place
Operations Personnel	All personnel maintaining the project area during and after the construction period is complete. It is expected that these personnel with have safe work practices in place
Users	General users of the project area, including pedestrians, cyclists, motor vehicle drivers, those who work in the area and residents

2.2.4 Critical Third-Party Infrastructure

A critical consideration in assessing climate risks is the potential for secondary impacts due to damage to or loss of critical third-party infrastructure. Three (3) categories for third party infrastructure assets are included in Table 2-4.

Table 2-4: Critical Third-Party Infrastructure Assets

Asset	Comments
Overhead Power Lines	Located on 34th Avenue SW
Underground Utilities	ATCO gas, Telus/Shaw, underground power lines
Stormwater System	Includes catch basins, sanitary/storm/water lines

2.3 Validation Workshop

Following a data gathering and review process with the City and its project team, Dillon completed a preliminary climate risk assessment on March 11 and 14. This workshop was convened internally and results from this session were summarised and prepared as draft, preliminary results in preparation for the Validation Workshops convened with the City and its design team.

The stakeholder validation workshop was intended to be held during one (1) two (2) hour session from 2:00 to 4:00 p.m. MDT on April 5, 2022, to present the preliminary results of the risk assessment. Dillon requested a three (3) hour workshop for this activity; however, schedule conflicts prevented the selection of a three (3) hour block of time for this session. Dillon attempted to complete as much of the workshop agenda as possible within the available two (2) hour window. Due to a high amount of stimulating discussion, time ran out to complete the second segment of the workshop within the two (2) hours allotted, and so Part 2 of the Workshop was set for completion in a third hour on April 20, 2022 at 2:30 p.m. MDT. Attendance at this portion of the Validation Workshop included three (3) representatives from Dillon, six (6) representatives from the City's Marda Loop Streetscape team and four (4) representatives from Calgary's contracted design team (Stantec) for the streetscape improvements. Both parts of the validation workshop were hosted on the Zoom video conferencing platform in conjunction with the MURAL engagement platform, with both workshop sessions recorded for assessment team reference.

To begin the workshop on April 5, background information on the project was shared through a summary presentation. Calgary's CCRA process was outlined, while areas of assessment, timeframes and projections, relevant climate hazards and climate/asset interactions were also summarised. A summary of climate/asset interactions was also presented in a "Yes/No" table: with this table indicating that when an asset is anticipated to interact with climate hazards, interactions are then indicated with as a "Yes" ("Y"), and where an asset does is not anticipated to respond to exposure to a given climate hazard, that interaction is indicated with a "No" ("N").

Preliminary risk scores for each climate hazard were presented in summary tables using MURAL, an online collaboration tool that workshop allowed participants to post their feedback live online to all participants in a process to review, adjust, confirm and validate preliminary scoring. Following this review, discussion and validation of the risk scores, the first Validation Workshop session (two (2) hours) was completed, and a Part 2 of the Validation Workshop was set for April 20 to explore and discuss potential adaptation options (risk reduction measures) to respond to identified climate impacts.

Following Part 1 of the Validation Workshop, inputs from all workshop participants were collected and analysed by Dillon. Through his engagement with workshop participants, consequence scores were refined, updated and summarized. A summary of the revised scoring was presented in Part 2 of the Validation Workshop on April 20. Following the review of the revised risk assessment scoring, the remainder of Validation Workshop Part 2 was used to identify existing resilience measures considered to be inherent to the project design, and to identify and explore potential new additional adaptation options (risk reduction measures) that could be added to the Marda Loop Streetscape Project design to improve the climate resilience of the Marda Loop Streetscape's urban environment.

3.0 Public Infrastructure Climate Risk Assessment

Dillon applied the City's Climate Risk Assessment Process, described as in alignment with the Public Infrastructure Engineering Vulnerability Committee (PIEVC) High Level Screening Procedure (ICLR, 2016). The City's process is also consistent with principles described within Infrastructure Canada's Climate Lens Guidance (GOC, 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 a transportation project involving the design and construction of the update to the Marda Loop Main Streets, 33rd Avenue and 34th Avenue (the Project) from Crowchild Trail to 14th Street SW. The Project is divided into two (2) zones: the 33rd Avenue portion of the Project which is at 60% design and the 34th Avenue portion which is in the earlier conceptual design stage. The climate risk and resilience assessment will consider both zones of the project. This 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.

The geographical extents of the Marda Loop Main Streets project were presented in Figure 2-1.

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. For the construction phase as an example, primary considerations in the assessment included impacts to construction personnel and construction equipment. For human wellbeing, the assessment considered both operations personnel impacts and impacts to users of the streetscape from the general public.

Table 3-1: Infrastructure under Assessment

System Categories	Considerations
Construction Phase	• Construction personnel; and • Construction equipment.

System Categories	Considerations
Built Infrastructure Assets	• Assets as identified by the design team, engineers, operations, etc. (e.g., Substructure, superstructure, etc.).
Human Wellbeing	• Operations personnel; and • Users.
Natural Environment	• Natural infrastructure; and • Ecosystem health and biodiversity.
Critical Third-Party Infrastructure	• Assets identified as critical by the design/operations team.

3.1.1.3 Assessment Timescale

Three (3) 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 baselines timescale refers to the global climate model (GCM) data for the climate normal period (1981 to 2010). The incorporation of two (2) future time periods (the 2050s and 2080s) accounts for the variety in anticipated design life across different forms of infrastructure, to ensure that short, medium and long-term risks can be illustrated 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.

The previously identified climate related hazards were identified by interested parties in 2017 and are included on the Public Infrastructure Climate Risk Assessment Worksheet. Climate hazards noted are at a city scale and may not be relevant for every project; relevant indicators and projected trends will be updated by the City as new information becomes available. All climate hazard data to be used should be accessed from Appendix A. The scope and budget allocation for this High Level PIEVC climate resilience assessment did accommodate the assessment team conducting supplementary detailed analyses of a wider range of climate hazard indicators for this project, relying on the climate hazard analytics as provided by the City for application in their CCRA process.

3.1.3 Step **3** – Impact Analysis

Climate-related impacts are the adverse and/or beneficial effects of climate-related hazards on the construction phase of the project, 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 (H&S: health and safety, SI: structural integrity, F: functionality)

Construction Phase		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
Extreme Heat	Construction personnel	H&S: Bodily injury/illness with work disruptions (heat stroke/heat related illnesses may occur, particularly when occupational requirements result in prolonged exposure)
Increased Air Temperature	Construction personnel	H&S: A slight increase will not result in major changes to these risks, potential for first aid injury
Wildfire	Construction personnel	H&S: Bodily injury/illness with work disruptions (smoke events may constrain safe work and exacerbate respiratory problems, especially during extended work periods)
SDHI Rainfall	Construction personnel	H&S: Work disruption and possible minor first aid injury
	Construction equipment	SI: No permanent damage, but site may need to be drained F: Minor service disruption if work needs to stop until rain passes
Severe Storms	Construction personnel	H&S: Scored with the assumption that procedures are in place to respond to storm events, however, larger sized hail may injure personnel
	Construction equipment	SI: Extreme winds from storms may cause damage F: Moderate service disruption if equipment needs to be restored
High Winds	Construction personnel	H&S: Score assumes procedures are in place to respond to storm events, but wind-blown debris creates potential to injure personnel
	Construction equipment	SI: Minor damage may occur from wind-blown debris F: Storms can last several hours and can potentially shut construction down for half a day or even a full day if event persists or damages result
Heavy Snowfall	Construction personnel	H&S: Depending on how much construction is done in the winter/shoulder months, there could be some risks from slips/trips/falls
	Construction equipment	SI: No permanent damage F: No or minimal service disruption since after removal of snow from equipment, access and resumption of work possible

Built Infrastructure		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
Extreme Heat	Sidewalks, curbs Bike Lanes Pathways (i.e., Multi-use paths) Road – driveway ramps, concrete	SI: No permanent damage (unlikely to have cracking of surface/sidewalk expansion over two days of extreme heat) F: No/minimal service disruption
	Road – driving surface and surface drainage – asphalt	SI: No permanent damage (unlikely to have rutting/potholes over two days of extreme heat) F: No/minimal service disruption
	Street Lighting Traffic Lights	SI: No permanent damage (potential to fail temporarily under extreme heat) F: Minimal service disruption (time to restore lights)
	Bus Stops and Shelters	H&S: First aid injury (may render bus stops unsafe to use as they can get very hot, especially if shelters are enclosed) F: Minimal service disruption (minor reduction in use due to poor conditions)
	Temporary Furnishings Fixed Furnishings Utility Access Covers	SI: No permanent damage F: No/minimal service disruption. In some cases, such as with guardrails, ease of use (functionality to users) may be impaired if heat renders railings too hot to touch
Increased Air Temperature	Sidewalks, Curbs Bike Lanes Pathways (i.e., Multi-use Path) Road – driving surface and surface drainage – asphalt Road – driveway ramps, concrete	SI: Minor damage (heat buckling, surface expansion) F: Minimal service disruption (may need a caution sign on sidewalks if damage could lead to accessibility issue)
	Event Space	SI: No permanent damage F: May present an opportunity to hold more events
Drought	Sidewalks, curbs Bike Lanes Pathways (i.e., Multi-use pathways) Road – driving surface and surface drainage Road – driveway ramps, concrete	SI: No permanent damage (soil shrinkage could potentially lead to movement and settlement (Calgary has a lot of clay soil)) F: Minimal service disruption

Built Infrastructure		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
	Temporary Furnishings	SI: No permanent damage (planters may experience reduced growth in extended drought) F: Minimal disruption, potential for higher maintenance load (with no additional maintenance, plants in planters may require replacement)
SDHI Rainfall	Sidewalks, curbs Bike Lanes Pathways (i.e., Multi-use path) Road – driveway ramps, concrete Road – driving surface and surface drainage, asphalt	SI: No permanent damage (temporary flooding/blockage of surfaces may occur, assets are designed to be submerged) F: No/minimal service disruption (some cleaning of debris may be needed, driving/cycling/walking speeds may be slower, potential for temporary reduction in traffic movement and flow)
	Temporary Furnishings Signage Fixed Furnishings Bus Stops and Shelters	SI: No permanent damage F: Minimal service disruption (surfaces will become wet, reducing the usability of seating, etc. Heavy rain can knock over light, unsecured signage, etc.)
	Tree Grates	SI: No permanent damage F: Minimal disruption (grates may overflow/become blocked and require clearing)
	Utility Access Covers	SI: No permanent damage, but access covers can pop off if surcharged F: Minimal service disruption (replacing/repositioning access covers)
	Traffic Lights	SI: No permanent damage, but potential traffic light damage F: Minor service disruption may occur (during period of light failure there may be some traffic confusion)
	Event Space	SI: No permanent damage F: Minor service disruption (delays to events due to rain)
Severe Storms	Sidewalks, Curbs Bike Lanes Pathways (i.e., Multiuse paths) Road – driving surface and surface drainage, asphalt	SI: No permanent damage F: Moderate service disruption (swept debris or branches can block access and clog drainage, driving/cycling/walking speeds may be slower)
	Road – driveway ramps, concrete	SI: No permanent damage F: Minor service disruption (swept debris or branches can block access temporarily)

