FROM Risk TO Resilience

EMRB Climate Resilience Study

Edmonton Metropolitan Region Board

From Risk to Resilience: EMRB Climate Resilience Study

was funded in part by the Government of Alberta, through the Municipal Climate Change Action Centre's Climate Resilience Capacity Building Program. The Municipal Climate Change Action Centre is a partnership of Alberta Municipalities, Rural Municipalities of Alberta, and the Government of Alberta.

LAND ACKNOWLEDGMENT

We respectfully acknowledge that the Edmonton Metropolitan Region is located on Treaty 6 territory, as well as the home of members of the Métis Nation of Alberta (North Saskatchewan River Territory), Inuit, and non-status Indigenous Peoples sharing this land.

This land – ᒥᐢᑲᐧᒌᐚᐢᑲᐦᐃᑲᐣ, amiskwacîwâskahikan – is a traditional meeting ground, gathering place, and travelling route of the Nêhiyawak (Cree), Anishinaabe (Saulteaux), Niitsitapi (Blackfoot), Dene, and Nakota Sioux; whose unique histories, languages, and cultures continue to enrich our shared heritage.

We recognize the long history and contributions of Indigenous Peoples who have cared for this land from time immemorial to the present. We share in the spirit of truth and reconciliation as we work collaboratively to steward the land we share as we plan for a future for all citizens, and we acknowledge that we are all Treaty People, bound to one another by the Spirit and Intent of Treaty "as long as the sun shines, the grass grows and the river flows."

Executive Summary

The Edmonton Metropolitan Region is a large and complex area consisting of diverse communities and geographical differences. The Region is structured into policy tiers of **rural area, metropolitan area, and metropolitan core**, which signifies its diversity. In recognizing the uniqueness between the policy tiers, this project aims to provide proactive measures to reduce the negative impacts of extreme weather events and changing climate on the built, natural, social, and economic systems. The project methodology included a systematic approach with logical progression from identifying climate impacts, conducting risk assessment, planning for adaptation, to analyzing financial impacts and investments, as shown below.

Section 3 Climate Impacts	**Section 4** Risk Assessment	**Section 5** Adaptation Planning	**Section 6** Cost of Inaction and Adaptation Investment	**Section 7** Recommendations
Identify relevant climate impact drivers	Prioritize risks considering likelihood & consequence	Prioritize actions focusing on highest risks	Analyze impacts due to inaction and potential investment for effective risk reduction	Identify considerations for future implementation

The project approach focused on six policy areas adopted from the Edmonton Metropolitan Region Board's (Board) growth plan to facilitate consistent adaptation planning and collaboration between member municipalities. The six policy areas are summarized below.

A significant amount of relevant work has already been completed by member municipalities of the Region. To leverage and build upon the knowledge and lessons generated through this work, a participatory, bottom-up approach was adopted to engage and co-produce this assessment. The robust engagement featured participation from over 22 organizations that included Edmonton Metropolitan Region Board members, and subject matter experts from the land development, agricultural, environmental, and economic development industries. From these workshops, 25 climate impact scenarios (three being beneficial climate impact scenarios) were discussed and 28 priority adaptation measures were subsequently identified and recommended to move the Region toward a more resilient future.

Adaptation planning does not constitute an implementation plan. The adaptation measures identified in this report are for considerations and approval by the Board. The key outcomes of this project are summarized below.

FUTURE CLIMATE

To inform the identification, characterization and prioritization of climate risks and opportunities, projections of future climate conditions in the Region were produced using the latest climate science and models. By mid-century, the expected changes in the Region's climate will exhibit the following:

Climate Hazard	Description
Rising Temperatures	Rising average temperatures, leading to longer summers, earlier springs and later falls, and shorter winters—overall, the Region will be far less cold and slightly warmer.
Extreme Heat	Hotter summers, with more extreme heat, and more intense and longer heat waves.
Milder Winters	Shorter winters will be milder, with fewer cold days, frost days, and freeze-thaw cycles. Earlier snowmelt and less summer run-off, reducing summer flows in major river systems (e.g. North Saskatchewan River).
Winter/Spring Precipitation	More rain falling in winter and spring, less falling in summer, though changes in all seasons are very modest.
Heavy Rainfall	More heavy rainfall events, as water vapour in the atmosphere increases.
Wildland Fire and Smoke	Increased fire weather, with increased risk of wildland fires and wildfire smoke days.
Hail Storm	More extreme weather events such as large hail and freezing rain events.

CLIMATE RISKS

Through the engagement process, a climate change risk assessment was conducted with the Edmonton Metropolitan Region members. The primary purpose of the risk assessment was to systematically analyze climate hazards and determine in what order, the risks should be reduced or, in the case of climate opportunities, to determine if and in what order investments should be made to capture potential benefits. The results of the risk assessment for the relevant projected climate hazards were summarized in four matrices *(Built Environment, Natural Environment, Economic, Public Health, Safety, and Wellbeing*) that aligned with the Region's growth plan policy structure.

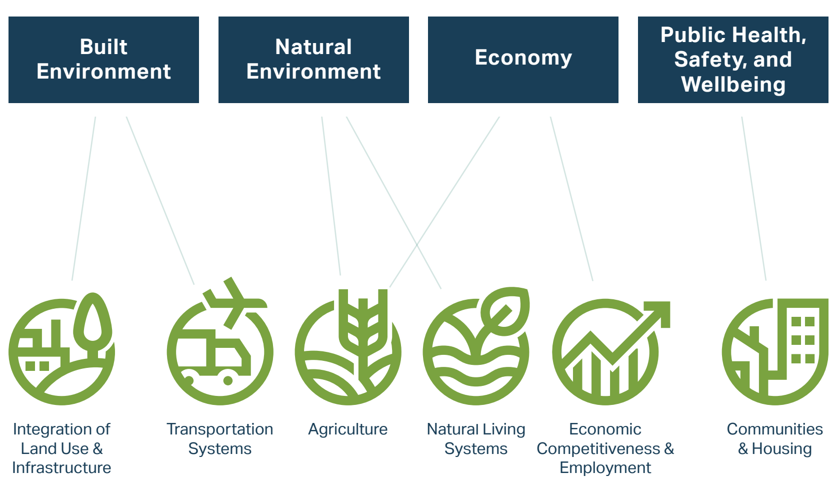

TABLE ES-1

Climate Risk Assessment Outcomes

Public Health, Safety, and Wellbeing

Very High Risk	High Risk	Moderate Risk	Low Risk
Air quality - wildfire smoke Extreme heat – public health & workforce Air quality – ground level ozone	Stormwater flooding Wildland fire (rural & urban) River & creek flooding	Tornado Supply chain disruption Hailstorm – large hail Invasive species & pests	Drought Shifting ecoregions Windstorm Freezing rain Extreme cold Freeze-thaw cycles Reduced winter rec Heavy snowfall

Economy

Very High Risk	High Risk	Moderate Risk	Low Risk
Space cooling demand Invasive species & pests Air quality – ground-level ozone Air quality – wildfire smoke Extreme heat – public health & workforce Summer drought Stormwater flooding (rural) Water shortage	Stormwater flooding (urban) Wildland fire Freezing rain, ice storm Hailstorm River & creek flooding Supply chain disruptions	Severe windstorm, gusts Extreme heat – agriculture Reduced winter rec Heavy snowfall Tornado	Extreme cold

Natural Environment

Very High Risk	High Risk	Moderate Risk	Low Risk
Invasive species & pests Extreme heat Summer drought Long-term water shortage	Shifting ecoregions Air quality – wildfire smoke River & creek flooding	Wildland fire (rural and urban) Hailstorm – large hail Air quality – ground level ozone	Severe windstorm, gusts Freezing rain, ice storm Heavy snow Tornado

Built Environment

Very High Risk	High Risk	Moderate Risk	Low Risk
	Summer drought Stormwater flooding Freezing rain, ice storm River & creek flooding Wildland fire (urban) Wildland fire (rural) Hailstorm – large Space cooling demand	Severe windstorms, gusts Extreme heat Freeze-thaw Reduced winter rec Wildfire smoke Heavy snowfall Tornado	Space heating demand Extreme cold

Figure ES-1 shows the hazards and risk levels for each system. **The "very high" and "high risks" were taken forward into adaptation planning.**

ADAPTATION MEASURES FOR CONSIDERATION

Stakeholders across the Region identified the values that should guide or motivate actions. These values formed the development of a vision statement and supporting principles, which guided prioritization of climate actions, established consistent language, and set a common direction.

The vision for climate adaptation was defined as: **"The work we do today builds the foundation of a resilient, vibrant and prosperous Region for future generations."** The guiding principles to support the vision include:

Regional Prosperity

Enabling a resilient regional economy in the context of global risks.

Environment

Protecting and restoring nature as the foundation for resilience.

Collaborative Action

Fostering trust across the Region to supercharge progress on climate action.

Proactive

Stewarding resilience planning so we are prepared for the storms ahead.

Local Sustainability

Strengthening local adaptive capacity.

Equity

Prioritize actions to protect the wellbeing and safety of the most vulnerable.

Existing initiatives and new measures required to integrate future climate risks were then identified. Enhancement of existing measures were also identified to integrate future climate risk. Based on stakeholder input, the recommended adaptation measures were grouped into seven (7) themes of similar measure **(Figure ES-2)**. These themes aligned with disciplines of practice and were compatible with the Region's growth plan.

FIGURE ES-2

Edmonton Metropolitan Region Climate Adaptation Themes

1. Coordinated Public Communication
2. Collaborative Disaster Preparedness
3. Supporting Our Most Vulnerable
4. Protecting Our Natural Environment
5. Managing Water Scarcity
6. Designing Resilient Infrastructure
7. Raising the Bar on Flood Management

It is important to note that a **regional climate adaptation plan does not replace the need for local plans,** which can **address the unique local context and needs,** but it enhances and builds on local resilience planning. Considerations for future measures most appropriate for a regional plan focus on the following:

- Using resources across communities efficiently,
- **Avoiding maladaptation** across the Region,
- Providing **consistent** messaging and measures, and
- Providing **certainty** that the Region is resilient to the future climate and a safe, reliable place to live, work and invest.

Table ES-2 provides a summary of the Region climate adaptation measures for consideration.

TABLE ES-2

Edmonton Metropolitan Region Climate Adaptation Measures

#	Measure Description
1-1	Develop a protocol for coordinated emergency alert and action communication materials that are accessible and targeted to different audiences in the Region.
1-2	Develop regional public education program on climate-related emergency preparedness.
1-3	Develop public education campaign discussing higher risk areas.
2-1	Develop a regional program to build resilience to supply chain disruptions.
2-2	Develop rapid regional response and evacuation protocols for people and livestock.
2-3	Develop and enforce regional wildland fire risk reduction and rapid response plan.
2-4	Develop comprehensive regional emergency management and business continuity plans in the case of a catastrophic event with the loss of critical services (e.g., tornado, wildland fire).
3-1	Develop a comprehensive map that highlights the locations of outdoor fountains, resilience hubs, cooling zones, and other resources accessible to vulnerable populations across the Region.
3-2	Develop programs to respond to vulnerable populations in extreme heat by fostering regional partnerships across social organizations or services.
3-3	Establish shelters for vulnerable populations during wildfire smoke events.
4-1	Develop regional policies for natural asset planning and maintenance.
4-2	Develop a regional invasive species management plan.
4-3	Allocate resources and establish regional funds to support riparian restoration projects, including tree planting and habitat enhancement along watercourses to mitigate extreme heat on the aquatic environment.
5-1	Develop regional strategies to achieve sustainable and equitable water distribution.
5-2	Promote consistent water conservation and efficiency measures across the Region.
5-3	Develop water management guidelines and promote water reuse and conservation.
6-1	Develop regional building standards to manage extreme heat.
6-2	Develop regional building standards to manage reduced air quality.
6-3	Enhance regional transportation design standards for culverts and bridges to protect major access/egress routes.
7-1	Rapidly develop regional river and creek flood hazard maps to accelerate mapping progress in smaller watercourses.
7-2	Develop higher, climate-informed regional river flood design standards and zoning changes.
7-3	Develop a regional river and creek flood management plan.
7-4	Develop a regional stormwater design standard using climate-adjusted IDF curves to mitigate localized flooding.
7-5	Develop a regional low impact development (LID) standard to mitigate localized flooding.

Regional climate resilience cannot be achieved by one entity alone, but rather will take a collaborative effort between municipalities, other orders of government, private organizations, citizens, and industry. For some adaptation considerations, the Board and municipalities may be required to lead. Additionally, other actions may require the Board to advocate to other orders of governments or industry.

Most of the adaptation measures will reduce risks for both urban and rural communities. Although many infrastructure-related standards have a stronger connection to urban development, the rural areas play a critical role in protecting and managing the natural environment, which is the foundation of resilience. Rural areas having lower density, large geographies, and less services due to increased costs mean that there will be unique needs around emergency preparedness and communication. The economic prosperity of the entire Region will need to address resilience across all policy tiers with support and collaboration across both urban and rural communities.

INVESTING IN ADAPTATION

To reduce the growing costs associated with climate impacts, investment in climate adaptation is required. Justification of investment in climate adaptation relies on the provision of defensible business cases. A key component of a business case is the **"costs of inaction"**—that is, the projected economic impacts of climate change under a business-as-usual approach, in the absence of no new adaptation policies and measures. To support a business case for adaptation action in the Region, the projected costs of inaction were estimated, and expected rates of return from adaptation investments identified.

The Region, representing 1.5 million people and generating $109 billion in economic activity, is already seeing the impacts of a changing climate. As the Region prepares to welcome another million people and nearly half a million new jobs in the next 20 years, development of infrastructure is required to support this growth. The Region's built and natural systems are intricately linked; as the Region continues to grow and evolve, it is critical to apply a climate lens to build resilience and minimize future risks associated with Region's rapid growth.

Under a high future climate scenario, expected economic losses are estimated to amount to **$4 billion per year** (2021 dollars) by mid-century (2050s). By the 2080s, expected losses are estimated to total **$10.1 billion per year**; this represents a 5-fold increase in expected annual costs compared to the 2020s. These losses will have wider macroeconomic implications. Gross Domestic Product (GDP) losses in 2055 and 2085 are estimated at **$3 billion per year** and **$8.6 billion per year**, respectively. There is an imperative for households, businesses, and governments in the Region to increase resilience to projected climate change.

The scale and direction of projected economic losses for the Region vary across climate-sensitive systems, as shown in Table ES-3. The largest source of future losses for the Region are related to:

- Adverse public health impacts, including illness, mental health disorders, hospitalization, and deaths resulting from climate-driven deteriorations in air quality, extreme heat, and other extreme weather.
- Impacts on buildings structures and function due to exposure to climate enhanced storms, floods, and rising space cooling costs.
- Damage to natural living systems, such as greenspace and ecosystem services.

While the results suggest agriculture will benefit from climate change, the estimated benefits should be viewed as overly optimistic due other challenges presented by climate change, including water availability and increased risk of pests and invasive species.

TABLE ES-3

Scale and Direction of Projected Economic Losses (2021 dollars) Across Climate Sensitive Systems in the Edmonton Metropolitan Region

SECTOR	PROJECTED LOSSES
	Losses of **$1,745M** (2050s) to **$3,335M** (2080s) annually from public health impacts caused by higher temperatures and periods of poor air quality (e.g., from wildfire smoke).
	Losses of **$110M** (2050s) to **$290M** (2080s) annually from reduced worker productivity due to higher temperatures.
	Losses of **$85M** (2050s) to **$165M** (2080s) annually from damages to transportation infrastructure and associated delays in the movement of people and freight due to high temperatures and heavy precipitation events.
	Losses of **$35M** (2050s) to **$70M** (2080s) annually from damages to electricity transmission and distribution (T&D) infrastructure due to a range of climate-related hazards.
	Losses of **$35M** (2050s) to **$95M** (2080s) annually from damages to water, wastewater, and drainage infrastructure due to river and stormwater flooding, drought conditions, extreme cold, and freeze-thaw cycles.
	Losses of **$585M** (2050s) to **$1,565M** (2080s) annually from damages to building structures and contents resulting from riverine and stormwater flooding.
	Losses of **$465M** (2050s) to **$1,570M** (2080s) annually from damages to building structures resulting from increased storms (e.g., high winds, hail) and freezing precipitation.
	Losses of **$405M** (2050s) to **$1,295M** (2080s) annually from a net increase in building energy costs (increasing cooling costs exceeding declining heating costs) due to rising seasonal temperatures.
	Losses of **$560M** (2050s) to **$2,180M** (2080s) annually from damage to natural assets and lost ecosystem services from high temperatures, drought, and increased storms.
	Increases in farmland values of **$315M** (2050s) to **$425M** (2080s) annually from rising agricultural productivity due to seasonal warming, a longer growing season, and increases in total annual precipitation.

Adapting municipalities for projected climate change and associated hazards has been conservatively estimated by the Insurance Bureau of Canada and the Federation of Canadian Municipalities to require an annual investment equivalent to **0.26% of GDP**. Over the next 10 years (2025-2035), this equates to a total investment of about **$3.2 billion** for the Region, shared between households, businesses, and all levels of government (per capita, this level of investment amounts to approximately $195 per resident per year for 10-years). Fortunately, the majority of strategies and actions to mitigate the impacts of climate hazards provide significant return on investment:
$2 to $6 in benefits (avoided costs and co-benefits) for each dollar invested.