Built Infrastructure		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
	Street Lighting	SI: No permanent damage F: Minor service disruption (if lights were to go out/power outage)
	Temporary Furnishings	SI: Significant damage if planters get blown around, may require complete replacement F: Lengthy service disruption (if furnishings are blown away and need to be replaced)
	Utility Access Covers	SI: No permanent damage (covers may pop out) F: Minor service disruption involved in restoration
	Signage – Commercial, Construction, Traffic	SI: Moderate damage (signage can be taken out by strong enough winds) F: Moderate service disruption if signs need to be replaced
	Traffic Lights	SI: Moderate damage (can be damaged by debris or taken out by strong enough winds) F: Minor service disruption from outages
	Bus Stops and Shelters	SI: Moderate damage potential from hail events F: Moderate service disruption if debris blocks shelter entrance or if users can't access shelters/stops
	Fixed Furnishings	SI: No permanent damage F: Minor service disruption (as people won't be able to use certain items under stormy conditions)
	Tree Grates	SI: Minor damage if grates are filled with debris/trees fall over pulling up grates F: Minor service disruption (grates need to be cleared out/repositioned)
	Event Space (Festival Street)	SI: No permanent damage F: Moderate service disruption (events planned may need to be cancelled so as to avoid H&S issues)
High Winds	Sidewalks, curbs Bike Lanes Pathways Road – driveway ramps, concrete	SI: Minor damage (part of path can possibly be damaged with the uprooting of a tree, requiring restoration) F: Minor service disruption (swept debris or branches can block access, might require detours for drivers/cyclists/pedestrians)
	Temporary Furnishings	SI: Moderate damage (if temporary furnishing (hanging plants) collide with other items, may collect debris as things are blown around. If items are heavy enough, they should see no damage. F: Moderate service disruption if furnishings need to be replaced, not as impactful as when combined with storm events (as in the previous hazard – severe storms)

Built Infrastructure		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
	Road – driving surface and surface draining, asphalt	SI: Minor damage possible F: Moderate service disruption (swept debris or branches can block access, driving/cycling/walking speeds may be slower)
	Utility Access Covers	SI: No permanent damage F: Minor service disruption if covers pop out H&S: If left un barricaded, a popped access cover at utility access along roadway or pathway may cause hazard to traffic (vehicle, bicycle, pedestrian)
	Signage	SI: Moderate damage (under high enough winds, signage can be downed (esp. for signage that it not fixed, e.g., construction signs) F: Moderate service disruption (signs will need to be replaced)
	Traffic Lights	SI: Minor damage, parts may come off under extreme winds F: Minor service disruption for restoration
	Bus stops and shelters	SI: Minor damage possible F: Moderate service disruption, debris can be caught by shelters which need to be cleared, bus stops could be blocked
	Tree Grates	SI: Minor damage if the tree in the grate falls, the grate may come up with it, requiring the grate to be replaced F: Minor service disruption, may require increased maintenance if debris settles in after storm, need to be swept out
	Event Space	SI: Minor damage possible F: Moderate service disruption (events planned may need to be cancelled so as to avoid H&S issues)
Heavy Snowfall	Sidewalks, curbs Bike Lanes Pathways	SI: No permanent damage F: Moderate service disruption (snow needs to be cleared in a timely manner to avoid accessibility challenges)
	Street Lighting Temporary Furnishings Utility Access Covers Signage Traffic Lights Bus stops and shelters Fixed Furnishings	SI: No permanent damage F: Minimal service disruption (assets may be covered temporarily in snow, may slightly impact usability of seating, etc.)

Built Infrastructure		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
	Road – driving surface and surface drainage, asphalt Road – driveway ramps, concrete	SI: No permanent damage F: Minor disruption from needing to clear snow/snow buildup; potential budget implications some winters
	Fire Hydrants	SI: No permanent damage
	Tree Grates	SI: No permanent damage, snow may rest on the grate but will melt through F: No/minimal service disruption
	Event Space	SI: No permanent damage F: No/minimal service disruption (unlikely events will be taking place during snowy months)

Natural Environment		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
Extreme Heat	Trees – street, ornamental	SI: Moderate asset damage (loss of leaves, reduced tree health especially for new trees) F: Minor service disruption (loss of provision of shade)
	Landscaping (lawns, footpaths, garden vegetation, flower beds)	SI: No permanent damage (loss of leaves, and reduced plant health can occur) F: No/minimal service disruption (no notable issues)
Increased Air Temperature	Trees – street, ornamental	SI: Minor asset or system damage (potential for influx of invasive species or pests, leading to tree degradation) F: No/minimal service disruption
	Landscaping (lawns, footpaths, garden vegetation, flower beds)	SI: No permanent damage (potential for influx of invasive species or pests, leading to degradation over time) F: Minimal service disruption (may require more maintenance from increased growth)
Wildfire	Trees – street, ornamental Landscaping (lawns, footpaths, garden vegetation, flower beds)	SI: No permanent damage (could be potentially impacted by a nearby grass fire but should see no real damage) F: No/minimal service disruption
Drought	Trees – street, ornamental Landscaping (lawns, footpaths, garden vegetation, flower beds)	SI: Moderate damage to asset or system (encompasses longer term drought impacts. Loss of leaves, potential for tree to be weakened and more susceptible to pests; potential death of plants and replacement/remediation, particularly for more drought sensitive assets e.g., garden vegetation/lawns) F: Minor service disruption may occur (some leaves dropping, may require additional maintenance e.g.,

Natural Environment		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
		watering, raking; temporary periods of brown lawns, may require additional maintenance to replace dead plants)
SDHI Rainfall	Trees – street, ornamental Landscaping (lawns, footpaths, garden vegetation, flower beds)	SI: No permanent damage (possible topsoil erosion) F: No permanent damage
Severe Storms	Trees – street, ornamental Landscaping (lawns, footpaths, garden vegetation, flower beds)	SI: Significant damage (uprooting and damage under extreme winds, damage from hailstorm to flowers/plants, could down trees) F: Lengthy service disruption (debris requires clearing from trees/branches blocking footpaths, potentially downed trees could need replacing)
High Winds	Trees – street, ornamental	SI: Moderate damage. 90km/h is the lower threshold but in conjunction with increased loading on trees from the presence of leaves, these wind levels can take down trees (trees can be downed at even 70 km/h). In conjunction with snow, the same can happen. This can be very damaging for municipalities F: Brief disruption may occur to clean up fallen trees/branches and for emergency response, possibly replace trees
	Landscaping (lawns, footpaths, garden vegetation, flower beds)	SI: Minor damage (parts of vegetation can be broken off by wind) F: Minor service disruption may occur to clean up plant debris
Heavy Snowfall	Trees – street, ornamental	SI: Significant damage (snow loading on branches can lead to breakage) F: Lengthy service disruption (debris requires clearing from trees/branches blocking footpaths, potentially downed trees could need replacing); possible safety risks
	Landscaping (lawns, footpaths, garden vegetation, flower beds)	SI: No permanent damage F: No/minimal service disruption

Human Wellbeing		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
Extreme Heat	Operations personnel	H&S: Heat stroke and heat related illnesses may occur, particularly when occupational requirements result in prolonged exposure

Human Wellbeing		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
	Users	H&S: Potential for heat stroke and heat related illnesses – users have less exposure time compared to personnel. Surfaces exposed to direct sunlight could lead to burns
Higher Average Temperature	Operations personnel Users	H&S: All users may need to be more cautious/aware of temperatures and take measures to protect themselves
Wildfire	Operations personnel	H&S: Smoke (low Air Quality) events may constrain safe work and exacerbate respiratory problems, especially during extended work periods
	Users	H&S: High smoke events can exacerbate respiratory problems, considering higher percentage of elderly residents in the South Calgary area; general users are unlikely go outside in poor conditions.
SDHI Rainfall	Operations personnel	H&S: Could lead to temporary work disruptions
	Users	H&S: General public may not have the right PPE; vulnerable populations may encounter more H&S issues
Severe Storms	Operations personnel	H&S: Getting caught in a hailstorm can injure people and expose them to higher risk of slips/trips/falls, work impacted but PPE will help
	Users	H&S: Getting caught in a hailstorm can injure people and expose them to higher risk of slips/trips/falls
High Winds	Operations personnel	H&S: Although procedures are likely in place to respond to storm events, blown debris can still injure personnel
	Users	H&S: Blown debris can injure people, general public may have reduced access to PPE or awareness training, etc.
Heavy Snowfall	Operations personnel	H&S: Slipping on snow, injuries
	Users	H&S: Slipping on snow, elderly population and those with mobility challenges can experience impacts to their access to services and ability to move around the city

Critical Third-Party Infrastructure		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
SDHI Rainfall	Underground Utilities	SI: Moderate damage (potential for damage from vault flooding) F: Minor disruptions resulting from power loss
	Stormwater Systems	SI: No permanent damage F: Moderate, temporary disruption, catch basins/drains may not be able to keep up, debris on streets may constrict drainage flow leading to pooling and curb level flooding

Critical Third-Party Infrastructure		
Climate Hazard	Asset Affected	Potential Climate Related Impacts
Severe Storms	Overhead Power Lines	SI: Moderate damage (high winds may impact integrity of overhead lines) F: Moderate disruptions (power loss)
	Underground Utilities	SI: No permanent damage (very small potential for damage from vault flooding) F: Minimal service disruption (very small potential for power loss)
	Stormwater Systems	SI: Minor damage from debris blockages F: Moderate service disruption (drainage may be blocked by debris, which can become a great concern when back-to-back events occur)
High Winds	Overhead Power Lines	SI: Minor damage (overhead components can be knocked off or damaged but at this wind speed impacts would be less pronounced) F: Minor service disruption (possible localized power loss)
	Stormwater System	SI: No permanent damage F: Minor service disruption from blockage by debris
Heavy Snowfall	Overhead Power Lines	SI: Moderate damage (if ice/snow buildup on lines causes downed wires F: Moderate service disruption (possible power loss)
	Stormwater System	SI: No permanent damage F: Possibility for plowed snow to block drainage assets if not fully cleared. A follow-up wet precipitation event could exacerbate effects.

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 CCRA 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 number of heat waves per year compared to historical).

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). The standardized probabilities presented in Table 3-3 were used for most of the climate hazards, except for flooding, SDHI rainfall and extreme heat (more specific likelihood scoring was introduced based on previous work

completed for the Community Climate Risk Index Final Report (WSP, 2021)). 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 – 34	1:100 event (1% chance)	Once every 2-10 years
3	Possible	35 – 64	1:70 event (1.4% chance)	Once every 2 years
4	Likely	65 – 89	1:50 event (2% chance)	More than 1 x every year
5	Almost Certain	≥ 90	1:25 event (4% chance)	More than 3 x every year

Table 3-4: Climate Hazard Likelihood Rating Summary

Climate related hazard	Projected climate hazard trend	Baseline	Future (2050s)	Future (2080s)
Extreme heat	↑	2	5	5
Increased air temperature	↑	4	5	5
Wildfires	↑	2	4	5
Droughts	Likely ↑	3	4	5
Short duration high intensity (SDHI) rainfall	↑	3	4	5
Severe Storms	Likely ↑	3	4	5
High winds	Likely stable	3	3	3
River Flooding	Likely ↑	2	3	3
Heavy Snowfall	↓	3	2	2

3.3 Step 5 – Consequence Analysis

The City's climate risk assessment process has defined five (5) point rating scales to describe Consequence Severities ranging from the lowest rating "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 (3) consequence types: 1) Health and Safety, 2) Structural Integrity and 3) Functionality in the City's CCRA process and are listed in
Table 3-5.

Table 3-5: Consequence Classification Matrix

Rating	Consequence Classification	Consequence Types		
		Health and Safety	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
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

Table 3-6: Risk Classification Matrix

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

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 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 Marda Loop Streetscape 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 below 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 CCRA 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 top 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) times (Impact Consequence Severity) = Risk Level. Definitions for consequence severity scoring and likelihood scoring are also presented in the worksheet figure.

Table 3-7: Yes/No Analysis

System	Asset Component	Climate-Related Hazard							
		Extreme Heat (Heat waves)	Increased Air Temperature (Freeze/thaw)	Wildfire (Fire Spread Days)	Drought (2-week Drought)	SDHI Rainfall (1-hour Rainfall >50mm)	Severe Storms (Hail and Severe T-storm Winds)	High Winds (Gusts > 90km/h)	Heavy Snowfall (10cm of snow in 12hr or less)
Construction Phase	Construction Personnel	Y	Y	Y	N	Y	Y	Y	Y
	Construction Equipment	N	N	N	N	Y	Y	Y	Y
Built Infrastructure	Sidewalks and Curbs	Y	Y	N	Y	Y	Y	Y	Y
	Bike Lanes	Y	Y	N	Y	Y	Y	Y	Y
	Pathways (i.e., Multi-use paths)	Y	Y	N	Y	Y	Y	Y	Y
	Street Lighting	Y	N	N	N	N	Y	Y	Y
	Temporary Furnishings (decorative lighting, heaters, fences, hanging planters)	Y	N	N	Y	Y	Y	Y	Y
	Road - Driving surface and surface drainage - asphalt	Y	Y	N	Y	Y	Y	Y	Y
	Road - Driveway ramps, concrete	Y	Y	N	Y	Y	Y	Y	Y
	Utility Access Covers	Y	N	N	N	Y	Y	Y	Y
	Signage - (Commercial, Construction, Traffic)	Y	N	N	N	Y	Y	Y	Y
	Traffic Lights	Y	N	N	N	Y	Y	Y	Y
	Bus Stops and Shelters	Y	N	N	N	Y	Y	Y	Y
	Fixed Furnishings (Bicycle racks, benches, water fountains, pay stations)	Y	N	N	N	Y	Y	Y	Y
	Tree Grates	N	N	N	N	Y	Y	Y	Y
	Retaining Walls	N	N	N	N	N	N	N	N
	Event Space (Festival Street)	Y	O	N	N	Y	Y	Y	Y
	Fire Hydrants	N	N	N	N	N	N	N	Y
Human wellbeing	Operations Personnel	Y	Y	Y	N	Y	Y	Y	Y
	Users	Y	Y	Y	N	Y	Y	Y	Y
Natural Infrastructure	Trees - Street, ornamental	Y	Y	Y	Y	Y	Y	Y	Y
	Landscaping (Lawns, footpaths, garden vegetation, flower beds)	Y	Y	Y	Y	Y	Y	Y	Y
Critical 3rd Party Infrastructure	Overhead Power Lines	N	N	N	N	N	Y	Y	Y
	Underground Utilities	N	N	N	N	Y	Y	N	N
	Stormwater System	N	N	N	N	Y	Y	Y	Y

These likelihoods for climate hazards in the current and projected climate are provided by the City's prescribed climate hazard information for application in this CCRA process. Once likelihood scale factors are indicated for each climate hazard for each of the systems and subcomponents for current and projected future climate, the assessment team developed a score to describe the consequence of each anticipated impact (response) to that climate hazard, using a Consequence Severity Impact 5-Point Scale also defined and prescribed by the City. The completed CCRA Worksheet listing all severity scores, likelihoods and risk levels for the elements assessed for the Marda Loop Project is provided in Appendix D.

A summary table is provided in Table 3-8, listing the number of climate interactions identified for the Marda Loop Project within each of the five (5) levels of risk defined by Calgary's CCRA process. Risk totals shown in each column are specific to each climate period indicated, i.e., the baseline climate and two (2) projected future climate time horizons (2050s, 2080s). The highest risk interactions across all the assessed climate hazards for the Marda Loop project are also tabulated and provided in Appendix D.

Table 3-8: Validated Risk Scores: Climate Impacts and Risk Levels across Present and Future Climate Conditions for the Marda Loop Project

Risk Classification	Rating	Present	2050s	2080s	Total
Very Low	1-2	151	53	53	257
Low	3,4, and 6	152	194	114	460
Medium	5, 7-9	61	117	191	369
High	10-16	12	14	19	45
Extreme	20-25	0	0	0	0

3.5 Step 7 – Resilience Analysis

An internal workshop was held to establish preliminary risk scores in the resilience analysis of the assets included in the Marda Loop Climate Change Risk Assessment. The scores were refined in validation sessions facilitated by Dillon with the City and their project team, where workshop participation engagement and input allowed for a consensus between Dillon and the City on impact severity scores and risk levels. Validation Workshop Part 2 focused on resilience measures for the project, with focused engagement on:

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

The following section outlines adaptation measures corresponding to the two (2) categories above. Resilience measures identified as "inherent in the design" come from the Master Plan and workshop comments from the City's project team and the design team. As the plans for 33rd Avenue W and 34th Avenue W of the Marda Loop Streetscape project were not yet finalized at the time of this risk assessment, there is an opportunity for this assessment to inform some important changes to increase the project's resilience going forward.

Areas where additional measures or recommendations were generated were determined based on the City's Risk Treatment Guidelines (Table 3-6). Recommendations were made for assets where risks were identified as medium or high, and recommendations generally focus on options for modifications to aspects of design or adjustments in operations and maintenance programs.

The risk levels summarised in Table 3-8 indicate the number of identified risks at High, Medium, Low and Very Low levels in this CCRA process. There were no identified risks that achieved an "Extreme" Risk Classification.

In Table 3-9, high risk levels are highlighted in orange and medium risk levels are highlighted in yellow. In situations where high and medium risks both exist for an asset, the overall risk is identified as high to ensure a conservative approach. Low and Very Low Risk Levels are not included in the table. Also, within this table, one column provides details on resilience measures that are already inherent in the project's design and a second column indicates options for additional resilience measures that are not currently incorporated into the project, but could be considered for further assessment (Cost/Benefit Analysis).

Table 3-9: Resilience Measures

Highlighted boxes indicate extreme, high and medium risk scores. No climate interactions were identified in the Extreme Risk Level. Bold items are options recommended to the City for further consideration.

Construction Phase *Consider the health, wellness and safety of construction personnel as well as the resilience of construction equipment to climate hazards.*			
Component	Risk Level Comments	Resilience Measures (already included in design)	Additional Measures or Recommendations
Construction personnel	High risk from extreme heat and wildfire, medium risk from high average temperature and SDHI rainfall	*No specific resilience measures identified*	• Enhanced SOPs (standard **operating procedures) for occupational health in extreme conditions**

Construction Phase *Consider the health, wellness and safety of construction personnel as well as the resilience of construction equipment to climate hazards.*			
Component	Risk Level Comments	Resilience Measures (already included in design)	Additional Measures or Recommendations
Construction equipment	High risk from SDHI rainfall, medium risk from high winds	*No specific resilience measures identified*	• Consider SOP of sheltering equipment and personnel in advance of forecasted extreme events

Built 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)	Additional Measures or Recommendations
Sidewalks and Curbs	High risk for higher average temperature, heavy snowfall. Medium risk for extreme heat, drought and SDHI rainfall	• Sidewalks graded to facilitate drainage of surface runoff	• Ongoing monitoring for ponding, settlement in sidewalks and curbs, effectiveness of snow clearing program under emerging snow conditions
Bike Lanes	High risk for higher average temperature, heavy snowfall. Medium risk for extreme heat, drought and SDHI rainfall	• Snow clearing considerations incorporated for bicycle users to ensure routes are accessible 12 months per year	• Ongoing tracking of snowfall in snow clearing program with an intent to modify to respond to emerging needs
Pathways (i.e., Multi-use paths)	High risk for higher average temperature, heavy snowfall. Medium risk for extreme heat, drought and SDHI rainfall	*No specific resilience measures identified*	• Replacement of impervious concrete and asphalt surfaces with pervious pavers to reduce surface runoff and enhance infiltration
Street lighting	Medium risk from extreme heat	*No specific resilience measures identified*	• N/A

Built 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)	Additional Measures or Recommendations
Temporary Furnishings	Medium risk from drought, SDHI rainfall, severe storms and high winds	• Anchoring of some temporary furnishings	• Anchoring of temporary furnishings is already included as a design measure
Road – driving surface and surface drainage – asphalt	High risk from higher average temperature, medium risk from extreme heat, drought, SDHI rainfall, high winds and heavy snowfall	• Consideration for snow storage during snowfall events incorporated into the roadway design	• Consider program to monitor for **rutting and/or deformation in** pavement that may impair drainage of runo**ff** • Consider program to clear driving **surface gutters of wind-blown** debris to maintain capacity of catch basins and inlets
Road – driveway ramps, concrete	High risk from higher average temperature, medium risk from extreme heat, drought, SDHI rainfall and heavy snowfall	• Reduction in size of driveways to provide room for additional pervious surfaces	• **Consider implementation of additional pervious materials in** road and driveway ramp design
Utility access covers	Medium risk from extreme heat and SDHI rainfall	*No specific resilience measures identified*	• Inspection of covers after rainfall events to confirm presence of any access cover blowouts
Signage	Medium risk from SDHI rainfall and high winds	*No specific resilience measures identified*	• Inspection and maintenance after each high wind event
Traffic lights	High risk from SDHI rainfall, medium risk from extreme heat	*No specific resilience measures identified*	• Monitoring for disruption in signal operations, potential for higher maintenance demand
Bus Stops and Shelters	Medium risk from extreme heat, SDHI rainfall and high winds	• Incorporation of transit shelters to protect from extreme weather events	• Evaluate proposed transit shelters to ensure there is strength of materials to accommodate intense weather/hail events