To shed light on the potential returns from different levels of shared investment in climate adaptation across the Region, two investment scenarios were examined. The scenarios and projected outcomes are summarized in **Table ES-4**. It is evident from **Table ES-4** that a total shared 10-year investment closer to $9.3 billion (or $570 per person per year for 10-years) may be required to reduce residual economic risks to levels that might be deemed acceptable.

"Climate change is one of the Region's most pressing challenges. Through collaborative efforts, we've crafted a comprehensive climate risk and vulnerability assessment for the Region. This empowers municipalities to consider recommendations based on what aligns best with their local, sub-regional and regional priorities to help ensure that our communities remain safe, affordable and attractive to investors."

— Mayor Allan Gamble, EMRB Board Chair

TABLE ES-4

Simulated Costs and Benefits of Different Climate Adaptation Investments Scenarios for the Region

Investment Strategies (2025–2035 10-year investment by government, businesses, households)	**Present value lifetime benefits of adaptation investment**	**Reduction in projected damages** (2025–2058)	**Residual economic risks** (2025–2058)
	($2021 M)	(% of baseline costs)	(% of baseline costs)
1. Invest **$3.2 billion** (= 0.26% of projected GDP)			
$1 returns $2	6,390	12%	88%
$1 returns $3	9,585	18%	82%
$1 returns $4	12,780	23%	77%
$1 returns $5	15,975	29%	71%
$1 returns $6	19,170	35%	65%
2. Invest **$9.3 billion** (= 0.78% of projected GDP)			
$1 returns $2	19,477	36%	64%
$1 returns $3	28,015	51%	49%
$1 returns $4	37,355	69%	31%
$1 returns $5	46,695	86%	14%
$1 returns $6	54,435	100%	0%

BUILDING FUTURE RESILIENCE

When considering how the Region moves from risk to resilience, it is important that regional climate adaptation planning does not replace the need for local plans which can address the unique local context and needs but is integrated with and enhances these local efforts. In building the road map for future resilience regionally, actions most appropriate for a regional plan should focus on:

Maximize effectiveness by working regionally.

The effectiveness of some actions relies on consistency across jurisdictional boundaries, while some actions do not need to be recreated, but pool resources for efficiency.

Build on the great work the Region is already doing.

The Region has established partnerships and conducted good work to mitigate and reduce climate risks. Where appropriate, align climate adaptation measures with these current initiatives to fast-track progress and ensure consistency and relevance.

Build understanding among municipal partners of how investment and decisions in policy areas impact, positively or negatively, climate risks.

Just as adaptation investments can provide co-benefits, investment in other policy areas can have co-benefits or co-costs for climate resilience, which need to be identified and understood. Understanding these interdependencies is necessary to avoid maladaptation, help mainstream adaptation into decision-making, and to ensure cost-effective adaptation.

Help municipal partners better understand the hurdles faced by households and businesses to adapt to climate change.

A significant share of the projected investment in climate adaptation needs to be made in the private sector. Understanding the barriers faced by different private sector actors is necessary to develop and target supports to encourage effective private adaptation.

Showcase substantial resilient measures to grow regional prosperity.

Consistency and certainty in enhanced standards and guidelines 'levels the playing field' for development across the Region, which in turn demonstrates that the Region is a resilient and reliable place to invest.

Communicate the urgency in ramping up investment in climate adaptation.

The business case for adaptation is robust — actions to increase climate resilience typically provide benefits well in excess of costs. An investment of $9 billion by households, businesses and governments over the next 10 years would significantly reduce projected losses, generating benefits of $19 billion-$54 billion.

Support the development of adaptation strategies that optimize the generation of co-benefits and facilitate multi-solving.

Given the scale of adaptation investment needed, there is a significant opportunity for that investment to provide benefits across multiple regional priorities. This will help achieve larger benefits for each dollar invested, improving the business case for action.

Develop a framework to demonstrate success.

The Edmonton Metropolitan Region Board needs to be able to demonstrate resilience for the Region to be perceived as a reliable place to invest. Implementation planning to operationalize the measures in this plan should include:

- Develop targets and indicators to drive actions and accountability, to be communicated publicly.
- Identify roles and responsibilities to carry out each of the measures considering equitable distribution of the workload and resource contributions.
- Identify existing initiatives and resources best suited to drive each of the measures in this plan.
- Develop a timeline and resource plan for implementation of the measures in this plan.

"In order to remain competitive and support our amazing businesses and entrepreneurs in a local, regional and international market, we must ensure the Region is prepared to protect our environment and adapt to a changing climate. The EMRB's comprehensive regional climate risk and vulnerability assessment will allow us to develop sustainable, resilience-based solutions that better protect the health and well-being of all the Region's businesses and infrastructure."

— Mayor Amarjeet Sohi, City of Edmonton

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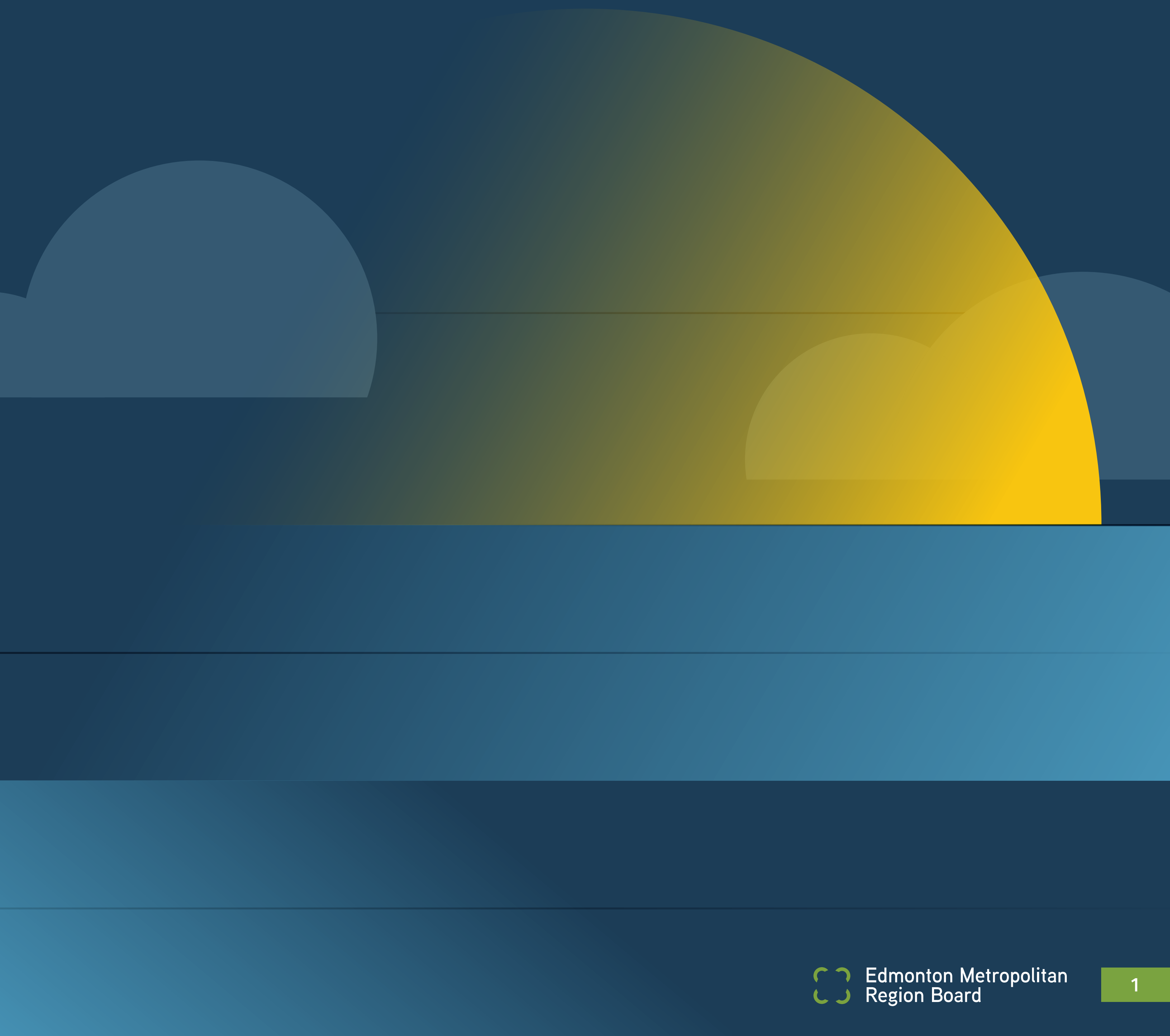
Introduction



The Edmonton Metropolitan Region Board growth plan, established a 50-year vision and guiding principles for the long-term sustainability for the Region. The **50-year vision** states that the Edmonton Metropolitan Region is:

- The dominant hub for northern Alberta and is recognized globally for its economic diversity, entrepreneurialism, leadership in energy development, environmental stewardship and excellent quality of life.
- Anchored by a thriving core that is interconnected with diverse urban and rural communities.
- Committed to growing collaboratively through the efficient use of infrastructure, building compact communities and fostering economic opportunities a healthy lifestyle.

The Region is a large and complex area that consists of diverse communities, and these areas have geographical difference of varying roles, opportunities, and constraints for growth. As such, the **regional structure** **(Figure 1-1)** introduces three policy tiers: rural area, metropolitan area, and metropolitan core, which reflect the diversity within the Region. The following briefly defines the areas:

FIGURE 1-1

Policy Tiers

Rural Area

is lands outside of the metropolitan area consisting of agricultural lands, natural living system, recreation areas, and resource extraction.

Metropolitan Area

is the area surrounding the metropolitan core including portions of county land, urban communities. This area encompasses the highest concentration of existing and future urban development and reflects the general direction of future urban growth.

Metropolitan Core

is the contiguous developed area within the City of Edmonton with the highest density development and amenities.

In recognizing that the changes in climate could impact the ability of the Edmonton Metropolitan Region Board to achieve its goals and vision, the Board embarked on this project to collectively conduct a regional climate risk assessment, and adaptation planning, while **recognizing the unique differences** between the metropolitan core, metropolitan area, and rural area policy tiers. The proactive adaptation measures have goals of reducing negative impacts to the built, natural, social, and economic systems from extreme weather events and changing climate conditions. The outcome of this project provided a list of prioritized regional actions for consideration to **guide future implementation.**

1.1 Climate Initiatives in the Edmonton Metropolitan Region

Collectively, members of the Edmonton Metropolitan Region have completed significant work that identified the opportunities to reduce climate risks within their communities. Several members have participated in and contributed to the **Edmonton Metropolitan Region Climate Resilience Exchange: State of Knowledge Summary**, which explored climate impacts and risks to the Region – see **Table 1-1**. Furthermore, some municipalities have completed climate risk and vulnerability assessments, and are working on adaptation planning. The completed climate work provided the **opportunity for sharing information and coordinating regional efforts** without "re-inventing the wheel". This project team has been involved in developing some of the content with the members. As such, the information from the completed climate work has been used to inform this project.

TABLE 1-1

Municipalities – Climate Initiatives

Municipality	GHG Reduction/Clean Energy	Adaptation/Environmental Planning
Beaumont	Partners for Climate Protection (no milestone)	Environmental Master Plan (Updated 2021) Urban Forest Management Strategy (2023)
Devon	Clean Energy Improvement Program (2019) Partners for Climate Protection (milestone 3)	Green Devon – the Town of Devon Green Strategy (2016) Climate Risk Assessment and Adaptation Plan (anticipated 2024)
Edmonton	Clean Energy Improvement Program (2021) Community Energy Transition Strategy (2021) Global Covenant of Mayors for Climate & Energy Partners for Climate Protection (milestone 5)	Climate Resilience Adaptation Strategy and Action Plan (2018)
Fort Saskatchewan	Fort Air Partnership	
Leduc	Clean Energy Improvement Program (2021) Environmental Plan (2012) Weather and Climate Readiness Plan (2014) GHG Reduction Action Plan (2020) Partners for Climate Protection (milestone 3)	Integrated Pest Management Plan (2017)

TABLE 1-1 - CONTINUED

Municipalities – Climate Initiatives

Municipality	GHG Reduction/Clean Energy	Adaptation/Environmental Planning
Leduc County	Developing Own Development Standards	
Morinville		Asset Management Program for Trees Water Conservation, Efficiency & Productivity Plan [CEP] (2012)
Parkland County	Partners for Climate Protection (milestone 2)	Climate Resilience Adaptation Strategy and Action Plan (2018)
St. Albert	Partners for Climate Protection (milestone 5) Clean Energy Improvement Program (2022) Energy Management Plan	Environmental Master Plan (2014) Developing Climate Action Plan Climate Adaptation Plan (2022)
Spruce Grove	Partners for Climate Protection (milestone 5)	Environmental Sustainability Action Plan (2011) Climate Change Action Plan (2022)
Stony Plain	Partners for Climate Protection (milestone 4)	Environmental Master Plan (2021) Environmental Stewardship Strategy (2021)
Strathcona County	Clean Energy Improvement Program (2023) Electric Vehicle Charging Program (2023) Strategic Energy Management Plan (2021) Waste Management Roadmap (2021) Partners for Climate Protection (no milestone)	BARC Program (milestone 3) (2023) Wetland Replacement Program (2023) Astotin Creek Resiliency Plan (2022) Environmental Framework (2021) Beaver Hills Biosphere Climate Resilience Action Plan (2019)
Sturgeon County	Benchmarking Energy Consumption Study (2022) Clean Energy Improvement Program (2021)	Climate Adaptation Plan (2022)

1.2 Project Approach

The project approach undertaken is illustrated in **Figure 1-2**. This systematic approach provided an evidence-based and logical progression, from identifying climate drivers to climate risk assessment and adaptation planning; the outcome of each task informed the next. The economic analyses (*cost of inaction and the level of investments*) were conducted based on the results of climate risk assessment and prioritized adaptation actions, respectively. **Figure 1-2** also identifies the corresponding sections of the report that follows the same logical flow.

FIGURE 1-2

Project Approach

Section 3 Climate Impacts	**Section 4** Risk Assessment	**Section 5** Adaptation Planning	**Section 6** Cost of Inaction and Adaptation Investment	**Section 7** Recommendations
Identify relevant climate impact drivers	Prioritize risks considering likelihood & consequence	Prioritize actions focusing on highest risks	Analyze impacts due to inaction and potential investment for effective risk reduction	Identify considerations for future implementation

The project approach focused on six policy areas adopted from the growth plan to facilitate consistent adaptation planning and collaboration between member municipalities.

FIGURE 1-3

Policy Areas

- **Economic Competitiveness & Employment**
- **Natural Living Systems**
- **Communities & Housing**
- **Integration of Land Use & Infrastructure**
- **Transportation Systems**
- **Agriculture**

Based on the policy areas, the climate risk assessment and adaptation planning for this project was conducted on the **four main systems: Built Environment, Natural Environment, Economy, and Public Health, Safety, and Wellbeing** to show their interconnectivity across the Region. These systems align with the National Adaptation Strategy National Adaptation Strategy for Canada - Canada.ca.

With the key focus on regional collaboration, the **stakeholder engagement** process was an important part of this project. The valuable input from the municipal and subject matter experts provided the foundation for a collaborative adaptation portfolio that encompassed the rural area, metropolitan area, metropolitan core.

In total, nine workshops were conducted to gather valuable input to inform each phase of the project. From these workshops, 25 climate impact scenarios were identified, three of which were beneficial climate impact scenarios. 28 key adaptation considerations were subsequently identified. Additional workshop descriptions and list of the municipal and subject matter experts are provided in **Appendix A**.

1.3 Assumptions

Work that was out of scope is listed as follows:

- New climate model for this Region.
- Risks associated with locations outside the geographical area. Discussion on supply chain impacted by climate hazards was considered but not analyzed.
- Detailed engineering assessment on specific impacts to individual assets or infrastructure components.
- Population growth and employment projections were not considered in climate risk assessment; the assessment was conducted on conditions of today.

Adaptation planning does not constitute an implementation plan. The outcome of adaptation measures in this report are for consideration and approval by the Edmonton Metropolitan Region Board.

Engagement

- **25** Hours of engagement through workshops 1 to 9
- **22** People participated in workshops
- **21** Edmonton Metropolitan Region members

Outcomes

- **22** Negative climate impact scenarios
- **3** Beneficial climate impact scenarios
- **28** Key adaptation actions identified

2

Future Climate for the Edmonton Metropolitan Region

2.1 Projected Changes in the Edmonton Metropolitan Region's Climate

Understanding how the Region's climate is projected to change is necessary to anticipate how existing pressures will compound and give rise to new risks. To inform the identification, characterization, and prioritization of climate-related threats and opportunities, our climate scientist at Prairie Adaptation Research Collaborative (PARC) from the University of Regina provided projections of future climate conditions in the Region.

To help address the main source of uncertainty and build a more accurate picture of future climate scenarios, outputs from an ensemble of **11 simulations of daily data** were developed based on four high-resolution Regional Climate Models (RCMs). Percentiles were then used to determine where the majority of outcomes fell across the different simulations and RCMs. **Table 2-1** provides projections for 15 climate variables for the 50th percentile (or median outcome across the 11 simulations) and the 10th and 90th percentiles. Apart from a few outliers, most of the projections fell between these two percentiles. 50% of the projected outcomes for the Region fell below the median value.

To address uncertainty in climate projections, an ensemble of results from various climate scenarios are typically provided. A low, moderate, or high climate scenario is defined by alternative levels of greenhouse gas emissions and Radiative Forcing[1]. For climate risk assessments, best practice necessitates working with the greatest plausible change scenario, Representative Concentration Pathway 8.5 (RCP 8.5)[2].