Built 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)	Additional Measures or Recommendations
Fixed Furnishings	Medium risk from SDHI rainfall and high winds	*No specific resilience measures identified*	• Inspect fixed furnishings for damage and repair as necessary to maintain safety to public users
Tree Grates	Medium risk from SDHI rainfall	*No specific resilience measures identified*	• Inspect and maintain: clear any accumulated debris from tree grates after SDHI rainfall events
Event Space	High risk from extreme heat and SDHI rainfall. Medium risk from high winds	*No specific resilience measures identified*	• **Close synchronization with local** weather warnings • **Event hosting and extreme** weather protocol: guidelines to warn, close events upon **notification of pending extreme** weather event

Natural Environment

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)	Additional Measures or Recommendations
Trees (Street and Ornamental)	High risks from extreme heat, higher average temperature, drought and heavy snowfall. Medium risks from wildfire, SDHI rainfall, severe storms and high winds	• Protection of selected mature established trees during construction • Introduction of additional tree canopy to support shady areas during extreme heat • Incorporation of soil cells (integrated with stormwater capture) to support additional water infiltration and enable stronger tree growth over time	• Select tree species that are moderately drought tolerant • Select tree species without lateral branching (to be less vulnerable to wind/snow buildup) • Pruning programs to restrict tree limbs to manageable lengths

Natural Environment

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)	Additional Measures or Recommendations
Landscaping (lawns, footpaths, garden vegetation, flower beds)	High risks from drought, medium risks from extreme heat, higher average temperature, wildfire, SDHI rainfall and severe storms	• Trees, shrubs and perennials are located in planters, which can capture and temporarily store stormwater • A variety of different plant species to be included in planters to reduce risk of all plants being wiped out by invasive species • Planted boulevards assist in controlling stormwater runoff	• Plant drought-resistant grasses in grass-**fi**re prone areas • Drought tolerant landscaping • Develop operational protocols to protect/sustain/maintain landscape features • Introduce bioswale along 18/19 Street south of 34th Avenue W • Blockades/high curbs to prevent utility vehicles from parking on boulevards and igniting grass fires (also in "Built Infrastructure")

Human Wellbeing

Consider the health, wellness and safety of people during construction as well as during the operational life of the infrastructure project. What resilience measures that could be built into the project that would increase the coping capacity of operators and users to climate hazards?

Component	Risk Level Comments	Resilience Measures (already included in design)	Additional Measures or Recommendations
Operations Personnel	High risks associated with extreme heat and wildfire, medium risks associated with higher average temperature, SDHI rainfall and high winds	• Heat protocols for workers	• Monitor established protocols for extreme weather conditions (high heat, SDHI rainfall, high winds) for ongoing effectiveness • Track weather-event related **operations staff injuries/accidents**

Human Wellbeing

Consider the health, wellness and safety of people during construction as well as during the operational life of the infrastructure project. What resilience measures that could be built into the project that would increase the coping capacity of operators and users to climate hazards?

Component	Risk Level Comments	Resilience Measures (already included in design)	Additional Measures or Recommendations
Users	High risks associated with extreme heat and wildfire, medium risks associated with higher average temperature, SDHI rainfall, and high winds	• Water fountains • Incorporation of additional benches which provide spaces for people to rest during extreme heat	• Installing publicly accessible reusable container water refill **stations** • Add bicycle equipment repair **station along 34th** Avenue W to enable users to repair/maintain bicycles

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)	Additional Measures or Recommendations
Overhead Power Lines	High risks for heavy snowfall, medium risks for extreme heat, higher average temperature, wildfire, drought and SDHI rainfall	*No specific resilience measures identified*	• Monitor for impact thresholds related to heavy snowfall and ice **accretion**
Underground Utilities	High risks from SDHI rainfall	*No specific resilience measures identified*	• **Consider relocation of the ATCO** gas line along 33rd Avenue to **accommodate additional soil** volume for trees
Stormwater Systems	High risks from SDHI rainfall, medium risk from heavy snowfall	*No specific resilience measures identified*	• **Install "Stormcrete" in gutter pan** – pervious pavers

3.6 Return on Investment (ROI) for Selected Adaptation Options

3.6.1 Identifying and Selecting Adaptation Options: Process

A set of potential climate resilience risk reduction options was developed from inputs received from participants in the technical workshops for the Marda Loop Project. Two (2) technical workshop sessions were facilitated by Dillon with the City team and representatives from its design consultant for the Marda Loop Streetscape Improvements. The second workshop session, convened on April 22, 2022, focussed on identifying potential additional resilience measure options that could be considered by the City for addition to the Marda Loop Project.

While multiple climate resilience measures were already integrated into the Marda Loop Project, identification of new, additional, climate resilience options for the project were made in pursuit of a goal in the City's CCRA process to identify measures with potential to *further enhance climate resilience* for the project, where those options are deemed feasible.

Additional resilience options identified in the second workshop session were listed for the City in a Memo from Dillon issued to the City on May 3, 2022. From that list of 26 proposed options to further enhance resilience, the City responded on May 12 with a list of six (6) top resilience options that the City selected for further consideration and implementation for the Marda Loop Streetscape enhancements. The top six (6) resilience options selected by the City were:

1. Add Water Bottle Refill stations to the Marda Loop Project;
2. Add a Bike Repair Station along 34th Avenue;
3. Introduce Drought Tolerant Plants/landscaping elements;
4. Replace impervious concrete with pervious pavers;
5. Allow for greater heat expansion joints in sidewalks and ramps; and
6. Install a Bioswale along 18/19th Street.

3.6.2 Return on Investment Assessment of Selected Adaptation Options

On May 17, Dillon issued the City a memo that summarised the City's selected six (6) resilience options and specified the requests for costing data related to design and construction and the data to help quantify the losses avoided due to impacts/costs prevented from each proposed resilience measure. The City then sought to collect the requested data and indicated to Dillon (June 6) that much of the data pertaining to avoided costs (associated with impacts avoided through implementation of a given resilience measure) would not be available until the City completes more internal analyses. The City indicated that the work required to complete these datasets will likely not be available until next year (2023).

A Return-on-Investment (ROI) consideration is a helpful component of many climate change risk assessment frameworks, including Infrastructure Canada's Climate Lens Requirements and the City's

prescribed CCRA process. For resilience measures under consideration for addition to any project, the completion of a ROI assessment allows for the prioritisation of resilience measures to yield benefit from the measure that exceeds the cost to implement and operate that measure.

The City's documented CCRA process (ref, November 2021) describes ROI consideration in Section 2.7 (Project Return on Investment) and does not indicate a specific approach, but requires noting if a ROI assessment was completed, and if not, the process requires rationale for not completing a ROI analysis. Rationale may include realities such as missing the datasets required to complete a ROI analysis, and a lack of assembled Calgary-specific data to apply to the adaptation options selected for this project prevent a quantitative Return on Investment calculation.

The approach Dillon sought to apply in the Marda Loop Project follows guidance in *Infrastructure Canada's Climate Lens General Guidance– Annex G – Return on Investment Guidelines.* The ROI guidance in the Climate Lens Guidance is as follows:

Return on Investment is calculated in two (2) steps. Step 1 is Loss Estimation Analysis and Step 2 is Return on Mitigation Investment.

For Step 1, Loss Estimation Analysis, a calculation is made to determine the dollar value estimate of damage that can be expected when the identified climate hazard event occurs and comparing the costs between two (2) scenarios: Scenario 1 – impact costs with no adaptation measure implemented and Scenario 2 – impact costs WITH the adaptation measure in place.

$$RP_A - RP_C = LA$$

Where:

- RP_A is Cost of Losses with Adaptation Absent;
- RP_C is Cost of Losses with Adaptation Complete; and
- LA= Losses Avoided.

All losses avoided should be expressed in present day values in this analysis.

Costs associated with the losses under consideration in this process include three (3) main categories:

1. Physical losses, such as vehicles and equipment, infrastructure;
2. Loss of Function losses, such as loss of business income, disruption of time of residents; and
3. Emergency Management-related losses, including debris cleanup and other government expenses.

Table 3-10 below includes a summary listing of these loss types and typical costing categories from the Climate Lens General Guidance.

Table 3-10: Summary Listing of Loss Types

Loss Type	Loss Category
Physical	• Buildings • Contents • Roads and Bridges • Landscaping • Environmental Impacts • Vehicles/Equipment
Loss of Function	• Displacement Expense • Loss of Rental Income • Loss of Business Income • Loss of Wages • Disruption Time of Residents • Loss of Public Services • Economic Impact of Utility Loss • Economic Impact of Road/Bridge Closure
Emergency Management	• Debris Cleanup • Government Expense

For Step 2, Return on Investment, the ROI percentage is determined using the Loss Avoided (calculated in Step 1) as a percentage of the proposed Project Cost:

$$\text{LA (\$)/PC (\$)} = \text{\% ROI}$$

Where:

- LA($) = Loss avoided in dollars;
- PC($) = Total investment estimated for the project being evaluated; and
- ROI = Return on Investment (percentage).

ROI calculations are to be amortised over the average useful service life of the asset and should be clearly indicated in the ROI assessment.

3.6.3 High Level ROI Recommendations for Selected Resilience Options

A consideration of *High-Level ROI Potential*, a qualitative review of anticipated resilience investment value for the six (6) selected resilience options was undertaken due to a lack of required data for numerical calculations. In this qualitative consideration, we applied the following definitions to describe varying degrees of ROI Potential for each selected option:

- **ROI Potential is** LOW if the costs are higher than the anticipated benefits from avoided losses or costs/avoided loss values are unknown while cost of option is significant;
- **ROI Potential is** REASONABLE if the costs are likely to be lower than avoided losses; and
- **ROI Potential is** HIGH if the avoided losses are significantly higher than the project cost.

High Level ROI Potentials are described below for each of the six (6) selected adaptation measures under consideration by the City.

3.6.3.1 Resilience Option 1: Water Refill Stations

Costs associated with this resilience option include costs to install and maintain a water refill station and the costs to supply this station with a seasonal supply of potable water for users equipped with their own portable refillable drinking containers.

Data to quantify losses avoided with the implementation of this resilience option are not currently available within the City, but this data is expected to be available in 2023. Losses avoided would include disruption costs to personnel and businesses directly responding to a heat stress/dehydration related exposure.

High-Level ROI Potential: REASONABLE. Project costs are likely to be lower than avoided losses associated with repeated costs incurred to respond to a medical emergency involving a Marda Loop user from the general public or a local business. Extreme heat events are projected to increase, and the likelihood of heat and/or dehydration related illness incidents will grow along with extreme heat events. When costs of EMT response, lost wages for heat-affected persons and costs of disruption to persons and business are considered, these avoided potential losses add up to provide a potential for a REASONABLE ROI for this selected adaptation measure.