The simulations of future projections for the Region used the RCP 8.5[3]; the primary justification was to ensure that the worst-case scenario would be considered and that the Region was best equipped to manage the most material impacts of climate change. Uncertainties relating to whether the future unfolds along RCP 8.5 or along a different, lower climate forcing scenario, can be managed during formulation and prioritization of actions in the adaptation planning phase.

Table 2-1 summarizes projections for 15 climate variables for the Region. When determining how much the climate is anticipated to change at a specific location like the Region, it is recommended to consider at least 30 years of data. This means calculating and comparing 30-year averages at different points in time. For instance, projected model outcomes for 2050s represent the annual average value for the period 2041-2070. This is necessary to ensure that long-term historical trends and projected changes in the climate are not biased by short-term natural variability in the climate, such as the influence that both El Nino and La Nina events exert on Canada's climate. Table 2-1 provides results for one future time period: the 2050s (the annual average over 2041-2070). Modelled historical results are also presented for the 1976-2005 baseline period to enable a comparison with past conditions. The modelled historical outcomes were compared with future projections from the same ensemble of models rather than with historical observations from local weather stations to reduce bias when contrasting future climate projections with past conditions.

[1] Radiative Forcing describes the amount of excess energy trapped within the Earth's climate system due to variations in a determinant of climate change, such as concentrations of heat-trapping, GHGs in the atmosphere—expressed in terms of Watts per m^2 in 2100. The larger the number, the higher the level of Radiative Forcing and corresponding anticipated changes in the climate.

[2] The number indicates the level of assumed Radiative Forcing by the end of the century—in this case, 8.5 Watts per m^2.

[3] The number indicates the level of assumed Radiative Forcing by the end of the century—in this case, 8.5 Watts per m^2.

TABLE 2-1

Projected Values for a Selection of Climate Variables for the Edmonton Metropolitan Region by the 2050s

Climate Variable	Historical (1976-2005)[8]	2050s (2041-2070)			
	Median Values	Median Values	Change[9]	10th Percentile	90th Percentile
Mean winter temperature (°C)	-7.9	-3.8	+4.1	-7.4	-0.9
Mean spring temperature (°C)	9.6	12.2	+2.6	10.6	14.1
Mean summer temperature (°C)	14.4	17.5	+3.1	15.7	19.5
Mean fall temperature (°C)	-3.3	-0.1	+3.2	-2.5	2.3
Mean maximum summer temperature (°C)	21.2	24.0	+2.8	21.8	26.6
Very hot days [≥ +30°C] (Days)	1	11	10	2	28
Very cold days [≤ -30°C] (Days)	6	0	-6	0	4
Cooling Degree Days (Degree Days)[10]	12	144	132	66	259
Heating Degree Days (Degree Days)[11]	5,657	4,331	-1,326	3,867	4,869
Frost-free days (Days)	165	213	+48	188	234
Freeze-thaw days (Days)	103	81	-22	63	101
1-day maximum precipitation (mm)	27	30	+3	19	46
Total annual precipitation (mm)	493	555	+62	439	688
Heavy precipitation days [≥ 10 mm] (Days)	9	12	+3	7	17
SPEI 12-months[12] (index value)	1.7	1.0	-0.7	0.5	1.3

[3] The number indicates the level of assumed Radiative Forcing by the end of the century—in this case, 8.5 Watts per m2.
[4] All historical values are "modelled values"—i.e., produced using the RCMs—as opposed to observed values. Modelled historical values are simulated data; as a result, annual values will not be exactly the same as observed historical data, although the 30-year climatological monthly, seasonal and annual averages over regional or larger scales will be similar. Since the climate models and weather station observations do not generally represent data at the same spatial scales, it is thus important to use modelled historical values when making direct comparisons with modelled future values—e.g., to calculate changes.
[5] Change is measured relative to the modelled historical value for the baseline period 1976-2005.
[6] The Cooling Degree Days (CDD) index is the annual sum of the number of degrees by which daily mean temperatures exceed 18°C. For example, a single day with a mean temperature of 20°C would contribute 2 to the annual sum of degree days. The CDD index provides a measure of the energy demand needed to cool buildings.
[7] The Heating Degree Days index is the annual sum of the daily mean temperatures that are less than 18°C. For example, a single day with a mean temperature of 16°C would contribute 2 to the annual sum. The HDD index provides a measure of the energy demand needed to heat
[8] The Standardized Precipitation Evapotranspiration Index (SPEI) is a water balance index based on the monthly difference between precipitation and potential evapotranspiration. The SPEI provides a measure of potential drought or excessive moisture conditions, with values greater than +1 being associated with excessive moisture, and values less than -1 being associated with dry conditions or drought. Values between -1 and +1 indicate normal moisture conditions.

The key expected changes in the Region's climate by the 2050s are summarized below:

TABLE 2-2

Key Expected Changes

Climate Hazard	Description
Rising Temperatures	Rising average temperatures, leading to longer summers, earlier springs and later falls, and shorter winters—overall, the Region will be far less cold and slightly warmer.
Extreme Heat	Hotter summers, with more extreme heat, and more intense and longer heat waves.
Milder Winters	Shorter winters will be milder, with fewer cold days, frost days, and freeze-thaw cycles. Earlier snowmelt and less summer run-off, reducing summer flows in major river systems (e.g. North Saskatchewan River).
Winter/Spring Precipitation	More rain falling in winter and spring, less falling in summer, though changes in all seasons are very modest.
Heavy Rainfall	More heavy rainfall events, as water vapour in the atmosphere increases.
Wildland Fire and Smoke	Increased fire weather, with increased risk of wildland fires and wildfire smoke days.
Hail Storm	More extreme weather events such as large hail and freezing rain events.

> "Our Region is as diverse as the people who call it home. This assessment explores the distinct challenges climate change poses in different locales and provides insights into what our communities may want to consider to enhance the resiliency of our infrastructure and local economies"
>
> **— Mayor Rod Frank, Strathcona County**

2.2 Climate Hazards and Impact Scenarios

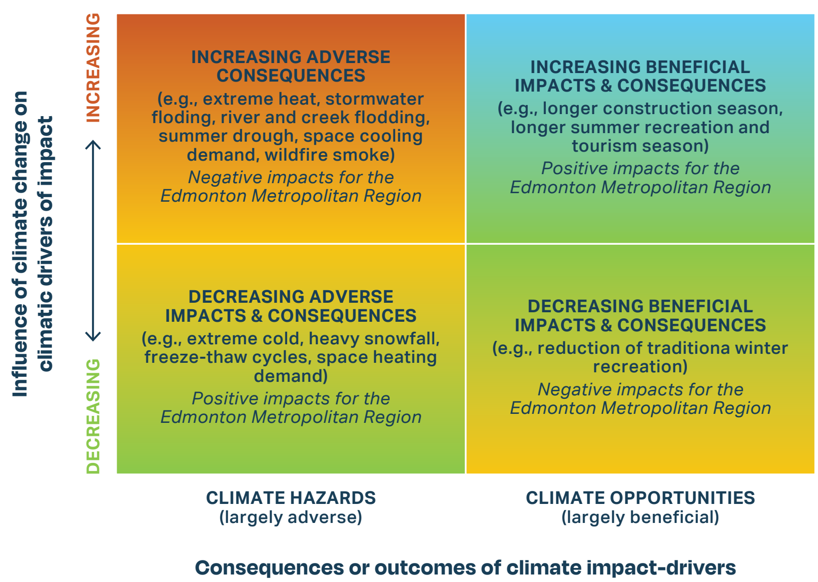
With an understanding of how the climate is anticipated to change, as well as insights gained from existing climate risk assessments in the Region, a set of relevant climate-driven impacts was identified. The **climate impact scenario** characterized the cause-and-effect relationship, or impact chain, between changes in climate variables, impacts, and the potential consequences of those impacts on the Region. The climate impact scenarios also accounted for local exposure to climatic drivers of impacts, including consideration of the vulnerability (sensitivity and lack of coping capacity) of local services, infrastructure, population groups, etc. Vulnerability to a given climate-related impact influences the magnitude or severity of expected consequences.

Climatic conditions that cause largely negative consequences are known as **climate hazards**. Conversely, climate conditions that cause largely positive consequences are commonly known as **climate opportunities** (i.e., beneficial opportunities of climate origin). In total, **22 climate hazards** and **three (3) climate opportunities** were identified. The details of the climate hazards are shown in **Appendix B**.

Depending on climatic conditions, a climate hazard may either increase (worsen) or decrease (become less problematic) in the future. These changes may result in either increased (enhanced) risk or decreased (reduced) opportunity as shown on **Figure 2-1**.

FIGURE 2-1

Assessing Climate Impacts



The climate impact scenarios were prepared and validated with the representatives from member municipalities and subject matter experts. The finalized set of 25 climate impact scenarios are found in **Appendix C**. Each climate impact scenario includes:

- A description of the event
- The main climatic drivers
- A threshold that defines the intensity of the scenario
- Estimates of the likelihood of the scenario occurring historically and in the 2050s
- Potential consequences should the scenario occur
- Factors that influence the Region's vulnerability

3

Assessing the Region's Climate Risks

3.1 Importance of Risk Assessment

Time, money, and resources available to households, businesses, and local governments are generally limited. As a result, it will not be possible to mitigate all identified climate hazards or fully take advantage of all the opportunities presented by climate change. A key purpose of a risk assessment is to systematically analyse threats to determine if, and in what order, they should be reduced or eliminated; or, in the case of climate opportunities, to determine if and in what order investments should be made to capture potential benefits. This involves sorting identified climate hazards and opportunities into different buckets in a matrix that can be used to help set priorities for adaptation planning. The risk matrix or heat map as shown on **Figure 3-1** combines two intersecting factors: the likelihood that a climate impact scenario will occur, and the anticipated consequences should the scenario occur. Creating a 5 x 5 risk matrix for the climate scenarios involved assessing likelihood and consequences on a 1 to 5 scale.

FIGURE 3-1

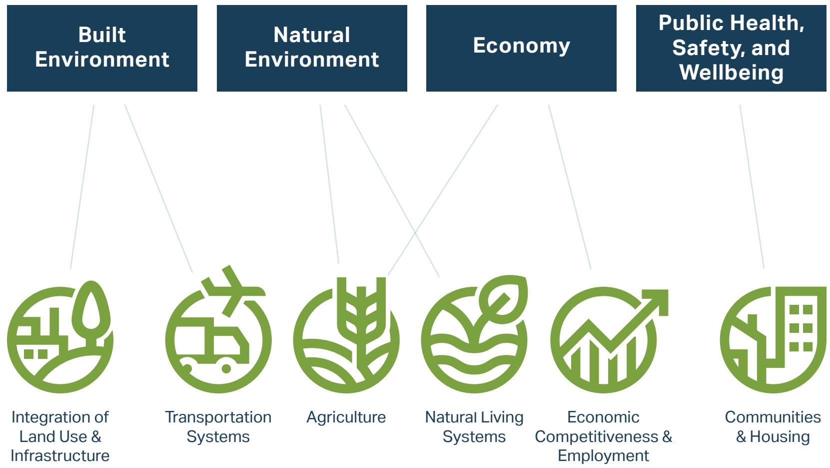
Risk Matrix

Consequence \ Likelihood	Rare (1)	Unlikely (2)	Possible (3)	Likely (4)	Almost certain (5)
Very High (5)	HIGH	HIGH	VERY HIGH	VERY HIGH	VERY HIGH
Likely (4)	MODERATE	HIGH	HIGH	VERY HIGH	VERY HIGH
Possible (3)	LOW	MODERATE	MODERATE	HIGH	HIGH
Unlikely (2)	VERY LOW	LOW	LOW	MODERATE	MODERATE
Rare (1)	VERY LOW	VERY LOW	LOW	LOW	LOW

To assess the level of threat posed to the six policy areas due to climate change, separate risk matrices were generated for Built Environment, Natural Environment, Economy, and Public Health, Safety, and Wellbeing. The linkages to the policy areas are illustrated in **Figure 3-2:**

FIGURE 3-2

RELEVANCE TO THE SIX POLICY AREAS



3.2 Assessing Likelihood

The goal of a likelihood assessment is to determine the chance of each climate impact scenario occurring, historically (during the baseline period 1976-2005) and in the future (the 2050s). Estimates of the likelihood of each impact scenario were developed by the consultant team, using one of the following methods:

- **Estimation based on climate projections:** Where projections for relevant climate variables were provided by our climate scientists, the annual (exceedance and non-exceedance) probability and return interval was calculated for defined intensity levels (or thresholds) of interest.
- **Research from other assessments or studies:** Where relevant numerical climate projections were not available from our climate scientist, data and results from other risk assessments or published studies were used to calculate or identify relevant likelihoods—e.g., Jeong et al. (2019) was used for the freezing rain-ice storm impact scenario and the Short-duration Rainfall IDF Data available from ClimateData.ca was used for the heavy rainfall and stormwater flooding scenario.
- **Professional judgement:** In cases where numerical data were not available through a data portal, or from other assessments or studies, professional judgement was used to generate relevant likelihood estimates.

[9] Jeong, D., Cannon, A. and Zhang, X., 2019: Projected changes to extreme freezing precipitation and design ice loads over North America based on a large ensemble of Canadian regional climate model simulations, Nat. Hazards and Earth System Science, 19, 857-872.

All likelihood estimates — whether calculated, researched, or based on professional judgement — were converted to 1 to 5 scores. The scoring rubric is shown on **Table 3-1**. Details of likelihood scoring for each climate impact scenario is shown in **Appendix C**.

> "The Region's built and natural environments are intricately linked. As our communities inevitably grow, we must continue to carefully weave the two with an eye to the climate risks we all face. This assessment serves as a compass, guiding us towards sustainable solutions and fostering a collective commitment to safeguarding our communities and the Region against the challenges of a changing climate."
>
> **— Mayor Cathy Heron, City of St. Albert**

TABLE 3-1

LIKELIHOOD SCORING RUBRIC

Score	Descriptor	Recurring Climate Impact Events	Ongoing Climate Impact Events
5	Almost Certain	Event is anticipated to occur once every two years or more (RI ≥ 1:2-years) (AP ≥ 50%)	Event is virtually certain to occur in specified timeframe
4	Likely	Event is expected to happen once every 3 to 10 years (1:2 < RI £ 1:10) (10% £ AP < 50%)	Event is expected to occur in specified timeframe
3	Possible	Event is expected to happen once every 11 to 50 years (1:10 < RI ≤ 1:50) (2% ≤ AP < 10%)	Event is just as likely as not to occur in specified timeframe
2	Unlikely	Evet is expected to happen once every 51 to 100 years (1:50 < RI ≤ 1:100) (1% ≤ AP < 2%)	Event is not anticipated to occur in specified timeframe
1	Rare	Event is expected to happen less than once every 100 years (RI < 1:100-years) (AP <1%)	Event is almost certain not to occur in specified timeframe

3.3 Assessing Consequence

The assessment also involved assigning categorical and numerical values to the potential consequences of each climate impact scenario on a 1 to 5 scale. A scoring rubric for rating these consequences was prepared specifically for the Region — enabling the scored consequences to be readily mapped considering the six policy areas in the growth plan. The scoring rubric also aligned with the Alberta Emergency Management Agency's Hazard Identification and Risk Assessment (HIRA) framework, and with guidance and best practices for climate change risk assessments[10]. The rubrics used to score the consequences for both identified climate hazards and climate opportunities are provided at **Appendix D**.

A participatory approach — **designed to engage the representatives from member municipalities and subject matter experts** — was adopted to develop and finalize consequence scores for all identified climate hazards and opportunities. This engagement assessed the consequences anticipated to arise should each of the identified climate impact scenarios occur. The consequences scoring for each climate impact scenario is shown on the same climate impact scenario sheets found the **Appendix C**. Potential consequences were mapped onto the six policy areas and were separately identified with colour codes shown in these climate impact scenario sheets, as follows:

1. **Public Health, Safety, and Wellbeing**
2. **Economy**
3. **Built Environment**
4. **Natural Environment**

When assessing consequences, workshop participants were instructed to overlay the expected climate of the 2050s onto the Region of today. This involved assuming the given climate impact scenario for the 2050s occurring today, in consideration of any relevant existing or planned initiatives that would mitigate the severity of the identified consequences.

3.4 Risk Outcome

Risk is calculated as the product of likelihood and consequence. The detailed risk scores for each climate impact scenarios are presented in **Appendix E.** For the three climate opportunities (longer construction season, longer summer recreation and tourism season, and longer agricultural growing season) the anticipated consequences and overall level of benefit for the Region were rated as "moderate"

[10] See for example: International Organization for Standardization (ISO) guideline 14092 – Climate adaptation planning for local governments and communities; All One Sky Foundation - Climate Resilience Express Community Climate Adaptation Planning Guide; and the Canadian Council of Ministers of the Environment (2021) Guidance on Good Practices in Climate Change Risk Assessment.

RISK MAPS

The following risk maps show the overall climate hazards from "low" to "very high risks" for the four systems.