Other cities may have metrics they can share with the City on Losses Avoided for water bottle filling stations. Between 2015 and 2025, New York City has committed to installing 500 water bottle filling stations across the five boroughs to promote proper hydration[1].

3.6.3.2 Resilience Option 2: Bike Repair Station along 34th Avenue

Costs associated with this resilience option pertain to the installation and ongoing maintenance and promotion of a bicycle repair station within the Marda Loop Streetscape.

Data to quantify losses avoided with the implementation of this resilience option are not currently available from the City, but this data is expected to be available in 2023. Losses avoided would include the following costs:

[1] Reference: https://portal.311.nyc.gov/article/?kanumber=KA-03088

- A cyclist who relies on bicycles for urban transport may bear costs associated with the loss of a properly maintained bike;
- This option may attract more cyclists to patronise the Marda Loop businesses, with potential economic benefit to the commercial zone; and
- Avoided losses for this option are difficult to quantify, as lack of a bike repair station may not necessarily equate to generating the costs triggered by an unusable bicycle.

High-Level ROI Potential: LOW. Costs associated with avoided losses through implementation of this adaptation option are highly uncertain and difficult to quantify. There are advantages potentially gained for marketing Marda Loop as an attractive zone for active transport (Walking and Cycling), but the resilience gains stemming from this option are LOW from the perspective of ROI considerations.

3.6.3.3 Resilience Option 3: Introduce Drought Tolerant Plants and Landscaping

Costs associated with this resilience option include the incremental cost to purchase, install and maintain drought-resistant or drought-tolerant plants and vegetation for Marda Loop landscape elements. With drought-resistant/tolerant plants/vegetation, there is an expectation of a reduction in maintenance effort compared to standard plants/vegetation maintenance requirements, which are assumed to be more intensive during drought events for plants without tolerance to drought conditions.

Data to quantify losses avoided with the implementation of this resilience option are not currently available from the City, but this data is expected to be available in 2023. Losses avoided would include the following costs:

- Cost to acquire, replace drought sensitive, standard vegetation species; and
- Higher cost maintenance program through drier conditions for non-drought tolerant species.

High-Level ROI Potential: REASONABLE. Data required to quantify the costs associated with avoided losses if this adaptation option is implemented are not available at the time of this project. However, this data is likely available through the City's existing processes in the future. The City indicated that datasets to inform aspects of ROI analysis are being developed and will not be available from the City until next year (2023).

Given the prospects for significantly lower maintenance and replacement costs realised with drought-tolerant/resistant plants/vegetation, it is anticipated that integrating drought-resistant plants/vegetation will yield benefits (avoided losses: extra maintenance to help drought sensitive species cope with drought conditions, avoided costs to replace drought-sensitive species die-off) that will likely produce a favourable ROI once costing and loss data values are available.

3.6.3.4 Resilience Option 4: Replace impervious concrete with pervious pavers.

Costs associated with this resilience option include the incremental cost to purchase, install and maintain pervious pavers in lieu of impermeable concrete pavement.

Data to quantify losses avoided with the implementation of this resilience option are not currently available from the City, but this data is expected to be available in 2023. Losses avoided would include the following costs:

- Higher maintenance costs for concrete (pavement or impermeable pavers);
- Less requirement for de-icing applications on pervious pavers (textured surface area); and
- Costs associated with impacts of higher peak surface runoff from prevalence of impervious surfaces (traffic flow disruption and related costs, surface impacts).

High-Level ROI Potential: REASONABLE. While pervious pavers are slightly more costly than impervious pavements, they do yield costs savings across their service life through a lower requirement for maintenance and a longer service life while reducing the need for stormwater upgrades by reducing the peak stormwater flow entering the system[2].

While Calgary-specific data required to quantify the costs associated with avoided losses if this adaptation option is implemented are not available at the time of this project, applications of successful implementations for pervious pavers and pervious pavements exist.

During the City's data gathering process to quantify avoided loss estimates, it is recommended that a selection of these case studies is reviewed and evaluated for applicability to the Calgary climate and context.

3.6.3.5 Resilience Option 5: Allow for Greater Heat Expansion in Joints in Sidewalks and Ramps

Costs associated with implementing this resilience option include cost and installation of additional heat expansion joints in sidewalks and ramps and costs for higher specification concrete to resist freeze/thaw (smaller aggregate, higher strength concrete, etc.) and improved maintenance for joint seals.

Data to quantify losses avoided with the implementation of this resilience option are not currently available from the City, but this data is expected to be available in 2023. Losses avoided would include the following costs:

- Avoided costs (losses) to repair concrete damage from heat expansion (cracks, heaves, failure).

[2] Reference: https://www.epa.gov/soakuptherain/soak-rain-permeable-pavement

High-Level ROI Potential: LOW. Costs related to repair of concrete damage with existing concrete are not currently available from the City. Costs related to increased maintenance of additional expansion joints are also not available currently from the City.

This adaptation option offers some potential benefit (reduced instances of heat-expansion related concrete damage for sidewalks and ramps) and project costs related to increased maintenance are not available. The current High-Level ROI Potential is low but may yield a more attractive ROI once the data is available for some of these costs in 2023.

3.6.3.6 Resilience Option 6: Bioswale along 18/19th Streets.

Costs associated with implementing this resilience option include the cost to install and maintain the bioswale asset. Sustainability benefits also are presented by this option, but these require valuation and may be available in the 2023 datasets developed by the City.

Sustainability Benefits potentially resulting from this option include several items without currently available valuation data for this location. These include:

- Habitat creation for bees, butterflies, insects, birds (helping pollination, biodiversity);
- Reduced degradation of urban watershed; and
- Improved aesthetics.

Data to quantify losses avoided with the implementation of this resilience option are not currently available from the City, but this data is expected to be available in 2023. Losses avoided would include the following costs:

- Costs avoided via reduced and delayed peak stormwater runoff volume;
- Costs avoided from reduced degradation of the urban watershed; and
- With widespread deployment, potential for infra cost savings due to rainwater capture reducing peak flows for runoff events.

High-Level ROI Potential: LOW. The ROI rating for this option is driven by a lack of valuation data to apply in Avoided Losses and Project Costs. While costs to implement this option are anticipated to be substantial, there is also potential for meaningful avoided losses and the opportunity to achieve sustainability benefits with this implementation may also be considered substantial. Only the lack of costing data prevents this option from achieving a REASONABLE ROI Potential.

Appendix A

Calgary Climate Profile

DILLON CONSULTING

Climate change is a global and local challenge that will increasingly impact environmental, social and built systems. The City of Calgary (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 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 global climate models (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., >99 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 (1) "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 A3-11 along with associated references.

Table A3-11: 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, high uncertainties	(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	↓ uncertainties	(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 (2) 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 A3-12 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 (10th), median (50th) and high (90th) 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 A3-12: 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	23.8	26.8	27.7	25.2	30.4
	Annual	10.3	12.9	11.8	14.6	14.9	13.7	17.0
Mean daily minimum temperature (°C)	Winter[1]	-11.6	-8.2	-10.7	-7.0	-6.2	-8.6	-5.0
	Annual	-1.2	1.7	0.6	2.7	3.8	2.6	5.2
Annual maximum temperature (°C)	Summer[1]	32.0	34.4	33.3	37.4	36.9	34.7	41.8
Mean number of hot days[3]	Annual	6.8	26.5	-	-	48.1	-	-
Longest heat wave (days)	Annual	4.0	16.0	-	-	24.0	-	-

Extreme Heat Indicators	Season[1]	Baseline	2050s			2080s		
			Median[2]	Low[2]	High[2]	Median[2]	Low[2]	High[2]
Mean number of heat waves	Annual	0.2	3.0	-	-	7.1	-	-

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] Hot days are defined as the daily maximum temperature ≥ 29°C.
[4] Heat waves are defined as the maximum temperature ≥ 29°C and minimum temperature ≤ 14°C for more than 48 hours (ECCC, 2021).

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 A3-13 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 A3-13: 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	7.4	6.3	8.7	9.5	8.2	11.1
	Winter	-6.2	-3.8	-5.4	-2.1	-1.7	-3.6	0.0
	Spring	4.2	6.7	5.4	8.1	8.7	6.9	10.5
	Summer	15.3	19.0	17.8	20.3	21.5	19.2	23.4
	Fall	4.7	7.8	6.7	8.8	9.7	8.1	11.2
Mean number of cooling degree days[3]	Annual	46.1	209.6	136.6	278.5	415.3	238.5	601.1
Mean number of heating degree days[4]	Annual	4,958.7	4,093.0	3,728.4	4,407.9	3,504.5	3,112.2	3,830.3
Mean number of freezing-thaw cycles	Annual	123.1	101.3	-	-	80.53	-	-
	Winter	17.6	18.5	17.7	19.1	17.6	16.4	18.4
Mean number of freezing degree days[5]	Annual	1,000.4	660.7	535.1	793.9	459.5	374.3	576.8
Mean growing season length	Annual	124	154	146	167	174	160	186
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 not be enough to offset increases in temperature (Flannigan, 2016). Table A3-14 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 A3-14: 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 (4) 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 (4) 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 (2) 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 A3-15 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 A3-12 and Table A3-20, 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 A3-15: 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	-	-	296.8	-	-
Mean number of dry spells[2,3]	5.9	6.0	-	-	6.0	-	-

Increased Air Temperature Indicators	Baseline	2050s			2080s		
		Median[1]	Low[1]	High[1]	Median[1]	Low[1]	High[1]
Longest dry spell[2] (days)	35.9	35.9	-	-	35.9	-	-
Return period of two (2) 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 A3-16 to Table A3-18 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 A3-19 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 (1) to two (2) hour events) and long duration (24 hours or longer) events. The projected increase in rainfall volumes can be described by employing the Clausius-Clapeyron relationship, which indicates 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 Global Climate Model (GCM) analysis for the City. In engagements to support the CCRA, the City project team indicated an interest in the one (1) hour rain event as an impact threshold.

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 based on the Clausius-Clapeyron relation (Table A3-20), the events for which systems should be designed to accommodate safely and efficiently. 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 A3-16: Baseline IDF of Rainfall Estimates (mm) for the Calgary International Airport

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

Table A3-17: 2050s Climate Adjusted IDF of Rainfall Estimates (mm) for the Calgary International Airport

Time	2 yrs	5 yrs	10 yrs	25 yrs	50 yrs	100 yrs	200 yrs	500 yrs
5 min	6.5	9.2	11	13.3	15	16.7	18.4	20.6
10 min	9.9	14.3	17.2	20.9	23.6	26.3	29.0	32.5
15 min	12.2	17.8	21.5	26.2	29.6	33.1	36.5	41.0
30 min	15.7	23.5	28.7	35.3	40.2	45.1	49.9	56.3
1 hr	18.7	27.9	34.1	41.8	47.5	53.2	58.9	66.4
2 hr	22.5	31.9	38.2	46.1	51.9	57.8	63.6	71.2
6 hr	31.5	42.1	49.1	58	64.6	71.1	77.6	86.2
12 hr	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 A3-18: 2080s Climate Adjusted IDF of Rainfall Estimates (mm) for the Calgary International Airport

Time	2 yrs	5 yrs	10 yrs	25 yrs	50 yrs	100 yrs	200 yrs	500 yrs
5 min	7.7	10.9	13.1	15.8	17.8	19.8	21.8	24.4
10 min	11.7	17.0	20.4	24.8	28.0	31.2	34.4	38.6
15 min	14.5	21.2	25.5	31.1	35.2	39.3	43.3	48.7
30 min	18.6	28.0	34.1	42.0	47.8	53.5	59.3	66.8
1 hr	22.2	33.2	40.5	49.6	56.4	63.2	69.9	78.8
2 hr	26.7	37.9	45.3	54.7	61.7	68.6	75.5	84.6
6 hr	37.4	50.0	58.4	68.9	76.7	84.4	92.2	102.3

Time	2 yrs	5 yrs	10 yrs	25 yrs	50 yrs	100 yrs	200 yrs	500 yrs
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 A3-19: 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)	10-15% increase [1]	10-20% increase [1]

Notes:

[1] Averaged over all return periods.

Table A3-20: Summary of climate projected rainfall for Calgary

Climate Indicators	Season	Baseline (mm)	2050s (mm)			2080s (mm)		
			Median[1]	Low[1]	High[1]	Median[1]	Low[1]	High[1]
Mean rainfall totals	Annual	324.6	378.2	-	-	400.1	-	-
	Winter	0.3	3.6	-	-	6.5	-	-
	Spring	58.5	89.5	-	-	103.4	-	-
	Summer	216.5	219.0	-	-	219.8	-	-
	Fall	49.5	66.1			70.4		

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). Figure A3-1 illustrates a summary of the convective events compared to favourable conditions for both weather observations and climate projections during an average year. As per the baseline mean, July is the most active month for convective events and favourable conditions; 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 A3-21). This may have an impact on future trends in extreme wind gusts.

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 A3-21) will likely contribute to Calgary experiencing more hail events in total (Etkin, 2018).

The frequency and duration of severe storms is likely to increase in the future, increasing risk to property owners. Buildings will increasingly be impacted by severe storm hazards such as heavy rain, lightning (Romps, D. M., 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.

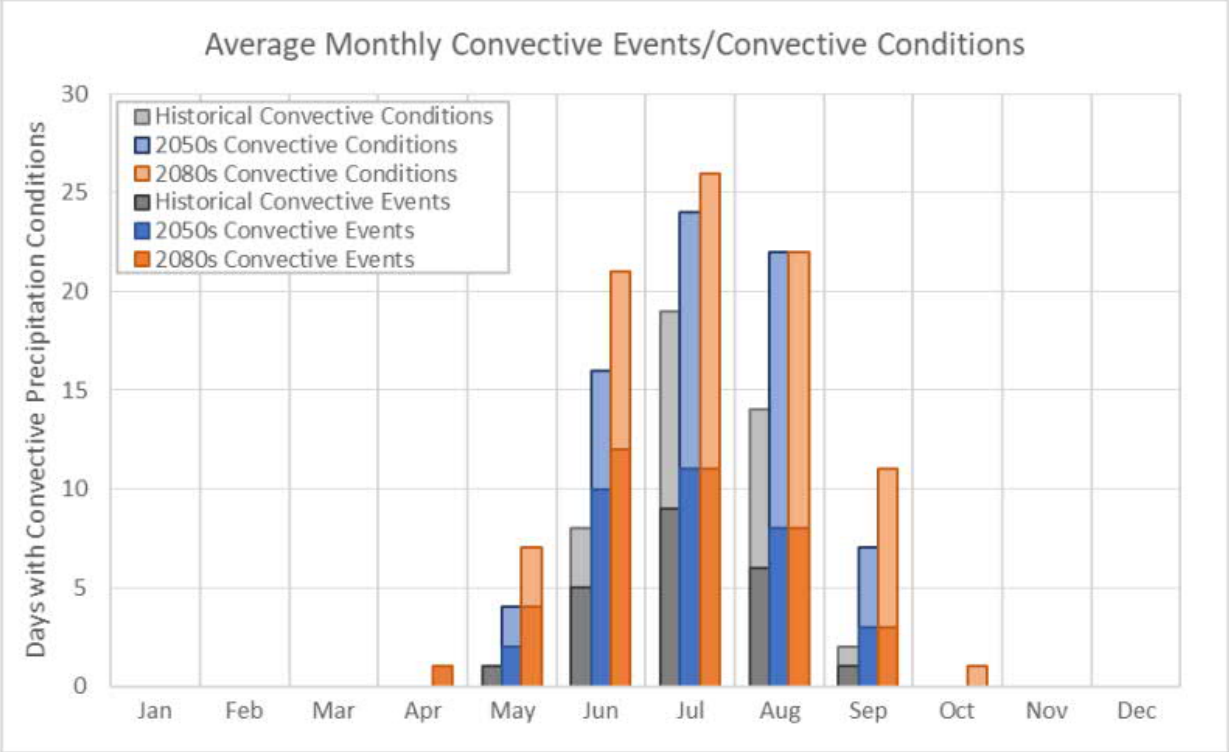

Figure A3-1: Average convective precipitation events and convective conditions per month at the Calgary International Airport (historical, 2050s and 2080s)

Table A3-21: 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	22	34	29	38	39	30	43
Mean number of days with lightning[3,4]	Annual	38.2	56.6	49.9	63.7	75.1	59.6	93.7

Severe Storms Indicators	Season	Baseline	2050s			2080s		
			Median[1]	Low[1]	High[1]	Median[1]	Low[1]	High[1]
Mean number of hail days/month[5]	Summer (JJA)	0.08	0.16	-	-	0.19	-	-

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).

[3] Lightning frequency was determined using lightning statistics from 1999-2018 for Alberta by Environment and Climate Change Canada (ECCC, 2021).

[4] Lightning projections were based on a 12% increase by degree of warming in the summer (Romps, D. M., Seeley, J. T., Vollaro, D., & Molinari, J., 2014); the median, low and high values presented are really the mean, 10th and 90th percentile of the expected values based on literature, and not the median, 10th and 90th percentile of GCM projections.

[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 A3-22 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 A3-22: 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	4.1	4.6	3.3	6.0	4.0	2.6	5.5

Notes:

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

[2] Data provided by GHD (GHD, 2020). The wind threshold of 90 km/hr was chosen based on ECCC's warning criteria for wind warnings (ECCC, 2021).

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 (2) 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 A3-23 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 A3-23: 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	10-12.5% (1:8 – 1:10)
1,230	1,500	275	5-10% (1:10 – 1:20)
1,660	2,150	494	2-5% (1:20 – 1:50)
2,020	2,820	803	1-5% (1:50 – 1:100)
3,340	5,610	2,270	0.1-1% (1:100 – 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 A3-24.

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 A3-24: 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	-	-	0.2	-	-
Mean snowfall total (cm)	Annual	93.6	72.4	64.5	82.7	59.49	53.25	69.84
1:50 year storm event[3] (cm)	Annual	32.5	17.2	-	-	17.6	-	-

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

DILLON CONSULTING

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 CCRA 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 (3) 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 B3-2:

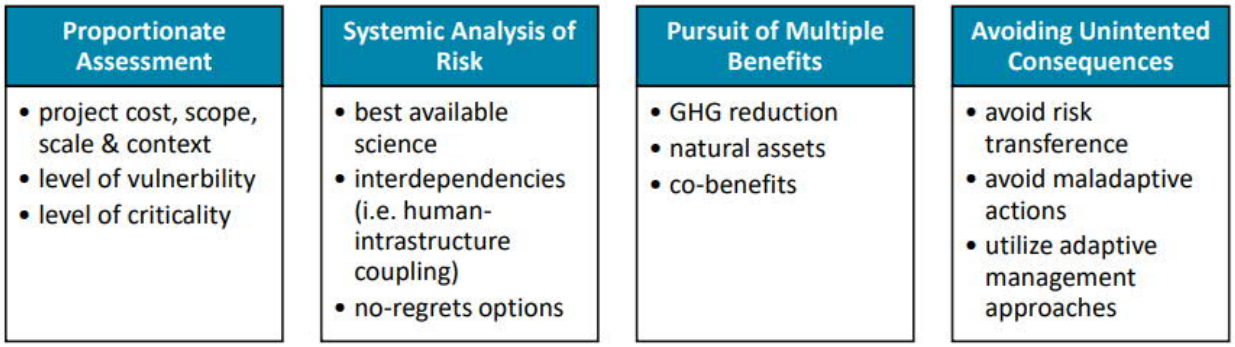

Figure B3-2: Climate Resilience Principles

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 B3-3.

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 2-4, and a full likelihood analysis for various climate indicators is provided in Appendix C with likelihoods specified by the City across its adopted five (5) point Likelihood Scale (1-5).

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 (5) 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 (5) point rating scale developed by the City).