FIGURE 3-3

PublicHealth, Safety, and Wellbeing

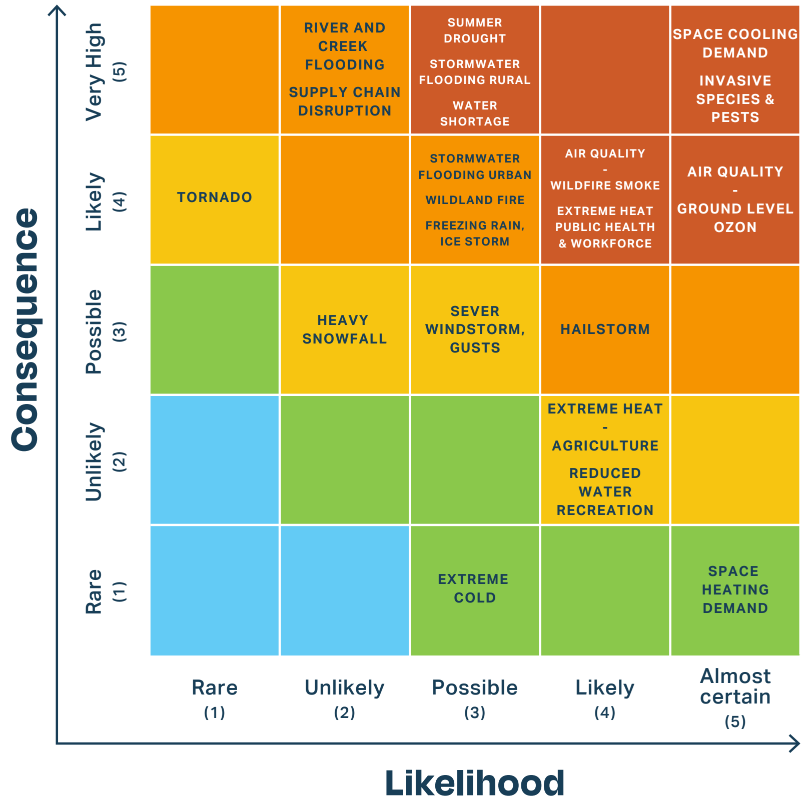
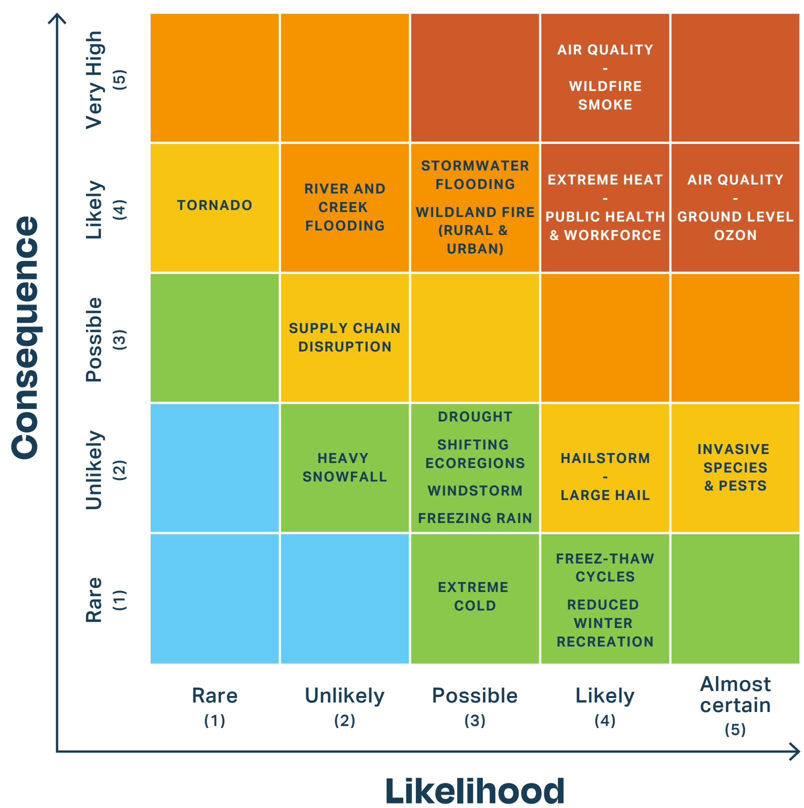


FIGURE 3-4

Economy



RISK MAPS

CONTINUED

FIGURE 3-5

Natural Environment

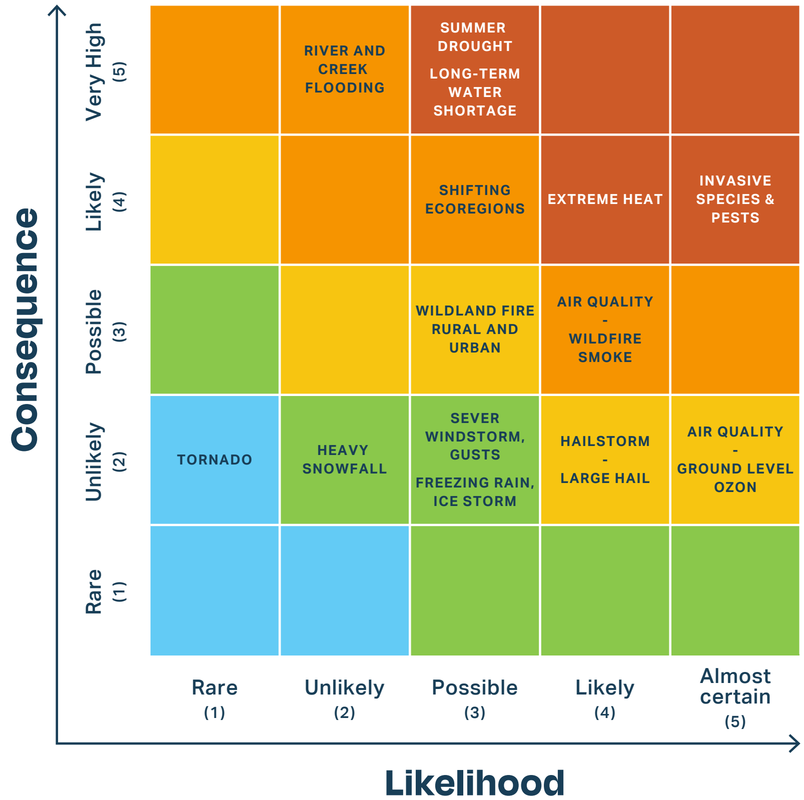
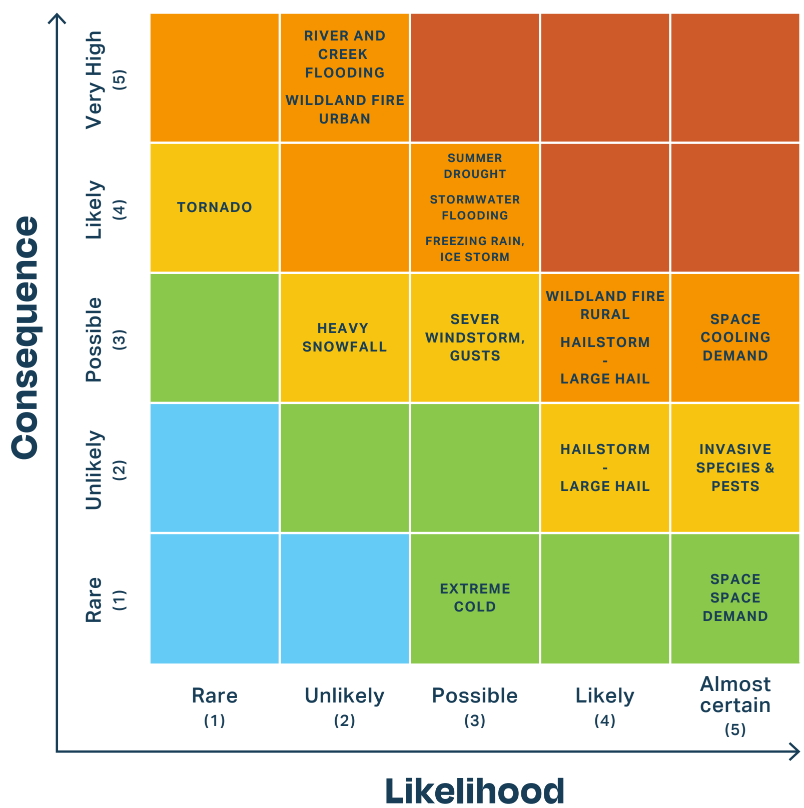


FIGURE 3-6

Built Environment



4

Adaptation Measures for Consideration

The purpose of the climate risk assessment is to focus the efforts on the highest risks while recognizing the related initiatives already underway. **Stakeholders across the Region provided input on existing initiatives and identified new measures required or enhancement of existing measures to integrate future climate resilience.** This does not mean that the lower priority risks should not be addressed, but rather that increased focus above and beyond existing initiatives may not be required at this time.

It is important to note that a **regional climate adaptation plan does not replace the need for local plans, which can address the unique local context and needs**, but in fact enhances and builds on local resilience planning.

Considerations for future measures most appropriate for a regional plan should focus on the following:

- Using resources across communities **efficiently** to avoid duplication of efforts and to supercharge the rate of progress (i.e., to take advantage of economies-of-scale offered by a collaborative response).
- **Avoiding maladaptation** across the Region, whereby actions in one jurisdiction or climate-sensitive sector increase risks or limit risk mitigation elsewhere.
- Providing coherent messaging and communication across the Region, and adopting **consistent** regulations and standards, where applicable.
- Provide **certainty** to individuals, families, and businesses that the Region is resilient to the future climate and a safe, reliable place to live, work and invest in.

The adaptation planning process included the following:

1 Development of Adaptation Vision and Guiding Principles

Stakeholders (municipal and subject matter experts) identified what values should guide or motivate actions. These values then formed the development of a vision statement and supporting principles, which guides prioritization of climate actions, establishes consistent language, and sets a common direction.

The vision for climate adaptation was defined as: **"The work we do today builds the foundation of a resilient, vibrant and prosperous Region for future generations."** The guiding principles to support the vision include regional prosperity, collaborative action, local sustainability, environment, proactive, and equity.

2 Identification of Adaptation Measures

Potential adaptation measures were collectively identified by stakeholders focusing on the high and very risks to the Region. Climate change is a risk multiplier, therefore, many of these hazards and associated impacts may already be managed to some degree by municipalities and organizations in the Region. Therefore, the action planning focused on where a regional approach would be most effective and where existing initiatives could be adjusted to incorporate future climate conditions.

3 Prioritization of Adaptation Measures

In addition to focusing actions on the highest risks, numerous potential adaptation measures (**258 potential adaptation measures** initially identified by stakeholders) were prioritized using a multi-criteria approach and informed by stakeholders' local knowledge and context of existing initiatives. **The 24 adaptation measures recommended** in this plan provided the **highest benefits to costs ratio**, where a regional approach would elevate the benefits even more.

PRIORITIZATION CRITERIA

BENEFIT

Effectiveness
Co-Benefits
Equality
Scalability

COST

Lifecycle total costs
Negative side-effects
Feasibility
Acceptability

4 Grouping into Themes

The identified actions were grouped together by similar topics. The resulting themes tend to be affiliated with various technical disciplines (e.g., engineering, emergency management, environmental specialists, or educators, for example), which can better support implementation of the measures by aligning them with existing initiatives or groups already focused on each theme.

The strategic direction for climate adaptation in the Region is summarized in **Figure 4-1**; it includes the vision statement, guiding principles and the seven theme areas. **Figure 4-2** provides an overview of the 24 priority adaptation measures for the Region to consider. **Appendix F** provides more details including:

- Why each theme is relevant for a regional plan;
- Key Region policy areas supported by the priority measures in each theme; and
- Details of each adaptation measure to provide additional context from stakeholder input.

Regional climate resilience cannot be achieved by one entity alone, but rather will take a collaborative effort between municipalities, other orders of government, private organizations, citizens, and industry. For some adaptation considerations, the Board and municipalities may be required to lead. Additionally, other actions may require the Board to advocate to other orders of governments or industry.

Most of the measures will reduce risks for both urban and rural communities. Although many infrastructure-related standards have a stronger connection to urban development, the rural areas play a critical role in protecting and managing the natural environment, which is the foundation of resilience. Rural areas having lower density, large geographies, and less services due to increased costs mean that there will be unique needs around emergency preparedness and communication. The economic prosperity of the entire Region will need to address resilience across all policy tiers with support and collaboration across both urban and rural communities.

FIGURE 4-1

Edmonton Metropolitan Region Strategic Direction for Climate Adaptation

Vision for Climate Adaption

The work we do today builds the foundation of a resilient, vibrant and prosperous Region for future generations.

Regional Prosperity

Enabling a resilient regional economy in the context of global risks.

Environment

Protecting and restoring nature as the foundation for resilience.

Collaborative Action

Fostering trust across the Edmonton Metropolitan Region to supercharge progress on climate action.

Proactive

Stewarding resilience planning so we are prepared for the storms ahead.

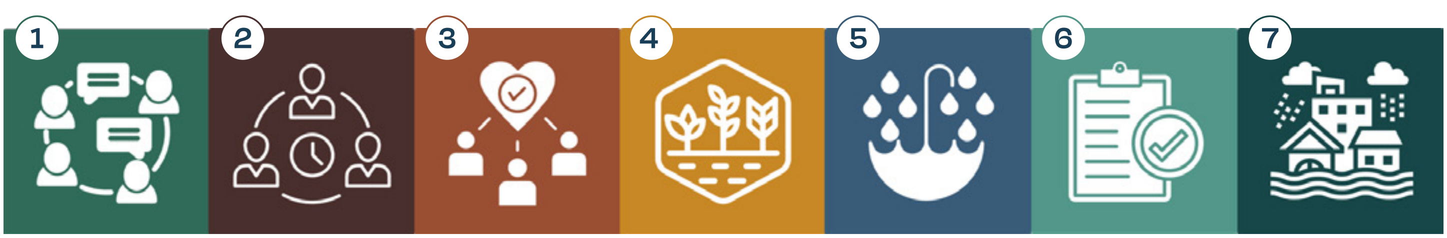
Local Sustainability

Strengthening local adaptive capacity.

Equity

Prioritize actions to protect the wellbeing and safety of the most vulnerable.

Action Themes



1. Coordinated Public Communication
2. Collaborative Disaster Preparedness
3. Supporting Our Most Vulnerable
4. Protecting Our Natural Environment
5. Managing Water Scarcity
6. Designing Resilient Infrastructure
7. Raising the Bar on Flood Management

FIGURE 4-2

Edmonton Metropolitan Region Climate Adaptation Measures for Consideration

1. Coordinated Public Communication
2. Collaborative Disaster Preparedness
3. Supporting Our Most Vulnerable
4. Protecting Our Natural Environment
5. Managing Water Scarcity
6. Designing Resilient Infrastructure
7. Raising the Bar on Flood Management

#	Action Description
1-1	Develop a protocol for coordinated emergency alert and action communication materials that are accessible and targeted to different audiences in the Region.
1-2	Develop regional public education program on climate-related emergency preparedness.
1-3	Develop public education campaign discussing higher risk areas.
2-1	Develop a regional program to build resilience to supply chain disruptions.
2-2	Develop rapid regional response and evacuation protocols for people and livestock.
2-3	Develop and enforce regional wildland fire risk reduction and rapid response plan.
2-4	Develop comprehensive regional emergency management and business continuity plans in the case of a catastrophic event with the loss of critical services (e.g., tornado, wildland fire).
3-1	Develop a comprehensive map that highlights the locations of outdoor fountains, resilience hubs, cooling zones, and other resources accessible to vulnerable populations across the Region.
3-2	Develop programs to respond to vulnerable populations in extreme heat by fostering regional partnerships across social organizations or services.
3-3	Establish shelters for vulnerable populations during wildfire smoke events.
4-1	Develop regional policies for natural asset planning and maintenance.
4-2	Develop a regional invasive species management plan.
4-3	Allocate resources and establish regional funds to support riparian restoration projects, including tree planting and habitat enhancement along watercourses to mitigate extreme heat on the aquatic environment.
5-1	Develop regional strategies to achieve sustainable and equitable water distribution.
5-2	Promote consistent water conservation and efficiency measures across the Region.
5-3	Develop water management guidelines and promote water reuse and conservation.
6-1	Develop regional building standards to manage extreme heat.
6-2	Develop regional building standards to manage reduced air quality.
6-3	Enhance regional transportation design standards for culverts and bridges to protect major access/egress routes.
7-1	Rapidly develop regional river and creek flood hazard maps to accelerate mapping progress in smaller watercourses.
7-2	Develop higher, climate-informed regional river flood design standards and zoning changes.
7-3	Develop a regional river and creek flood management plan.
7-4	Develop a regional stormwater design standard using climate-adjusted IDF curves to mitigate localized flooding.
7-5	Develop a regional low impact development (LID) standard to mitigate localized flooding.

5

Investing in Adaptation

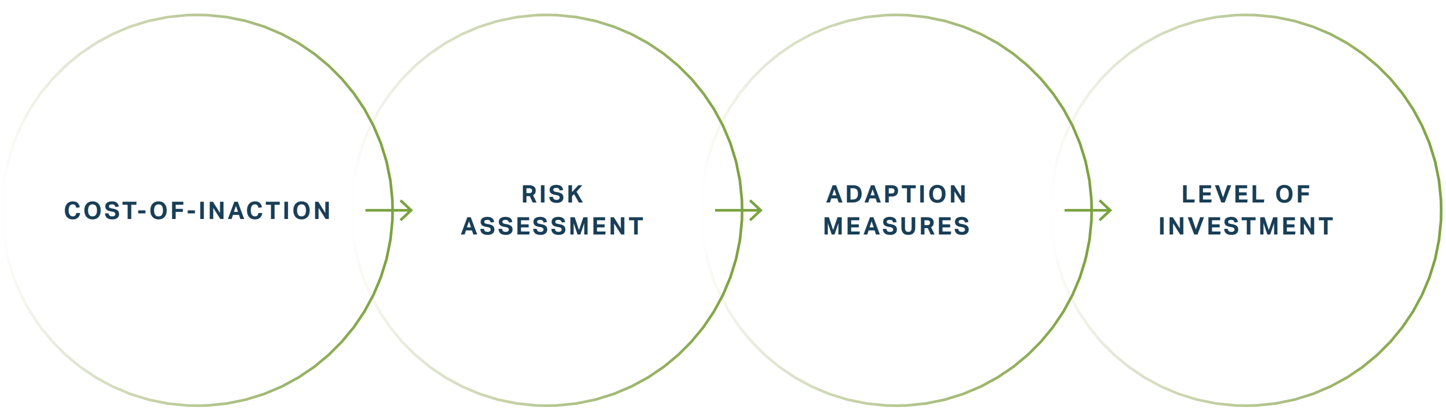
Climate change is already causing economic impacts in the Region and will do so increasingly if no additional action is taken. Impacts include damage to the built and natural environment, disruption to flows of goods and services, increased illness, injuries and premature deaths, reduced labour supply and productivity, and lower economic output and tax revenues. There is a need to provide decision-makers with a defensible business case to justify investment in climate adaptation and reduce these impacts. With a view to developing a business case for adaptation, estimates of the projected economic costs of climate change for the Region are discussed below. The discussion includes the absence of new adaptation policies or measures along with expected rates of return from adaptation investments.

A key message in the national climate change knowledge assessment states:

> "Faced with limited resources and competing priorities, economic analysis can help decision-makers clarify trade-offs, and make the case for allocating resources to climate adaptation and specific actions, by providing information on the costs and benefits of different choices."[11]

The following sections discuss two types of economic analysis to guide adaptation planning, which are:

- **Section 5.1:** The cost of climate change, or "cost-of-inaction", that reflects the scale of the impacts and informs the risk assessment process to identify the highest risks to the Region (Sections 2 and 3).
- **Section 5.2:** The level of investment to reduce the projected costs-of-inaction being incurred in the Region informed by the adaptation measures identified in Section 4.



[11] Boyd, R. and Markandya, A., 2021: Costs and benefits of climate change impacts and adaptation; Chapter 6 in Canada in a Changing Climate: National Issues Report, (Eds.) F.J. Warren and N. Lulham; Government of Canada, Ottawa, Ontario [https://changingclimate.ca/national-issues/chapter/6-0/].

5.1 Economic Costs of Climate Change for the Region

A key component of a business case for allocating resources to climate adaptation is the **"costs-of-inaction"** — that is, the projected economic impacts of climate change under a business-as-usual approach, with no new adaptation policies and measures. In support of the business case for adaptation action in the Region, estimates of the costs-of-inaction were developed and used to:

- Quantify the overall scale of the challenge presented by the physical risks of climate change and convey the urgency for adaptation.
- Show the distribution of economic impacts across population groups, assets, climate-sensitive systems, and areas.
- Support the prioritization of climate-related threats and opportunities as part of a climate risk assessment.
- Guide the required level of investment in adaptation and estimate associated benefits.

Information on the costs-of-inaction can also be used to support the selection, timing, and sequencing of specific adaptation options, during development of implementation plans. The methodology, cost concepts, and scope of the costing analysis are described in **Appendix G.**

5.1.1 Direct Costs of Climate Change

While climate change is anticipated to bring some benefits for the Region (e.g., longer growing season or construction season), the overall economic impact is projected to be negative. Projected annual direct costs in 2025, 2055, and 2085 are presented in **Table 5-1**. Under a high future climate forcing scenario (RCP 8.5), expected direct economic losses are estimated to amount to **$4 billion per year** (2021 dollars) by mid-century. By the 2080s, direct expected losses are estimated to total **$10.1 billion per year**; this represents a 5-fold increase in expected annual costs compared to the 2020s. See **Figure 5-1** for further information.

FIGURE 5 -1

PROJECTED DIRECT ECONOMIC IMPACTS OF CLIMATE CHANGE FOR THE REGION, BY EXPOSED SYSTEM AND FUTURE TIME PERIOD

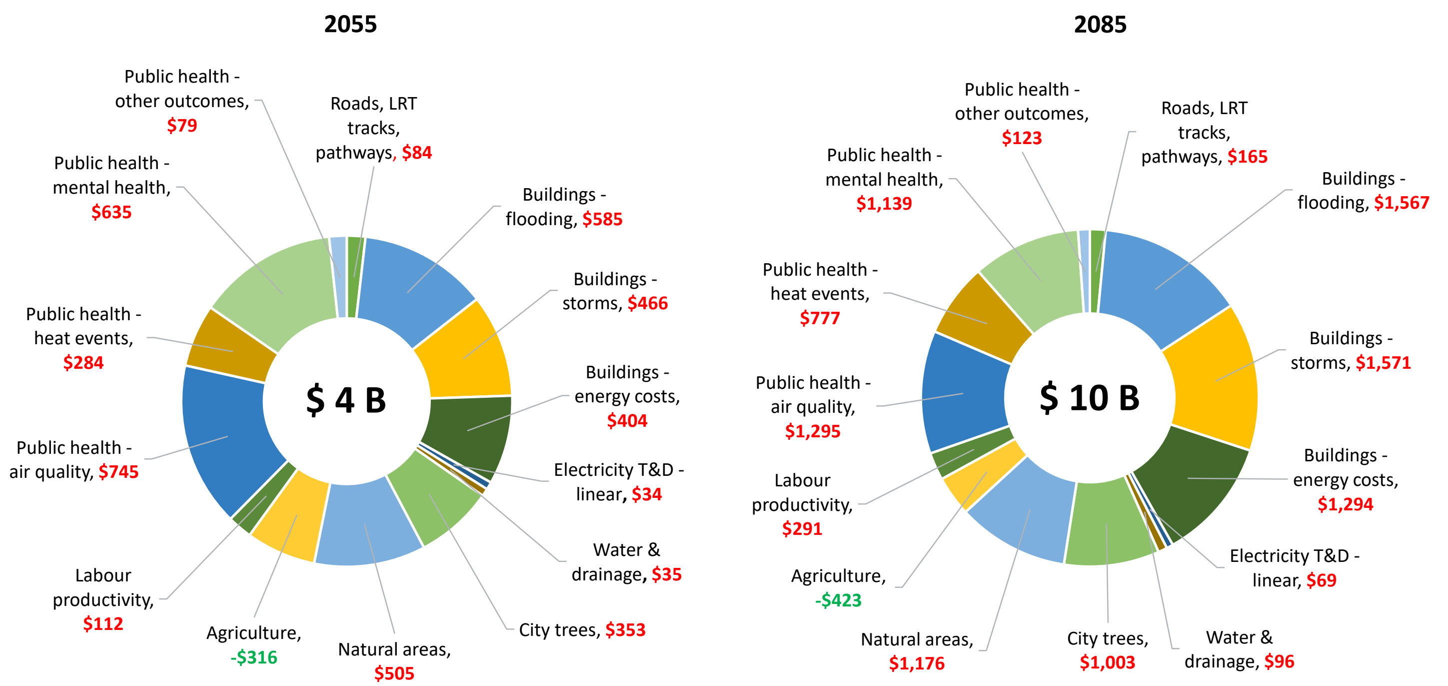
Exposed human and natural systems	Climate impact-drivers	Economic consequences	2025 ($ 2021 M)	2055 ($ 2021 M)	2085 ($ 2021 M)	Change: 2025 to 2055 ($ 2021 M)	Change: 2025 to 2085 ($ 2021 M)
Roads	High temperatures, heavy precipitation, freeze-thaw cycles	Damages	27	62	128	34	101
	High temperatures, heavy precipitation, freeze-thaw cycles	Delays (value of time)	4	8	17	4	13
Rails, including LRT	High temperatures	Damages	0.19	0.34	0.69	0.15	0.50
Active transport network	High temperatures, drought, extreme cold, freeze-thaw cycles, pluvial flooding	Damages	9	14	20	5	11
Buildings	Fluvial and pluvial flooding	Damages	133	511	1,374	378	1,241
	Fluvial and pluvial flooding	Indirect losses	20	74	193	54	173
	Hail storm, high winds, freezing rain, freeze-thaw cycles, heavy snow	Damages	161	466	1,571	305	1,410
	Heating degree days, cooling degree days	Energy costs	90	404	1,294	314	1,203
Electricity T&D (linear)	High temperatures, hail storm, high winds, freezing rain, heavy snow, pluvial flooding, NSR flooding, wildland fire	Damages	20	34	69	14	49
Potable water (linear)	Cold temperatures, drought, freeze-thaw cycles	Damages	0.4	1.2	5.5	0.8	5.1
Potable water (plant)	NSR flooding at Edmonton, extreme cold	Damages	0.0	0.1	0.1	0.0	0.1
Wastewater (linear)	Freeze-thaw cycles, pluvial flooding	Damages	6	16	43	10	37
Wastewater (plant)	NSR flooding at Edmonton	Damages	0.0	0.1	0.2	0.1	0.1
Drainage (linear)	Freeze-thaw cycles, pluvial flooding	Damages	7	18	47	10	39
City trees	High temperatures, drought, heavy snow, freezing rain, high winds, wildland fire, tornado, lightning	Damages	131	290	708	159	577
		Ecosystem services	15	63	295	48	280
Natural areas	High temperatures, drought, extreme cold, hail storm, high winds, freezing rain, heavy snow, pluvial flooding, river flooding, wildland fire, tornado	Damages	33	63	140	30	107
		Ecosystem services	283	442	1,036	159	753
Agriculture	Mean seasonal temperatures, mean annual precipitation, frost-free days, growing degree days	Farmland value	-93	-316	-423	-223	-330
Labour	High temperatures	Lost output	33	112	291	79	258
Public health	Air quality (ground-level ozone) - mortality	Welfare losses	40	107	204	66	164
	Air quality (ground-level ozone) - mortality	Lost output	4	16	46	12	42
	Air quality (ground-level ozone) - morbidity	Welfare losses	0.04	0.18	0.47	0	0
	Air quality (smoke PM2.5) - mortality	Welfare losses	148	619	1,054	471	906
	Air quality (smoke PM2.5) - mortality	Lost output	15	95	238	80	223
	Air quality (smoke PM2.5) - morbidity	Welfare losses	4	19	36	15	32
	High temperatures - mortality	Welfare losses	80	275	750	195	670
	High temperatures - mortality	Lost output	8	42	170	34	161
	High temperatures - hospitalizations	Healthcare costs	2	8	25	6	23
	High temperatures - hospitalizations	Lost output	0.1	0.4	1.2	0.3	1.1
	Exacerbation of mental health disorders - multiple climate impact-drivers	Welfare losses	332	635	1,139	304	807
	Other public health and safety impacts - multiple climate impact-drivers	Welfare losses	52	79	123	28	72
Sub-total		Tangible costs	609	1,911	5,941	1,302	5,332
		Intangible costs	958	2,249	4,655	1,291	3,697
Total		**Social costs**	**1,539**	**4,006**	**10,142**	**2,467**	**8,604**

*T&D – Transmission and Distribution

The scale and direction of projected direct economic losses for the Region vary across climate-sensitive systems (community-wide including private and public), as shown in **Figure 5-1:**

FIGURE 5-1

Projected Direct Economic Impacts of Climate Change for the Region (Community-Wide) in 2055 and 2085, by Exposed Human and Natural System **($ 2021M)**



The largest source of future losses for the Region are adverse public health impacts. This includes illness and premature death resulting from episodes of deteriorating air quality associated with—primarily—increased wildfire smoke. The exacerbation of mental health disorders due to climate-enhanced extreme weather, such as, drought, wildfires, smoke, flooding, heatwaves, hospitalizations, and premature death from exposure to extreme heat are also significant sources of projected losses. Climate-related impacts to buildings (from exposure to increased storminess and flooding, as well as rising space cooling costs) likewise account for a consistently large share of total direct costs throughout the century, even with two key climate drivers of impacts—specifically, freeze-thaw cycles and heavy snow—projected to decrease. Damage to natural capital (urban tree canopy, forest areas, shrublands, grasslands, wetlands) and disrupted ecosystem services is a third major source of projected losses in the Region resulting from climate change.

The results for agriculture suggest the sector is expected to benefit from climate change as indicated by projected increases in farmland values due to net improvements in productivity across both crop and livestock farms. However, there are numerous reasons why these estimated benefits should be viewed as overly optimistic[12]. Realizing net-benefits in the sector will require significant adaptation to limit the impacts of climate extremes, including on water availability, and the increased risk of pests and invasive species[13].

[12] Boyd, R., 2023: Costs of Climate Change on the Prairies. Prepared by All One Sky Foundation for ClimateWest.

[13] For further details see Sauchyn, D., Davidson, D., and Johnston, M., 2020: Prairie Provinces; Chapter 4 in Canada in a Changing Climate: Regional Perspectives Report, (ed.) F.J. Warren, N. Lulham and D.S. Lemmen; Government of Canada, Ottawa, Ontario.

5.1.2 Secondary (Macroeconomic) Costs of Climate Change

Impacts to buildings, infrastructure, the workforce, and other "tangible" items will have ripple effects throughout the economy, as household, business, and government spending is impacted. This will have macroeconomic consequences. Projected macroeconomic losses from the impact of climate change on the Region are shown in Table 5-2. The overall impact of climate change for gross output[14] by mid-century is estimated at about **$7.3 billion per year**. By the 2080s, the cost of climate change for gross output is projected to amount to approximately **$20.7 billion per year**. Expected annual gross domestic product (GDP) losses due to climate-related impacts in the Region in 2055 and 2085 are estimated at, respectively, about **$3 billion per year** and **$8.6 billion per year.** Table 5-2 also shows expected annual forgone municipal, provincial and federal tax revenues because of climate related impacts in the Region.

TABLE 5-2

Projected Macroeconomic Losses from the Impacts of Climate Change on the Region, by Time Period **($ 2021B ANNUALLY)**

Macroeconomic Indicators	2025	2055	2085
Tax Revenues	$0.1 B	$0.2 B	$0.6 B
Labour Income	$0.5 B	$1.7 B	$4.7 B
Gross Output	$2.3 B	$7.3 B	$20.7 B
GDP	$1.0 B	$3.0 B	$8.6 B

Note: Amounts have been rounded to the nearest $100 million. Estimated costs reflect secondary losses across the provincial economy resulting from direct biophysical impacts and associated tangible costs incurred in the Edmonton Metropolitan Region.

[14] That is, the value of total sales of goods and services plus changes in the value of business inventories.

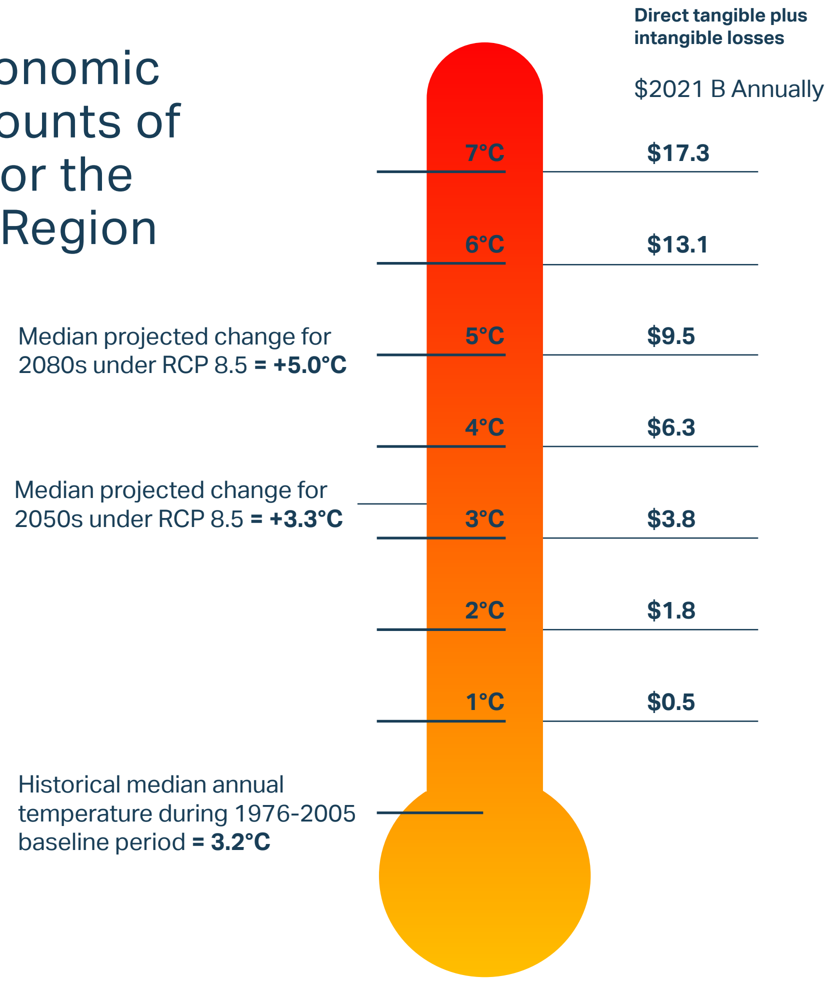
5.1.3 Projected Costs of Different Amounts of Climate Change

Figure 5-2 illustrates the economic consequences from different levels of climate change relative to the recent past. The expected direct annual costs associated with one degree-Celsius increments in the Region's mean annual temperature relative to the average over the period 1976-2005 are shown on the left-hand-side of the thermometer. For reference, the projected mean annual temperature for the Region for the 2050s and 2080s under the high climate forcing scenario are shown on the right-hand-side of the thermometer. If the Region develops as projected and the climate continues to change as expected, when the mean annual temperature change and reaches 3°C above the average for 1976-2005, for example, total direct costs attributable to this level of warming are estimated at about **$3.8B per year**. Higher levels of warming, result in larger annual losses.