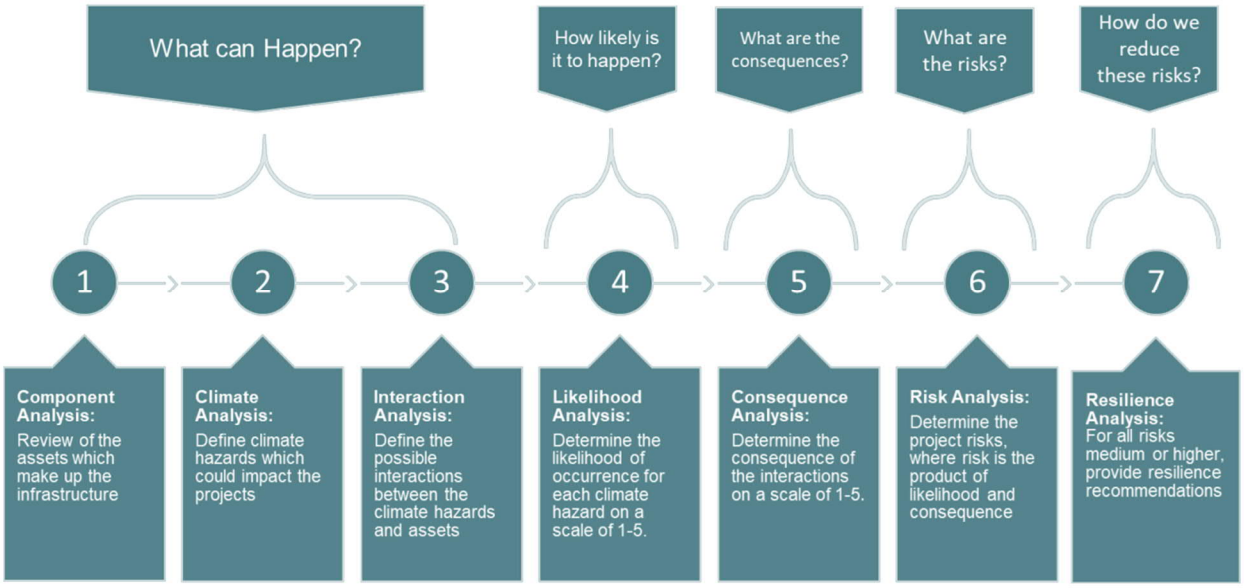

Figure B3-3: The Assessment Process

Appendix C

City of Calgary Climate Indicators and Likelihood Scores

Climate Hazard	Climate Indicator	Time Period	Likelihood			Occurrences / time period			
			Baseline	2050s	2080s	Historical	Baseline	2050s	2080s
Extreme Heat	Heatwaves [1,2]	Annual	2	5	5	-	0.2	3.0	7.1
	Hot days [3,4]	Annual	3	5	5	6.1[4]	6.8	26.5	48.1
Increased air temperature	Heating degree days (HDD) > 5000 [5,6]	Annual	5	4	4	-	4,958.7	4,093.0	3,504.5
	Cooling degree days (CDD) [4,7]	Annual	4	5	5	46.1	46.1	201.7	401.3
	Freeze-thaw cycles [4]	Annual	5	4	3	120.2	123.1	101.3	80.5
	Freeze-thaw cycles [4]	Winter	4	5	4	16.2	17.6	18.5	17.6
Wildfires	Fire spread days [8]	Annual	2	4	5	-	3.0	5.5	5.7
Drought	Dry spells [4,9,10]	Annual	4	5	5	5.8	5.9	6.0	6.0
	Dry days [4,9]	Annual	5	5	5	296	296.2	296.7	296.8
	Drought days [11]	Annual	5	5	5	-	265.2	265.7	266.2
	2-week drought [12]	Annual	4	5	5	-	0.7	0.9	1.0
	Longest dry spell [4]	Annual	5	5	5	35	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	2	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) [4,15]	Annual	3	4	5	21.6	22.0	34.0	39.9
	Days with lightning [16]	Annual	3	4	5	-	38.2	56.6	75.1
	Hail days/station/month [17]	Summer	1	2	2	-	0.08	0.16	0.19
High winds	Days where max wind gust > 90 km/hr [2,4]	Annual	3	3	3	4.7	4.1	4.6	4.0
River Flooding	1:100 year flooding [18]	Annual	2	3	3	-	-	-	-
Heavy Snowfall	10 cm of snow in 12 hours or less [2,4]	Annual	4	2	2	1.1	0.87	0.20	0.20
	Annual maximum snow load (cm) exceeding 1:50 year storm for ground snow [6,19]	Annual	1	1	1	32.5	-	17.20	17.60

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] Hot days are defined as maximum temperature ≥ 29°C.
[4] Threshold chosen based on frequency of occurrence compared to the historical average (1960 to 2014). Historical values were chosen as thresholds when other criteria were unavailable.
[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 < 10^{th} percentile.
[12] Where Precipitation – Evaporation (P-E) is < 10^{th} percentile for two (2) 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] Lightning frequency was determined using lightning statistics from 1999 to 2018 for Alberta by Environment and Climate Change Canada (ECCC, 2021). Lighting projections were based on a 12% increase by degree of warming in the summer (Romps, D. M., Seeley, J. T., Vollaro, D., & Molinari, J., 2014).
[17] Hail projections for 2050 and 2080 used a linear regression (Etkin, 2018).
[18] Derived from the Community Climate Risk Index report (WSP, 2021).
[19] 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.

Appendix D

Workshop-Validated Summary Risk Scores, CRRA Summary Worksheet

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Table D1: Extreme Heat (Heat Waves)

Asset Affected		Impact Description	Consequence Type	Preliminary Risk		
				Present	2050s	2080s
Construction Phase	*Construction Personnel*	**Bodily injury/illness with work disruptions** (heat stroke/heat related illnesses may occur, particularly when occupational requirements result in prolonged exposure)	Health & Safety	6	15	15
	Construction Equipment	**No permanent damage** **No/minimal service disruption**	Structural Integrity/ Functionality	2	5	5
Built Infrastructure	*-All transportation surfaces/facilities -All lighting/traffic control -All furnishings -Misc. (Utility Access Covers, Tree Grates, Fire Hydrants, Retaining Walls)*	**No permanent damage** (buckling/cracking may occur, occasional rutting or potholes in asphalt, necessitating signage/repair) **No/minimal service disruption** (failure of traffic lights, bus shelters, guardrails)				
	Event Space	**Minor service disruption** (reduced use of the space due to high heat)	Functionality	4	10	10
Human Wellbeing	*Operations Personnel*	**Bodily injury/illness with work disruptions** for personnel (heat stroke and heat related illnesses may occur, particularly when occupational requirements result in prolonged exposure)	Health & Safety	6	15	15
	Users	**Medical treatment for minor injury** (potential for heat stroke and heat related illnesses. Surfaces exposed to direct sunlight could lead to burns)		6	15	15
Natural Infrastructure	*Trees*	**Minor asset damage** (loss of leaves, reduced tree health esp. for new trees) **Minor service disruption** (loss of provision of shade)	Structural Integrity/ Functionality	4	10	10
	Landscaping	**No permanent damage** (loss of leaves, and reduced plant health can occur) **No/minimal service disruption** (natural infrastructure will not see any notable issues)		2	5	5
Critical 3rd Party Infrastructure *All*		**No permanent damage** **No/minimal service disruption**				

Table D2: Higher Average Temperature (Annual Freeze-thaw Cycles)

Asset Affected		Impact Description	Consequence Type	Preliminary Risk		
				Present	2050s	2080s
Construction Phase	*Construction Personnel*	A slight increase will not result in major changes to these risks, potential for **first aid injury**	Health & Safety	5	4	3
	Construction Equipment	**No permanent damage** **No/minimal service disruption**	Structural Integrity/ Functionality			
Built Infrastructure	*All transportation surfaces*	**Minor damage** (heat buckling, heat "explosions")	Structural Integrity	10	8	6
		No/minimal service disruption	Functionality	5	4	3
	-All lighting/traffic control -All furnishings -Misc. (Utility Access Covers, Tree Grates, Event Space, Fire Hydrants, Retaining Walls	**No permanent damage** **No/minimal service disruption**	Structural Integrity/ Functionality			
Human Wellbeing *All*		**First Aid Injury** (likely no serious impacts at these temperatures)	Health & Safety			
Natural Infrastructure	*Trees*	**Minor damage** (potential for influx of invasive species or pests, leading to tree degradation)	Structural Integrity	10	8	6
		No/minimal service disruption on ecosystem services	Functionality	5	4	3
	Landscaping	**No permanent damage** (potential for influx of invasive species or pests, leading to degradation) **No/minimal service disruption**, higher score associated with garden vegetation and footpaths which may require more maintenance from increased growth	Structural Integrity/ Functionality			
Critical 3rd Party Infrastructure *All*		**No permanent damage** **No/minimal service disruption**				

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Table D3: Wildfire (Fire Spread Days)

Asset Affected		Impact Description	Consequence Type	Preliminary Risk		
				Present	2050s	2080s
Construction Phase	*Construction Personnel*	**Bodily injury/illness with work disruptions (**smoke events may constrain safe work and exacerbate respiratory problems, especially during extended work periods)	Health & Safety	6	12	15
	Construction equipment	**No permanent damage** **No/minimal service disruption**	Structural Integrity/ Functionality	2	4	5
Built Infrastructure *All*		**No permanent damage** **No/minimal service disruption**				
Human Wellbeing	*Operations Personnel*	**Medical treatment for minor injury** (high smoke events can exacerbate respiratory problems, particularly when personnel have to spend extended periods of time outside in poor conditions)	Health & Safety	6	12	15
	Users	**Medical treatment for minor injury** (high smoke events can exacerbate respiratory problems, considering higher percentage of elderly residents in the South Calgary area; general users are unlikely go outside in poor conditions). Those who work and live in the area may still need to be using the space during poor air quality events		6	12	15
Natural Infrastructure *All*		**No permanent damage** **No/minimal service disruption**	Structural Integrity/ Functionality	2	4	5
Critical 3rd Party Infrastructure *All*		**No permanent damage** **No/minimal service disruption**				

Table D4: Drought (2-week Drought)

Asset Affected		Impact Description	Consequence Type	Preliminary Risk		
				Present	2050s	2080s
Construction Phase	*Construction Personnel*	**First aid injury**	Health & Safety	4	5	5
	Construction Equipment	**No permanent damage** **No/minimal service disruption**	Structural Integrity/ Functionality			
Built Infrastructure *All*		**No permanent damage** **No/minimal service disruption**				
Human Wellbeing *All*		**First aid injury**	Health & Safety			
Natural Infrastructure *All*		**Minor damage to asset or system** (encompasses longer term drought impacts. Loss of leaves, potential for tree to be weakened and more susceptible to pests; potential death of plants and replacement/remediation, particularly for more drought sensitive assets e.g., garden vegetation/lawns) **Minor service disruption may occur** (some leaves dropping, may require additional maintenance e.g., watering, raking; temporary periods of brown lawns, may require additional maintenance to replace dead plants)	Structural Integrity/ Functionality	8	10	10
Critical 3rd Party Infrastructure *All*		**No permanent damage** **No/minimal service disruption**		4	5	5

Table D5: SDHI Rainfall (1-hour Rainfall >50 mm)

Asset Affected		Impact Description	Consequence Type	Preliminary Risk		
				Present	2050s	2080s
Construction Phase	*Construction Personnel*	Work disruption and possible minor **first aid injury**	Health & Safety	2	4	5
	Construction Equipment	**No permanent damage** (site may need to be drained)	Structural Integrity			
		Minor service disruption may occur (work may be stopped until rain passes)	Functionality	4	8	10
Built Infrastructure	*-All transportation surfaces/facilities -All lighting/traffic control -All furnishings -Misc.*	**No permanent damage** (access covers can pop off if surcharged. Outdoor assets are designed to withstand brief submersion from temporary flooding) **No/minimal service disruption** (some clearing of debris may be needed for pathways)	Structural Integrity/ Functionality	2	4	5
	Pathways (i.e., Multi-use path)	**First aid injury** (potential for ponding of footpaths causing a tripping hazard)	Health & Safety			
	-Traffic Lights -Event Space	**No permanent damage** (traffic light failure)	Structural Integrity			
		Minor service disruption may occur (during period of light failure there may be some traffic confusion, events may be postponed)	Functionality	4	8	10
Human Wellbeing *All*		Work disruption and/or **first aid injury** (higher risk, general public not PPE equipped; users will likely stay inside in these weather conditions)	Health & Safety	2	4	5
Natural Infrastructure *All*		**No permanent damage** (poss. topsoil loss from erosion) **No/minimal service disruption**	Structural Integrity/ Functionality			
Critical 3rd Party Infrastructure	*Overhead Power Lines*	**No permanent damage** **No/minimal service disruption**				
	Underground Utilities	**Moderate damage to asset or system** (potential for damage from vault flooding)	Structural Integrity	6	12	15
		Minor service disruption may occur (power disruptions)	Functionality	4	8	10
	Stormwater Systems	**No permanent damage** (temporary flooding/pooling)	Structural Integrity	2	4	5
		Minor service disruption may occur (catch basins/drains may not be able to keep up/debris on streets may constrict drainage flow, leading to pooling and curb level flooding)	Functionality	4	8	10