FIGURE 5-2

Projected Aggregate Economic Impacts of Different Amounts of Future Climate Change for the Edmonton Metropolitan Region

($2021 B ANNUALLY)



5.1.4 Other Considerations

The projected costs of climate change for the Region are expected to be higher than the estimates presented above, for several reasons including:

- The omission of losses from disrupted service flows resulting from damage to infrastructure. Numerous studies show that households and businesses have positive willingness-to-pay to avoid disruption to utility services.
- The omission of compounding effects; for example, when chains of linked impacts occur simultaneously (like extreme heat, drought, and wildfire) or in sequence (like the back-to-back atmospheric rivers that hit BC in 2021).
- The omission of cascading effects, whereby, direct impacts on one piece of infrastructure (e.g., electricity T&D systems) causes indirect impacts on interdependent infrastructure (e.g., traffic signals, pumping stations, etc.).
- A focus on extreme weather events of a singularly defined intensity, thereby ignoring events with lower intensities and a higher likelihood of occurring that might cause smaller economic losses, but in aggregate may be large.

5.2 Expected Rates of Return from Investment in Adaptation

Adapting municipalities for projected climate change has been conservatively estimated by the Insurance Bureau of Canada and the Federation of Canadian Municipalities to require an annual investment equivalent to 0.26% of GDP[16]. Over the next 10 years (2025-2035) this equates to a total investment of about **$3.2 billion** for the Region, **shared between the private and public sector** Per capita. This level of investment amounts to approximately $195 per resident per year for 10-years[17].

[15] For example, see: Zamuda, C., et al., 2019: Monetization methods for evaluating investments in electricity system resilience to extreme weather and climate change, The Electricity Journal, 32, 106641; Sullivan, M., et al., 2015: Updated Value of Service Reliability Estimates for Electricity Utility Customers in the United States, Ernest Orlando Lawrence Berkeley National Laboratory, San Francisco, CA; Schroder, T. and Kuckshinrichs, W., 2015: Value of Lost Load: An Efficient Economic Indicator for Power Supply Security? A Literature Review, Frontiers in Energy Research, Vol. 3, Article 55; Brozovic, N., et al., 2007: Estimating business and residential water supply interruption losses from catastrophic events, Water Resources Research, 43, W08423; and Appiah, A., 2016: Estimating the Economic Value of Drinking Water Reliability in Alberta, Dissertation for Master of Science in Agricultural and Resource Economics, University of Alberta, Edmonton, AB.

[16] IBC and FCM, 2020: Investing in Canada's Future: The Cost of Climate Adaptation at the Local Level, Final Report, February 2020.

[17] Based on the projected average annual population of the Edmonton Metropolitan Region over this period.

The Shared Responsibility for Climate Adaptation

It is important to note that the **levels of adaptation expenditure investigated in this section will in practice be spread across households, businesses, and all levels of government, so a collaborative approach to adaptation is required.** The identified levels of investment in adaptation **do not fall solely to municipalities** in the Region. A significant amount of adaptation to climate change would be undertaken by households and businesses; however, households and businesses face multiple barriers, which limits their ability to achieve efficient levels of adaptation, much in the same way they consistently underinvest in energy efficiency.

As a result, governments—including municipalities—have a focused set of roles to fulfil in support of climate adaptation, including1:

- Using regulatory and economic instruments to overcome market barriers and providing incentives for efficient private adaptation;
- Providing "public goods and services" dedicated to adaptation, such as investment in early warning systems and large-scale flood protection, as well as improvements in emergency response and preparedness planning; and
- Ensuring the equitable distribution of adaptation investment and benefits, so the transition to a climate resilient future is just and inclusive.

Fortunately, the national climate change knowledge assessment found "the benefits of planned actions to adapt to climate change in Canada generally exceed the costs, sometimes significantly, providing a strong business case for proactive investment in adaptation." While some adaptation actions may not make economic sense, most i**nvestments in adaptation typically offer rates of return from $1 to over $12**, with the majority providing $2 to $6 in benefits for each dollar invested (see the examples in **Table 5-3**).

Benefit-cost ratios indicate the dollar value of benefits produced for each dollar invested. For benefit-cost ratios derived from databases, the central value is the trimmed median, and the range denotes the 25th and 75th percentile values. **The ratios in the table should not be used to rank-order or prioritize adaptation investments.** The scope of the avoided costs and co-benefits included in the underlying studies differs considerably, making comparisons across adaptation strategies misleading. When it comes to developing implementation plans for adaptation strategies, individual actions should be subject to new cost-benefit analysis.

[16] IBC and FCM, 2020: Investing in Canada's Future: The Cost of Climate Adaptation at the Local Level, Final Report, February 2020.

[17] Based on the projected average annual population of the Edmonton Metropolitan Region over this period.

[18] Boyd and Markandya (2020) ibid.

TABLE 5-3

ESTIMATED Benefit-Cost (B-C) Ratios for Strategies to Adapt to Weather Extremes

		Benefits per $1 Spent	
Targeted Climate Hazard	**GHG Reduction/Clean Energy**	**Central Estimate**	**Range**
Wildland Fire	Comprehensive plan (response & mitigation)	3.1	1.6 - 8.3
Wildland Fire	Public awareness, communications	5.0	2.3 - 11.9
Heat Stress—Public Health	Structural, design standards – homes	2.0	1.1 - 2.9
Heat Stress—Public Health	Urban planning, land-use, nature-based solutions	1.7	1.4 - 1.9
Heat Stress—Public Health	Comprehensive plan (response & mitigation)	2.3	1.4 - 3.9
Heat Stress—Workforce	Administrative (management plan)	1.7	0.6 - 7.3
Smoke—Public Health	Structural, design standards – homes	2.4	1.6 - 3.3
Smoke—Workforce	Structural, design standards – workplace	1.8	1.6 - 1.9
River & Creek Flooding	Comprehensive plan (response & mitigation)	6.1	3.4 - 7.6
River & Creek Flooding	Public awareness, communications	2.6	0.6 - 5.2
Stormwater Flooding	Nature-based solutions	5.0	1.9 - 9.7
Stormwater Flooding	Structural, design standards – drainage	6.2	3.6 - 8.0
Tornado and High Winds	Comprehensive plan (response & mitigation)	5.1	2.8 - 9.9

5.2.1 Benefits and Costs – Adaptation Investment Scenarios

To shed light on the potential returns (projected costs-of-inaction avoided) from different levels of shared investment in climate adaptation across the Region, **two investment scenarios were investigated.** The results are summarized in **Table 5-4**. The key discussions are noted below.

Sources: Boyd and Markandya (2020 ibid; Multi-hazard Mitigation Council, 2019: Natural Hazard Mitigation Saves, 2019 Report, National Institute of Building Sciences. Washington, DC.; FEMA Benefit-Cost Analysis Database, accessed September 2023 [https://www.fema.gov/grants/tools/benefit-cost-analysis]; Boyd, R., 2023: Mortality and Morbidity Impacts from Heat Exposure, Technical Report prepared for the Canadian Climate Institute and the Government of BC; IBRD, 2021: Investment in Disaster Risk Management in Europe Makes Economic Sense, Economics for Disaster Prevention and Preparedness, International Bank for Reconstruction and Development (IBRD) and The World Bank, Washington, DC.; Fisk, W. and Chan, W., 2017: Health benefits and costs of filtration interventions that reduce indoor exposure to PM2.5 during wildfires, Indoor Air, 27, 191-204; and Washington State Government, 2023: Preliminary Cost-Benefit Analysis and Significant Legislative Rule Analysis, Wildfire Smoke, Washington State Department of Labor & Industries, Tacoma, WA.; and Willams, A., et al., 2020: Health and climate benefits of heat adaptation strategies in single-family residential buildings, Frontiers in Sustainable Cities, 2, Article 561828.

TABLE 5-4

Costs and Benefits of Two Adaptation Investment Scenarios for the Edmonton Metropolitan Region

Investment Strategies (2025–2035 10-year investment by government, businesses, households)	**Present value lifetime benefits of adaptation investment** ($2021 M)	**Reduction in projected damages** (2025–2058) (% of baseline costs)	**Residual economic risks** (2025–2058) (% of baseline costs)
1. Invest **$3.2 billion** (= 0.26% of projected GDP)			
$1 returns $2	6,390	12%	88%
$1 returns $3	9,585	18%	82%
$1 returns $4	12,780	23%	77%
$1 returns $5	15,975	29%	71%
$1 returns $6	19,170	35%	65%
2. Invest **$9.3 billion** (= 0.78% of projected GDP)			
$1 returns $2	19,477	36%	64%
$1 returns $3	28,015	51%	49%
$1 returns $4	37,355	69%	31%
$1 returns $5	46,695	86%	14%
$1 returns $6	54,435	100%	0%

Key discussions of Table 5-4:

- The **top blue box** shows the estimated benefits and residual economic costs from a total shared investment of **$3.2 billion** (i.e., 0.26% of projected GDP, or $195 per person per year) in adaptation in the Region over the 10-year period 2025-2035, assuming the money is invested in actions offering typical benefit-cost ratios the of between $2 and $6.
- The **bottom green box** shows the expected outcomes from a higher total shared investment of **$9.3 billion** (i.e., 0.78% of projected GDP, or $570 per person per year) in adaptation over the next 10 years (2025-2035).
- "*Present Value Lifetime Benefits of Adaptation Investment*" shows the corresponding benefits over the useful life of the implemented actions (assumed to be 25 years).
- *"Reduction in Projected Damages"* shows the percentage reduction in the projected costs-of-inaction.
- "*Residual Economic Risk*" shows the percentage of the projected costs-of-inaction still being incurred in the Region even with the total 10-year investment of $3.2 billion in adaptation; the residual costs of climate change after adaptation.

It is evident from the two investment scenarios that:

- A shared investment roughly three times that suggested by the Insurance Bureau of Canada and the Federation of Canadian Municipalities is needed to reduce the projected costs of climate change for the Region to what might be deemed acceptable levels—achieve reductions of 70% or more.
- A total investment by households, businesses, and all levels of government close to $9.3 billion over the next 10-years (equivalent to roughly $570 per person per year) will avoid $19 billion-$54 billion in projected costs from climate impacts in the Region, depending on whether adaptation actions achieved $2-$6 rates of return—rates typically observed in other jurisdictions.

Further analysis of shared investment scenarios for some of the adaptation strategies formulated in Section 4 is presented in **Appendix H.**

"Over just eight days in 2019, Stony Plain experienced two once-in-a-century rainfall events causing widespread flooding, resulting significant impacts to our community and infrastructure. While this is unprecedented, we understand these weather events will become more common. This assessment is critical to identifying all the risks our communities may face and offering a suite of adaptation actions we can consider to minimize the impacts of climate change in the future."

— Mayor William Choy, Town of Stony Plain

6

Building Future Resilience

Climate change will, and is, affecting the Region in a multitude of ways which can often feel overwhelming. The Region will continue to respond to more severe and more frequency extreme weather events. By directing an appropriate level of resources to the scale of these issues, the effects of these events will be reduced, and the response will be more efficient having less of an interruption on day-to-day operations and community wellbeing.

The Region has a population of 1.5 million people and generating $109 billion in economic activity. As the Region prepares to welcome another million people and nearly half a million new jobs in the next 20 years, development of infrastructure is required to support this growth; therefore, it is critical that the Region apply a climate lens to build resilience and minimize future risks as the Region continues to grow.

Based on the results of the assessment and engagement, the **key takeaways** to guide the next steps in the Region's resilience journey include:

Maximize effectiveness by working regionally.

A regional plan does not replace the need for local plans which can address the unique local context and needs. However, some actions are most effective and efficient to be done regionally. The effectiveness of some actions relies on consistency across jurisdictionally boundaries, while some actions do not need to be recreated but rather pool resources for efficiency. This effort will also need to include Indigenous communities, integrating Indigenous knowledge and collaborating with the community leaders for a holistic outcome.

Build on the great work the Region is already doing.

The Region has established partnerships and initiatives that align to many of the climate risks. Where appropriate, align climate adaptation action with these current initiatives to fast-track progress and ensure consistency and relevance. These initiatives may need to be:

- adjusted to integrate future climate conditions,
- broadened to consider multiple climate hazards and maximize benefits, or
- reprioritized to target the highest risks as identified in this plan.

Build understanding among municipal partners of how investment and decisions in policy areas impact, positively or negatively, climate risks.

Just as adaptation investments can provide co-benefits, investment in other policy areas can have co-benefits or co-costs for climate resilience, which need to be identified and understood. Understanding these interdependencies is necessary to avoid maladaptation, help mainstream adaptation into decision-making and to ensure cost-effective adaptation.

Help municipal partners better understand the hurdles faced by households and businesses to adapt to climate change.

A significant share of the projected investment in climate adaptation needs to be made in the private sector. However, multiple barriers prevent households and businesses from making the required investments and behavioural changes—analogous to the challenges faced to improve the energy efficiency of the building stock. Understanding the barriers faced by different private sector actors is necessary to develop and target supports to encourage effective private adaptation.

Showcase substantial resilient measures to grow regional prosperity.

Consistency and certainty in enhanced standards and guidelines 'levels the playing field" for development across the Region, which in turn demonstrates that the Region is a resilient and reliable place to invest. Resilience requires actions from both public and private sectors and with the entire Region raising the bar on how and where we build, other businesses and people will be drawn to the Region.

Communicate the urgency of ramping up investment in climate adaptation.

The costs of climate impacts on the Region are significant and growing — estimated to reach $4 billion per year by mid-century, rising to $10 billion per year by the 2080s. The adaptation actions to increase climate resilience typically provide benefits well in excess of costs. An investment of $9 billion by households, businesses and governments over the next 10 years would significantly reduce projected losses, generating benefits of $19 billion-$54 billion.

Support the development of adaptation strategies that optimize the generation of co-benefits and facilitate multi-solving.

Adaptation is multi-dimensional, with the potential to impact a broad range of private interests and public policy goals and objectives. Given the scale of adaptation investment needed, there is a significant opportunity for that investment to provide benefits across multiple regional priorities. This will help achieve larger benefits for each dollar invested, improving the business case for action. Support could involve building the capacity of decision-makers to optimize the capture of co-benefits when forming adaptation actions.

Develop a framework to demonstrate success.

- The Board needs to be able to demonstrate resilience for the Region to be perceived as a reliable place to invest. Implementation planning to operationalize the actions in this plan should include:
- Develop targets and indicators to drive action and accountability, to be communicated publicly.
- Identify roles and responsibilities to carry out each of the measures considering equitable distribution of the workload and resource contributions.
- Identify existing initiatives and resources best suited to drive each of the measures in this plan.
- Develop a timeline and resource plan for implementation of the measures in this plan.

Glossary

Adaptation (to climate change)
Adjusting to actual or expected climate impacts to reduce negative effects on people, society, infrastructure, and the environment.

Climate
The weather of a place averaged over a period of time, typically 30 years.

Climate change
Significant changes in global temperature, precipitation, wind patterns and other measures of climate that occur over several decades or longer.

Climate parameters
Climate variables or indices that influence the hazard, e.g. a high intensity, short duration rainfall event.

Climate hazard
A special type of hazard that is (at least partially) caused by climatic drivers, e.g. drought, high winds, extreme heat, etc.

Climate-impact drivers
Physical climate conditions (e.g., mean or extreme temperature or rainfall, extreme weather events) that affect human or natural systems.

Consequence
The result or effect from climate impacts to people, society, infrastructure or the environment.

Direct costs
Costs that arise from the direct biophysical impacts of climate impact-drivers to (tangible or intangible) goods and services—e.g., costs to repair homes damaged by hail, ecosystem services lost when trees are blown down by strong winds.

Greenhouse gas (GHG)
A gas that absorbs and emits radiant energy causing the greenhouse effect, which warms the atmosphere and changes the climate. The primary greenhouse gases are water vapour, carbon dioxide, methane, nitrous oxide and ozone.

Hazard
A potential source of harm.

Impact
An estimate of the harm that could be caused by an event or hazard.

Indirect costs
Secondary losses incurred as direct tangible costs ripple through the wider economy as subsequent spending by households and businesses is reduced.

Intangible costs
Costs that arise from direct biophysical impacts to items not bought or sold in a traditional market and thus with no readily observable price as a basis for monetization (e.g., ecosystem services, stress or pain levels, travel delays, premature deaths). Also referred to as non-market impacts.

Likelihood
The probability or chance of a hazard occurring, and how this likelihood changes in the future due to climate change.

Mitigation (of climate change)
Human interventions to reduce the sources and enhance the sinks, or absorption, of GHGs.

Representative Concentration Pathway (RCP)
RCPs represent models that predict how concentrations of GHGs in the atmosphere will change in the future as a result of human activities. There are four RCPs (2.6, 4.5, 6.0 and 8.5) with a higher value representing higher GHG concentrations in 2100.

Resilience
The capacity of a system, community, or society exposed to hazards to minimize damages by responding or changing to reach and maintain an acceptable level of functioning and structure.

Risk
A combination of likelihood and consequences of an adverse event or condition occurring.

Stakeholder
People who are, or perceive themselves to be, affected by a decision, strategy or process. A stakeholder can be an individual, an organization or a group within an organization. Stakeholders can change at different stages in a process.

Tangible costs
Direct or indirect losses that arise from impacts to goods or services traded in traditional markets and captured in financial and economic accounts.

Weather
Short term day-to-day changes in atmospheric conditions like temperature and precipitation.

Acknowledgements

This report was developed with the input and hard work of a diverse group of individuals and organizations.

We extend our sincere appreciation for the dedication, time, effort, and expertise invested in the quest to develop a resilient and cooperative Region. Special acknowledgment is extended to the stakeholders who actively supported and participated in the workshops, as well as those who provided invaluable feedback throughout the course of this project.

Edmonton Metropolitan Region Board (EMRB) Project Management Team

EMRB MEMBERS

City of Beaumont
Town of Devon
City of Edmonton
City of Fort Saskatchewan
City of Leduc
Town of Morinville
Parkland County
City of Spruce Grove
City of St. Albert
Town of Stony Plain
Strathcona County
Sturgeon County

ORGANIZATIONS WITHIN THE EDMONTON METROPOLITAN REGION

Alberta Industrial Heartland Association
Alberta Capital Region Wastewater Commission
Climate West
Canadian National Rail
EPCOR
North Saskatchewan Watershed Alliance
Urban Development Institute (UDI) Edmonton Metro
Agriculture Financial Services Corporation

GOVERNMENT

Government of Alberta

APPENDIX A

Engagement Approach and Details

Table A-1 Workshop Participants (Technical Working Group)

Members	Invitees
City of Beaumont	Lenore Turner; Aaron Lewicki
Town of Devon	Paresh Dhariya; Sean Goin
City of Edmonton	Danielle Koleyak; Chandra Tomaras
City of Fort Saskatchewan	Shree Shinde; Sadie Miller; Brad McDonald
City of Leduc	Michael Hancharyk; Alan Grayston; Ryan Graham; Des Mrygold; Sean Olson
*Leduc County	
Town of Morinville	Duncan Martin, TJ Auer
Parkland County	Krista Quesnel; Matthew Good
City of Spruce Grove	Avelyn Nicol; Rae-Lynne Spila
City of St. Albert	Meghan Myers; Gage Tweedy
Town of Stony Plain	Aleks Cieply; Doug Fraser; Chelseay Rudolph
Strathcona County	Jocelyn Thrasher-Haug; Kat Villeneuve
Sturgeon County	Milad Asdaghi; Brandon Sandmaier; Jeffrey Yanew
EPCOR	Matthew Langford; Derek Mueller
North Saskatchewan Watershed Alliance	Scott Millar
Climate West	Kerra Chomlak
*Canadian National Rail	Sarah Fulton
Agriculture Financial Services Corporation	Sara Schmidt; Mark Prefontaine
Alberta Industrial Heartland Association	David Howe
*Alberta Capital Region Wastewater Commission	Kate Polkovsky
Government of Alberta	Demetria Zinyemba; Kanwaljit Chaudhry

*Members who were invited but were not able to attend.

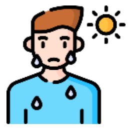
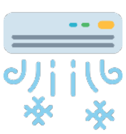
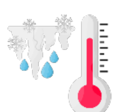
The workshops that were conducted with the stakeholders are described in **Table A-2**.

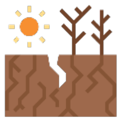
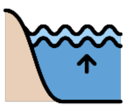
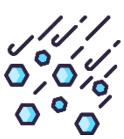
Table A-2 Workshops Description

Workshop	Description
Workshop 1	Defined and validated climate impact scenarios
Workshop 2 and 3	Conduced climate risk assessment for the metropolitan core and area and rural area to assess the prioritize the climate risk and opportunities.
Workshop 4	Evaluated and verified climate risks.
Workshop 5	Developed long-term vision and goals for adaptation actions.
Workshop 6	Identified actions to manage high risks for Natural Environment.
Workshop 7	Identified actions to manage high risks for Built Environment.
Workshop 8	Identified actions to manage high risks within the context of economic competitiveness and employment.
Workshop 9	Prioritized adaptation actions and develop action themes.

APPENDIX B

Cliamte Hazards and Opportunities

Climate Hazards and Opportunities	
	**#1. Extreme Heat – Impacts to Public Health and the Workforce** A year with 7 "heat warnings", which is 3-4 times the number of "heat warnings" the egion historically gets
	**#2. Extreme Heat – Impacts to the Built and Natural Environment** A year with 7 times the number of "hot days" (when the daily high reaches at least 30°C) the Region historically gets
	**#3. Outbreak of Invasive Species or Pests** A doubling of climate conditions conducive to the spread of invasive species or pests
	**#4. Extreme Cold** A year with 6 very cold days (when the daily low drops to at least -30°C) affecting the Region
	**#5. Increased Space Cooling Demand** A year with 11 times the Cooling Degree Days the Region gets historically
	**#6. Reduced Space Heating Demand** A year with 75% of the Heating Degree Days that the Region historically gets
	**#7. Freeze-Thaw Cycles** A year with 80% of the freeze-thaw days the Region historically gets
	**#8. Reduced Traditional Winter Recreation** A year with 75% of the winter days the Region historically gets, when the daily low drops to at least -5°C
	**#9. Air Quality - Wildfire Smoke** Wildfire smoke reduces visibility to 2km or less causing 'very unhealthy' air quality conditions

Climate Hazards and Opportunities	
	**#10. Summer (Meteorological) Drought**
	5 ‘extreme’ summer droughts per decade (or one ‘extreme’ summer drought every 2 years)
	**#11. Heavy Precipitation and Stormwater Flooding**
	Historic 1:100-year 15-minute rainfall event (rainfall intensity =103 mm per hour)
	**#12. River and Creek Flooding**
	Historic 1:100-year maximum flow in river or creek
	**#13. Wildland Fire**
	A 200-hectare wildfire occurs within the Region, impacting people and structures
	**#14. Severe Windstorm, Gust**
	One day with a maximum wind gust to 110 km/hr or more
	**#15. Tornado**
	A ‘strong’ tornado is on the ground for 20 km in the Region, with wind speeds of 178-266 km/hr (EF2 or EF3)
	**#16. Freezing Rain, Ice Storm**
	A day with 10-11 mm of freezing precipitation affecting the entire Region
	**#17. Heavy Snowfall**
	Historic 1:50-year snowfall event (12 cm in 12 hours)
	**#18. Hailstorm, Large Hail Event**
	One “‘very large hail day’ (i.e., with hailstones ≥ 4cm) impacting about 7-8% of Region

Climate Hazards and Opportunities

#19. Air Quality – Ground Level Ozone

8 parts per billion by volume (ppbv) increase in 1-hour concentrations of ground level ozone in the Region; this is equivalent to a 40% increase in the average July-August 1-hour average concentration between 1990-2020

#20. Shifting Ecoregions

A shift from mainly mixed woodland/parkland to parkland/grasslands in the R

#21. Long-Term Water Supply Shortage

A monthly average flow rate less than 25 m3 per second reducing ability to reliability and sustainability draw water from the North Saskatchewan River, and other natural water sources

#22. Supply Chain Disruption

Supply chains upstream (inputs from suppliers) and downstream (outputs to customers) of businesses in the Region experience disruption (e.g., delays in receiving inputs, reduced quality of inputs, increased costs, impaired access to customers and markets, etc.)

#23. Longer Construction Season

A doubling of climate conditions conducive to a longer construction season, with a 30% increase in the frost-free season

#24. Longer Summer Recreation And Tourism Season

A doubling of climate conditions conducive to a longer summer recreation and tourism season, with a 30% increase in the frost-free season

#25. Longer Agricultural Growing Season

An improvement in mean climate conditions resulting in a 1.5%-2% improvement in farmland values in the Region, indicative of increase yields and productivity

APPENDIX C

Climate Impact Scenarios

#1: Extreme Heat – Impacts To Public Health And The Workforce (Climate Hazard, Increasing)

Description	Multiple days of extreme heat causes negative impacts to human health	
Climate Driver(S)	Increasing summer temperatures, more hot days and heat waves	
Threshold:	A year with 7 heat warnings, which is 3-4 times the number of "heat warnings" the Region historically gets[19]	
Historic Likelihood	About 2 "heat warnings" issued per year (1976-2005)[20] <1% annual probability of 7 "heat warnings" issued in one year	**1 (Rare)**
Future Likelihood	About 7 "heat warnings" issued per year (2050s) 12% annual probability of 7 "heat warnings" issued in one year	**4 (Likely)**
Potential Consequences	Negative health impacts (e.g., heat exhaustion, heat stroke, etc.) resulting in increased mortality, injuries, and mental illness, as well as reduced quality of life and well-being, associated with health effects (about 30 additional deaths and 280 additional hospitalizations expected annually, along with expected welfare losses of about $860 million annually, including exacerbation of mental health illnesses[21]) Stress on health care system / resources (about $6 - $7 million annually)	**4 (High)**
	Reduced labour productivity and economic output (about $230 million loss of labour productivity)	**4 (High)**
Determinants of Vulnerability	Prevalence of vulnerable populations: Older adults (65+ year); Infants and young children; Pregnant women; People with pre-existing medical conditions, illness or chronic conditions People living in high density housing People who exercise outdoors People who work outdoors People who work indoors in close proximity to radiant heat sources (e.g., manufacturing, kitchens) People who are socially or materially deprived People who live in poor quality housing or experience homelessness	

[19] Heat warnings are issued when the following criteria is met: 2 or more consecutive days with daily highs reaching 29C or more and the intervening nighttime low not falling below 14C. Climate modelling for this scenario was based on 2 or more consecutive days with daily highs reaching 29C or more.

[20] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative.

[21] Estimated damages and welfare losses listed throughout all impact scenarios are expected annual values for the year 2055 in 2020 dollars. By "expected", we mean estimated damages in 2055 are multiplied by the likelihood of the climate impact-driver occurring in that year.

#2: Extreme Heat – Impacts To The Built And Natural Environment (Climate Hazard, Increasing)

Description	Multiple days of extreme heat causes negative impacts to the built and natural environment	
Climate Driver(s)	Increasing summer temperatures, more hot days and heat waves	
Threshold:	A year with 7 times the number of "hot days" the Region historically gets[22]	
Historic Likelihood	About 2 "hot days" per year[23] 1-2% annual probability of 14 "hot days" in one year	**2 (Unlikely)**
Future Likelihood	About 14 "hot days" per year 45% annual probability of 14 "hot days" in one year	**4 (Likely)**
Potential Consequences	Reduced agricultural yields and productivity from heat stress on crops and livestock	**2 (Low)**
	Accelerated degradation of transportation network, energy infrastructure, water infrastructure (wastewater treatment facilities, etc.), and buildings (about $50 million damages to roads and rail network, $5 million damages to electricity network) Increased water demand resulting in increased stress on water supply infrastructure, and increased water supply costs Disruption of critical services (water supply, energy, telecommunications, etc.) (about $8 million delays on roads)	**2 (Low)**
	Increased surface water temperatures leading to degradation of water quality, with consequences for biodiversity and treatment of water Increased heat stress on natural landscape resulting in vegetation dying off (about $335 million damages to natural assets, including urban trees) Negative health impacts for animals and livestock, causing distress and potential mortality	**3 (Moderate)**
Determinants of Vulnerability	Age and condition of building systems, and the level of deferred maintenance (how far behind the owner is with general maintenance) Age and condition of infrastructure, and the level of deferred maintenance Presence of building cooling systems Presence of shade, shelter and water for livestock Crop type (e.g., heat tolerance, diversification)	

[22] A 'hot day' is a day when the temperature reaches at least 30°C.

[23] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative.

#3: Outbreak of Invasive Species and Pests (Climate Hazard, Increasing)

Description	A Hazard Index is used as a proxy for an increase in invasive plants, animals, insect pests and plant diseases in the Region induced by climate change; the index comprises projected changes to the following climate variables: mean winter temperature, frost-free days, and growing degree days. A Hazard Index value of 10 = maximum change in climate conditions for invasive species and pests this century or worst-case.	
Climate Driver(S)	An outbreak of invasive plants, animals, insect pests and/or plant diseases occurs, as a result of changing ecosystems, warmer temperatures, and a longer frost-free season	
Threshold:	A doubling of climate conditions conducive to the spread of invasive species and pests	
Historic Likelihood	Hazard Index = 3.4 (median)[24] <1% annual probability of Hazard Index = 6.6	**1** **(Rare)**
Future Likelihood	Hazard Index = 6.6 (median) 51% annual probability of Hazard Index = 6.6	**5** **(Almost Certain)**
Potential Consequences	Health and safety risks for humans and domestic animals from animals carrying diseases, parasites and pathogens (e.g., Norway Rat, Wild Boar) Disruption of aquatic recreation access from invasive plans (e.g., Eurasian Watermilfoil, Hydrilla, etc.)	**2** **(Low)**
	Damage to water infrastructure, clogging pipes and water intake systems, due to invasive aquatics (e.g., Zebra/Quagga mussel)	**2** **(Low)**
	Damage or diminished forest and urban tree canopy from insect pests (e.g., Emerald Ash Borer) Reduced biodiversity and altered ecosystem function Reduced wildlife habitat and forage	**4** **(High)**
	Reduced yields and agricultural productivity from invasive plants (e.g., thistle, Burdock, Reed, Hawkweed, etc.) Increased pest management costs to municipalities	**4** **(High)**
Determinants of Vulnerability	Condition of tree canopy Condition of natural habitats Prevalence of endangered, threatened, special concern and extirpated animals and plants Critical habitat monitoring and rehabilitation Invasive species and pest detection programs	

[24] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative.

#4: Extreme Cold (Climate Hazard, Decreasing)

Description	A "very cold day" is a day with a minimum temperature less than -30°C	
Climate Driver(S)	Milder winter temperatures	
Threshold:	A year with 6 very cold days affecting the Region	
Historic Likelihood	About 6 very cold days per year (median)[25] 43% annual probability of 6 very cold days in one year	**4 (Likely)**
Future Likelihood	About 2 very cold days per year (median) 5% annual probability of 6 very cold days in one year	**3 (Possible)**
Potential Consequences	Negative health impacts resulting in increased mortality, injuries, and mental illness, as well as reduced quality of life and wellbeing, associated with health effects	**1 (Very Low)**
	Reduced labour productivity and economic output	**1 (Very Low)**
	Damage to critical infrastructure (electricity, water, wastewater) due to cracks, fracture Equipment failure and replacement costs	**1 (Very Low)**
Determinants of Vulnerability	Prevalence of vulnerable population groups: Older adults (65+ year); Infants; Individuals with chronic cardiovascular and respiratory conditions Prevalence of underground (near-surface) water infrastructure Thermal efficiency of building stock People who work outdoors (e.g., agriculture, primary extractive industries, construction, utilities, transportation) People who are socially or materially deprived People who live in poor quality housing or experiencing homelessness	

[25] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative.

#5: Increased Space Cooling Demand (Climate Hazard, Increasing)

Description	Increase in cooling degree days; the number of degree days accumulated above 18°C over the period of a year. Cooling degree days provide an indication of the amount of space cooling (passive or active air conditioning) that may be required to maintain comfortable building conditions during warmer months.	
Climate Driver(S)	Increasing summer temperatures, more hot days and heat waves	
Threshold:	A year with 11 times the Cooling Degree Days the Region gets historically	
Historic Likelihood	12 Degree Days per year (median)[26] 3% annual probability of 144 DDs in one year	**3** **(Possible)**
Future Likelihood	144 Degree Days per year (median) 52% annual probability of 144 DDs in one year	**5** **(Almost Certain)**
Potential Consequences	Increased building energy costs (about $710 million additional costs across residential, commercial and institutional building) Increased maintenance costs for HVAC systems and controls	**5** **(Very High)**
	Increased greenhouse gas emissions Increased power demand and costs if new generation is required Increased risk of power outages	**3** **(Moderate)**
Determinants of Vulnerability	Condition and efficiency of HVAC systems Condition and energy efficiency of building envelope Energy prices and energy source Prevalence of energy poor individuals and families	

[26] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative.

#6: Reduced Space Heating Demand (Climate Hazard, Decreasing)

Description	Decrease in heating degree days; the number of degree days accumulated below 18°C over the period of a year. Heating degree days provide an indication of the amount of space heating that may be required to maintain comfortable building conditions during colder months	
Climate Driver(S)	Milder winters	
Threshold:	A year with 75% of the Heating Degree Days that the Region historically gets	
Historic Likelihood	5,655 Degree Days per year (median)[27] 100% annual probability of 4,330 DDs in one year	5 (Almost certain)
Future Likelihood	4,330 Degree Days per year (median) 51% annual probability of 144 DDs in one year	5 (Almost certain)
Potential Consequences	Reduced greenhouse gas emissions	1 (Very Low)
	Reduced building energy costs (about $305 million cost savings across residential, commercial and institutional building) Reduced maintenance costs for HVAC systems and controls Reduced revenues for energy sector, from reduced demand for natural gas Reduced produced surplus for energy sector, from reduced demand for natural gas	1 (Very Low)
Determinants of Vulnerability	Condition and efficiency of HVAC systems Condition and energy efficiency of building envelope Energy prices and energy source Prevalence of energy poor individuals and families	

[27] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative.