Table D6: Severe Storms (Hail and Severe T-storms)

Asset Affected		Impact Description	Consequence Type	Preliminary Risk		
				Present	2050s	2080s
Construction Phase	*Construction Personnel*	**Minor injury** (procedures in place)	Health & Safety	2	4	4
	Construction Equipment	Damage from extreme winds (requiring restoration, minor service disruption)	Structural Integrity/ Functionality	3	6	6
Built Infrastructure	*-Sidewalks, Curbs -Bike Lanes -Pathways –Road, asphalt -Event Space*	**Minor service disruption** (blockage from debris)	Functionality			
	-Street Lighting -Roads (concrete) -Utility access covers -Fixed Furnishings	**Minor service disruption (**function impaired**)**		2	4	4
	-Temporary Furnishings	**Moderate damage** (loose items can be blown around) **Brief service disruption** (if furnishings need to be replaced)	Structural Integrity/ Functionality	4	8	8
	-Traffic Lights	**Moderate damage (**damaged by debris, toppled by strong wind)	Structural Integrity	3	6	6
		Minor service disruption (from outages)	Functionality	2	4	4
	-Bus Stops and Shelters -Signage	**Moderate damage to asset**, minor repairs may be required, signage may be a large source of debris **Brief service disruption** may occur	Structural Integrity/ Functionality	3	6	6
	-Tree Grates	**Minor damage** (from debris) **Minor service disruption** (in the case of debris blockages	Structural Integrity/ Functionality	2	4	4
Human Well-being	*Operations Personnel*	**Minor injury** (procedures in place)	Health & Safety			
	Users	**Bodily injury** (from hail, higher risk of slips/trips/falls)		3	6	6
Natural Infrastructure *All*		**Moderate damage** (uprooting and damage under extreme winds) **Brief service disruption** (debris require cleaning)	Structural Integrity/Functionality	4	8	8
Critical 3rd Party Infrastructure	*Overhead Power Lines*	**Moderate damage** (integrity of overhead lines may be affected) **Moderate service disruption** (power outages)		3	6	6
	Stormwater Systems	**Minor asset or system damage**, minor repairs or restoration		2	4	4
		Brief service disruption (debris can block drainage)	Functionality	3	6	6

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

Asset Affected		Impact Description	Consequence Type	Preliminary Risk		
				Present	2050s	2080s
Construction Phase *Construction Equipment*		**Moderate damage** (caused by debris from signage, tree branches, loose materials, etc.) **Brief service disruption** (if replacement equipment is required)	Structural Integrity/ Functionality	9	9	9
Built Infrastructure	*Temporary Furnishings*	**Moderate damage** (can be blown around if not secured) **Brief service disruption** (during period where furnishings are being replaced)	Structural Integrity/ Functionality			
	Road – driving surface and surface drainage - asphalt	**Moderate damage** (can be blocked by debris from signage, tree branches, etc.) **Brief service disruption** (for debris removal)	Functionality			
	Signage	**Moderate damage** (higher risk associated with commercial signage as it is often loose) **Brief service disruption** (during period where signs are being replaced)	Structural Integrity/ Functionality			
	-Bus stops and shelters -Fixed furnishings -Event space	**Moderate damage** (caused by debris from signage, tree branches, etc.) **Brief service disruption** (all of these assets have reduced usability under high winds/hazardous conditions)	Functionality			
Human Wellbeing *Users*		**Bodily injury/illness with work disruptions (**swept debris (e.g., construction debris, plywood and signs) can injure people, higher score compared to city personnel or construction personnel as regular users generally do not have access to PPE or awareness training, etc.)	Health & Safety			
Natural Infrastructure *Trees – street, ornamental*		**Moderate damage** (trees can be blown over and need to be restored) **Brief service disruption** (in terms of services provided by trees, i.e., shade etc.)	Structural Integrity/ Functionality			

Table D8: Heavy Snowfall (10 cm of snow in 12 hr or less)

Asset Affected		Impact Description	Consequence Type	Preliminary Risk		
				Present	2050s	2080s
Built Infrastructure	*-Sidewalks, curbs -Bike Lanes*	**Brief service disruption** (usability and accessibility maintenance issues related to snow clearing (e.g., paths may become slightly harder to use)	Functionality	12	6	6
	-Road - driving surface and surface drainage -Road - driveway ramps, concrete	**Minor service disruption** (usability and maintenance issues related to snow clearing)		8	4	4
Natural Infrastructure *Trees*		**Significant damage, loss, or complete replacement** (considering wet snow events and shoulder season snow events where leaves are still intact) **Lengthy service disruption** (considering the time required for complete tree replacement)	Structural Integrity/ Functionality	16	8	8
Critical 3rd Party Infrastructure	*Overhead Power Lines*	**Moderate damage** (downed lines due to wet snow buildup) **Brief service disruption** (considering time to restore power if an outage occurs)		12	6	6
	Stormwater Systems	**Minor service disruption** (possibility for plowed snow to block drainage assets, a follow-up rain or wet precipitation event could exacerbate impacts)	Functionality	8	4	4

References

Brimelow, J. C. (2017). The changing hail threat over North America in response to anthropogenic climate change. Nature Climate Change, 7(7), 516-522.

Cheng, C. S. (2014). Possible impacts of climate change on wind gusts under downscaled future climate conditions: Updated for Canada. Journal of climate, 27(3), 1255-1270.

Climate Atlas. (2021, 09 27). Climate Variables. Retrieved from Climate Atlas: https://climateatlas.ca/variables

COC. (2011). Stormwater Management & Design Manual. Calgary: Water Resources.

COC. (2020). Climate Resilience Strategy and Action Plans: Annual Report 2020. Retrieved from City of Calgary: https://www.calgary.ca/uep/esm/energy-savings/climate-change.html#strategy

COC. (2020b). Design Guidelines for City of Calgary Funded Buildings, Volume 1, Technical Guide, Version 2.0. Calgary.

COC. (2021, July). Drought. Retrieved from City of Calgary: https://www.calgary.ca/uep/water/waterconservation/drought.html

COC. (2021b). Community Climate Risk Profile: South Calgary.

COC. (2021, November), Public Infrastructure Climate Risk and Resilience Assessment

DeBeer, C. M. (2016). Recent climatic, cryospheric, and hydrological changes over the interior of western Canada: a review and synthesis. Hydrology and Earth System Sciences, 20(4), 1573-1598.

ECCC. (2021, 09 27). Criteria for public weather alerts. Retrieved from Environment and Climate Change Canada: https://www.canada.ca/en/environment-climate-change/services/types-weather-forecastsuse/public/criteria-alerts.html#heat

ECCC. (2021, 10 05). Lightning activity in Canadian cities. Retrieved from Environment and Climate Change Canada: https://www.canada.ca/en/environment-climatechange/services/lightning/statistics/activity-canadian-cities.html

Etkin, D. (2018). Hail Climatology for Canada: An Update. Toronto: Institute for Catastrophic Loss Reduction.

Flannigan, M. D. (2016). Fuel moisture sensitivity to temperature and precipitation: climate change implications. Climatic Change 134.1, 59-71.

GHD. (2020). 11203679-MEM-2-Technical Memorandum 2 Final. Calgary.

GOC. (2019, 10 31). Climate Lens - General Guidance. Retrieved from Infrastructure Canada: https://www.infrastructure.gc.ca/pub/other-autre/cl-occ-eng.html?wbdisable=true

Greene, S. M. (2010). Wind climatology, climate change, and wind energy. Geography Compass, 4(11), 1592-1605.

ICLR. (2016). PIEVC Engineering Protocol for Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate - Principles and Guidelines. Toronto: Institute for Catastrophic Loss Reduction.

NRC. (2019). National Building Code - 2019 Alberta Edition Volume 1. Ottawa: National Research Council of Canada. 29 November 17, 2021 Public Infrastructure 29 PCIC. (2021).

PCIC Science Brief: Should the RCP 8.5 Emissions Scenario Represent "Business as Usual?". Victoria: Pacific Climate Impacts Consortium.

Pomeroy, J. (2015). The 2013 flood event in the South Saskatchewan and Elk River Basins: Causes, assessment and damages. Canadian Water Resources Journal, Volume 41 - Issue 1-2, https://doi.org/10.1080/07011874.2015.1089190.

Rajulapati, Tesemma, Shook, Paplexiou, & Pomeroy. (2020). Climate Change in Canadian Floodplain Mapping Assessments. Saskatoon: Saskatoon: Centre for Hydrology Report No. 17, Centre for Hydrology, University of Saskatchewan.

Romps, D. M., Seeley, J. T., Vollaro, D., & Molinari, J. (2014). Projected increase in lightning strikes in the United States due to global warming. Science, 346(6211), 851-854.

Tesemma, et. al. (2020). Diagnosis of Historical and Future Flow Regimes of the Bow River at Calgary Using a Dynamically Downscaled Climate Model and a Physically Based Land Surface Hydrological Model. Saskatoon: Centre for Hydrology Report No. 18, University of Saskatchewan Centre for Hydrology.

The City of Calgary. (2017). Climate Change Adaptation Research: Vulnerabilities, Risks and Adaptation Actions, Technical Report V2.

Trenberth, K. E. (2011). Changes in precipitation with climate change. Climate Research, 47(1-2), 123-138.

Vautard, R. C. (2010). Northern Hemisphere atmospheric stilling partly attributed to an increase in surface roughness. Nature geoscience, 3(11), 756-761.

Wang, X. P. (2017). Projected changes in daily fire spread across Canada over the next century. Environmental Research Letters, 12(2), 025005.

Wotton, B. M. (2017). Potential climate change impacts on fire intensity and key wildfire suppression thresholds in Canada. Environmental Research Letters, 12(9), 095003.

WSP. (2021). Community Climate Risk Index, Final Report. Calgary: City of Calgary.

Zeng, Z. Z. (2019). A reversal in global terrestrial stilling and its implications for wind energy production. Nature Climate Change, 9 (12), 979-985.

Zhang, X. H. (2001). Spatial and temporal characteristics of heavy precipitation events over Canada. Journal of Climate, 14(9), 1923-1936.