#7: Freeze-Thaw Cycles (Climate Hazard, Decreasing)

Description	A freeze-thaw cycle occurs when the daily high (maximum temperature) is higher than 0°C and the daily low (minimum temperature) is less than or equal to -1°C	
Climate Driver(S)	Milder winters, changing seasons	
Threshold:	A year with 80% of the freeze-thaw days the Region historically gets	
Historic Likelihood	103 freeze-thaw days per year (median)[28] 93% annual probability of 81 freeze-thaw days in one year	**5** **(Almost Certain)**
Future Likelihood	81 freeze-thaw days per year (median) 48% annual probability of 81 freeze-thaw days in one year	**4** **(Likely)**
Potential Consequences	Potential for falls and injuries, due to damaged sidewalks and pathways Road traffic accidents injuries due to damaged roads	**1** **(Very Low)**
	Damage to, and decreased service life of, buildings and infrastructure (foundations, walls, roofs, roads, sidewalks, parking lots, recreation facilities, pipes, culverts, etc.) (about $55 million damages to buildings and $5 million damages to roads) Operational issues with water and sewer infrastructure, for example from frazil ice	**2** **(Low)**
Determinants of Vulnerability	Materials, condition and age of homes and buildings Materials, condition and age of roads, trails, sidewalks and parking lots Materials, condition and age of underground infrastructure (pipes and culverts) and depth of buried pipes Inspection and maintenance regimes	

[28] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative.

#8: Reduced Traditional Winter Recreation (Climate Opportunity, Decreasing)

Description	Warmer winters resulting in a decrease in the number of mild winter days[29] conducive to traditional outdoor winter recreation	
Climate Driver(S)	Milder winters and warmer temperatures	
Threshold:	A year with 75% of the mild winter days that the Region historically gets	
Historic Likelihood	130 mild winter days per year (median)[30] 98% annual probability of 96 mild winter days in one year	5 (Almost Certain)
Future Likelihood	96 mild winter days per year (median) 49% annual probability of 96 mild winter days in one year	4 (Likely)
Potential Consequences	Reduced quality and reliability of natural outdoor ice and reduced opportunities for ice skating and ice fishing, leading to reduced quality of life and well-being Reduced and inconsistent snow cover and quality and reduced opportunities for snow-related sports, leading to reduced quality of life and well-being (physical and mental health)	1 (Very Low)
	Increased costs to maintain outdoor winter recreation assets (rinks, Nordic trails, etc.)	2 (Low)
	Loss of winter events (festivals) focused on cold, snow and ice Lose regional identify as a Region of "winter cities" (e.g., winter is a core part of the Edmonton's identity)	2 (Low)
Determinants of Vulnerability	Participation rates in traditional winter activities The number and accessibility of alternative indoor recreation options – e.g., indoor rinks Design and functionality of parks and outdoor recreation facilities for the cold season	

[29] A mild winter day is defined as a day a daily low (minimum temperature) less than or equal to -5C. Cold temperatures enable traditional outdoor winter activities—e.g., temperatures below -5C are typically needed to make artificial snow.
[30] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative.

#9: Air Quality - Wildfire Smoke (Climate Hazard, Increasing)

Description	Wildfire smoke causes 'very unhealthy' conditions across the Region	
Climate Driver(S)	Increasing summer temperatures, more hot days and drier summer conditions	
Threshold:	Wildfire smoke reduces visibility to 2km or less causing 'very unhealthy' air quality conditions[31]	
Historic Likelihood	16 occurrences where visibility fell below 2km between 1961-2021[32] Annual probability about 27%	**4 (Likely)**
Future Likelihood	Increasing. Projected 30-70% (mid-point of 50%) increase in the number of wildfire spread days in fire zones that could affect smoke levels in the Region[33] 50% increase in spread days assumed to increase annual probability of "very unhealthy" conditions to about 40%	**4 (Likely)**
Potential Consequences	Negative health impacts resulting in increased mortality, injuries, and mental illness, as well as reduced quality of life and wellbeing, associated with health effects (about 70 additional deaths expected annually, along with expected welfare losses of about $640 million annually) Reduction in outdoor recreation opportunities, reduced quality of life and well-being Increased risk of traffic accidents due to impaired visibility Potential cancellation of public and outdoor events	**5 (Very high)**
	Increased building (HVAC) maintenance and operating costs (e.g., filter replacement) Increase stress on indoor recreation facilities to provide indoor programing to vulnerable populations Reduced efficiency of solar power generation	**2 (Low)**
	Reduced economic output and value-added (about $325 million and $140 million in lost output and GDP, respectively) Impact to sporting events and festivals, decreased revenue and employment from reduced local participation and tourism.	**4 (High)**
	Negative health impacts for animals and livestock, causing distress and potential mortality	**3 (Moderate)**
Determinants of Vulnerability	Prevalence of vulnerable populations: Older adults (65+ year); Infants and young children; Pregnant women; People with pre-existing medical conditions, illness or chronic conditions; People who exercise outdoors; People performing strenuous work outdoors	

[31] The corresponding approximate 1-3 hour average concentration of PM2.5 is >300 microns per m3 (see Table 1 in Smoke Exposure from Wildfire: Guidelines for Protecting Community Health and Wellbeing, Government of Northwest Territories, May 2016.)
[32] Data from Edmonton International Airport for 'smoke days'
[33] A "spread day" measures of the number of days suitable for active fire growth within the potential or observed lifetime of a fire. They are conditional on the joint occurrence of a drying period where fuel moisture is expected to support fire ignitions and survival, b) extensive fuels to support fire spread, c) extreme fire weather (hot, dry, and windy).

#10: Summer (Meteorological) Drought (Climate Hazard, Increasing)

Description	Extreme drought during the months of June-September (3-month SPEI value <= -2.00)[34]	
Climate Driver(S)	Drier summer conditions, hotter summer temperatures	
Threshold:	5 extreme drought summers per decade (or one extreme drought every 2 years)	
Historic Likelihood	None <1% annual probability of 5 extreme summer droughts per decade[35]	**1 (Rare)**
Future Likelihood	5 extreme drought summers per decade 2%-10% annual probability of 5 extreme summer droughts per decade	**3 (Possible)**
Potential Consequences	Damage to trails, parks, playing fields leading to a loss of recreation amenity, reduced quality of life and well-being (about $15 million welfare losses from exacerbation of mental health illnesses)	**2 (Low)**
	Increased water demand Infrastructure damage from subsidence caused by low groundwater levels	**4 (High)**
	Reduced crop yields and increased stress on livestock, with potential for reduced income for farmers	**5 (Very High)**
	Stress on natural systems (soil, water bodies, forests, shrublands, grasslands, etc.) and green infrastructure (e.g., urban tree canopy, managed parks and sports fields) (about $265 million damages and loss of ecosystem services)	**5 (Very High)**
Determinants of Vulnerability	Availability and quality of infrastructure (e.g., water and sanitation, water storage, reservoirs, wells, water quality) Farming practices (e.g., access to technology, irrigation, use of agricultural inputs (fertilizer), fodder) Crop types (e.g., drought resistance, diversification) Soil condition and quality Water-intensity of power supply Per capita residential and total water demand Plans and strategies (e.g., drought planning and preparedness, water management planning)	

[34] SPEI is a relative measure of surface water surplus (positive values), or deficit (negative values) based on the difference between precipitation and potential evapotranspiration. A surface water deficit may be interpreted as dryness (ranging from moderate to extreme) or, alternatively, an indicator of drought conditions. The values in the table represent the average of the SPEI-3 month encompassing June through September, inclusive.

[35] Historic and future likelihood estimates based on average of 3-month SPEI (for August and September) projections for Edmonton Metropolitan Region downloaded from Climate Data Canada.

#11: Heavy Rainfall And Stormwater Flooding (Climate Hazard, Increasing)

Description	A high intensity, short duration rainfall event creates a surface water flood independent of an overflowing water body, typically when the drainage system is overwhelmed	
Climate Driver(S)	More severe weather, increased precipitation	
Threshold:	Historic 15-minute 1:100-year rainfall intensity (103 mm per hour)	
Historic Likelihood	15-minute 1:100 rainfall intensity = (103 mm per hour)[36] 1% annual probability of 15-minute rainfall intensity = 103 mm per hour	**2 (Unlikely)**
Future Likelihood	15-minute 1:100 rainfall intensity = 103 mm per hour 4% annual probability of 15-minute rainfall intensity = 103 mm per hour	**3 (Possible)**
Potential Consequences	Safety risks – potential for injuries and fatalities, as well as increased anxiety and distress and chronic mental health issues (expected welfare losses of about $30 million annually due to exacerbation of mental health illnesses)	**4 (High)**
	Flooding of homes and buildings in low lying areas and damage to buildings and facilities, resulting in increased maintenance and repair costs (about $235 million annual damage to residential and non-residential buildings and contents) Damage to parks and sports fields, resulting in temporary loss of use, and increased maintenance expenditures Increased runoff and erosion, with potential adverse impacts on water quality (turbidity) and resultant increased treatment costs (about $35 million annual damage to linear water infrastructure)	**4 (High)**
	Flooding of agricultural fields, resulting in delayed seeding or harvesting, leading to reduced agricultural productivity Disruption of transportation routes and access, and disruption of public and private sector goods & services (about $10 million annual damage to roads and about $2 million annual costs due to delays)	**4 - Urban (High)** **5 – Rural (Very High)**
Determinants of Vulnerability	Engineering design standard, condition and age of stormwater management system (pipes, culverts, stormwater ponds, drainage areas, etc.) Proportion of total area that is impervious Building density Local topography	

[36] Historic and future likelihood estimates based on average of IDF curve data downloaded from Climate Data Canada for 5 weather stations across the region.

#12: River And Creek Flooding (Climate Hazard, Increasing)

Description	Excessive rainfall raises the water level in rivers and creeks across the Region overflows onto the neighboring land	
Climate Driver(S)	More severe weather, increased precipitation	
Threshold:	Historic 1:100-year maximum flow	
Historic Likelihood	1:100-year maximum flow = 5,270 m3 per second (NSR at Edmonton)[37] 1% annual probability of maximum flow (5,270 m3 per second) in NSR	**2 (Unlikely)**
Future Likelihood	1:100-year discharge ~6,000 m3 per second (NSR at Edmonton) Increased likelihood. ~2% annual probability of maximum flow in NSR at Edmonton = 5,270 m3 per second	**2 (Unlikely)**
Potential Consequences	Safety risks – potential for injuries and fatalities, as well as increased anxiety and distress and chronic mental health issues (expected welfare losses of about $30 million annually due to exacerbation of mental health illnesses) Potential for evacuations and the need for temporary accommodation, reduced quality of life and well-being	**4 (High)**
	Flooding and damage to homes and buildings in low lying areas, resulting in increased maintenance and repair costs (expected damages to buildings of about $345 million annually, on average) Damage to water and wastewater treatment plants, with potential for disruption to services, increased treatment costs, and water quality concerns (expected damages >$1 million annually) Damage to recreation facilities in flood-prone area (parks, golf courses, sports fields, etc.), resulting in temporary loss of use, and increased maintenance expenditures	**5 (Very High)**
	Flooding of agricultural fields, resulting in delayed seeding or harvesting, leading to reduced agricultural productivity Disruption of transportation routes and access, and disruption of public and private sector goods & services Loss of land available for development	**5 (Very High)**
	Damage and erosion to riverbanks and riparian areas, resulting in damage loss of wildlife habitat and ecosystem services (expected damages and ecosystem service losses of about $20 million annually) Damage to ecosystem from premature discharge of sewage lagoons, meaning sewage leaking into environment	**4 (High)**
Determinants of Vulnerability	Building materials, condition and age Dependence of regional transport network on roads/rail that cross rivers or run adjacent to rivers Engineering design standard, condition and age of flood protection infrastructure Early warning systems and emergency response plan (for river flooding)	

[37] Historic 1:100-year flow rate from NSR Flood Risk Mapping Study, Technical Report, Alberta Environment, February 2007. Future flow rate and likelihood estimates based on scaling factors derived from NSR flow rate data provided by the Prairie Adaptation Research Collaborative.

#13: Wildland Fire (Climate Hazard, Increasing)

Description	A wildland fire occurs within the Region boundary	
Climate Driver(S)	Increasing summer temperatures, more hot days and drier conditions	
Threshold:	A 200-hectare wildfire occurs within the Region, impacting people and structures at risk[38]	
Historic Likelihood	**RURAL**: Estimated 1:20 year return period fire (~ 5% annual probability) of a large wildfire in the Region	3 (Possible)
	URBAN: Estimated 1:100-year return period fire (<1% annual probability) of a large wildfire in the Region	1 (Rare)
Future Likelihood	**RURAL**: Increasing. Projected 30-70% (mid-point of 50%) increase in the number of wildfire spread days in the Region	4 (Likely)
	URBAN: Increasing. Projected 30-70% (mid-point of 50%) increase in the number of wildfire spread days in the Region	2 (Unlikely)
Potential Consequences	Safety risks – injuries and potential loss of life, and mental health issues – stress, anxiety, distress (expected welfare losses amount to about $4 million annually) Potential for evacuations and the need for temporary accommodation, reduced quality of life and well-being Potential for temporary evacuations	4 (High)
	Damage to / loss of buildings, contents and inventories (commercial) (expected damages to buildings and infrastructure amount to about $80 million annually) Damage to / loss of infrastructure and potential impairment of services and disruption to daily life Increased water demand to suppress fires	5 - Urban (Very High) 3 - Rural (Moderate)
	Delays and disruption to transportation networks (main highways transportation arteries and rail lines) Municipal costs for emergency services Loss of crops and livestock - reduced yields / productivity	4 (High)
	Damage to / loss of terrestrial wildlife habitat, resulting in impacts to wildlife health and impairment or temporary loss of ecosystem services (expected damages and loss of ecosystem services amount to about $5 million annually)	3 (Moderate)
Determinants of Vulnerability	Vegetation and use of wildfire-resistant materials in the area around buildings and property The use of wildfire-resistant materials in building envelopes The presence of trees, shrubs, and other potential fuels Local topography (slope, aspect and elevation all influence fire risk)	

[38] Represents that largest wildfire size class recorded in Alberta Agriculture and Forestry database). This fire is roughly the size the 2008 (250 ha) and 2018 (> 600 ha) wildfires that impacted Strathcona County.

#14: Severe Windstorm, Wind Gusts (Climate Hazard, Stable)

Description	A severe windstorm occurs in the Region	
Climate Driver(S)	More severe weather	
Threshold:	One day with maximum wind gusts to 110 km/hr or more	
Historic Likelihood	About 7% annual probability of a severe windstorm historically, return interval = 1:15 year[39]	**3 (Possible)**
Future Likelihood	Insufficient evidence to determine trend About 7% annual probability of a severe windstorm, return interval = 1:15 year	**3 (Possible)**
Potential Consequences	Safety risks - injuries and potential fatalities from blowing debris and wind-induced traffic accidents (about $1 million welfare losses annually from injuries)	**2 (Low)**
	Damage to buildings and facilities directly or indirectly (from falling tree branches or blowing debris) from high winds (about $25 million damages annually to residential, commercial and institutional buildings) Damage to electricity T&D infrastructure directly from high winds or indirectly from falling tree branches, with potential for power outages and disruption to businesses and daily life (about $3 million damages annually to electricity T&D infrastructure)	**3 (Moderate)**
	Secondary economic impacts associated with lost output and value added due to direct damages to buildings and infrastructure and tree canopy, and associate disruption to the provision of goods and services (estimated direct and indirect lost economic output and value-added amount to $50 million and $22 million annually, respectively)	**3 (Moderate)**
	Damage to trees / tree branches resulting in loss of ecosystem services and increased clean-up and replacement costs (about $8 million damages and loss of ecosystem services) Increased soil erosion, resulting in loss of ecosystem services	**2 (Low)**
Determinants of Vulnerability	Construction materials (e.g., brick vs wood frames) and building design (e.g., addition of fasteners, ties, anchors) Building Code Condition and age of buildings and infrastructure, and level of deferred maintenance Condition of tree canopy Proportion of electricity T&D and ICT network underground Tree density and proximity to property and infrastructure	

[39] Historic values are based on data from the EIA weather stations; future values are based on Canon, A. et al., 2020, Climate Resilient Buildings and Core Public Infrastructure, An assessment of the impact of climate change on climatic design data in Canada, Infrastructure Canada.

#15: Tornado (Climate Hazard, Stable)

Description	A tornado is a violently rotating column of air that extends from a cumuliform cloud to the surface[40]	
Climate Driver(S)	More severe weather	
Threshold:	A "strong" tornado is on the ground for 20 km in the Region, with wind speeds of 178-266 km/hr (EF2 or EF3)[41]	
Historic Likelihood	There has been one "strong" or higher tornado in the Region—Edmonton, Beaumont, Millet, etc. on 31.07.1987 <1% annual probability of strong tornado	**1 (Rare)**
Future Likelihood	Insufficient evidence to determine trend Assumed <1% annual probability of strong tornado in future	**1 (Rare)**
Potential Consequences	Safety risks - injuries and potential fatalities, as well as adverse mental health impacts (stress, anxiety, PTSD) (welfare losses from health impacts amount to $16 million annually[42])	**4 (High)**
	Damage to buildings, facilities and property (including vehicles) directly or indirectly (from falling tree branches or blowing debris) (estimated damages to buildings and infrastructure amount to $1.1 billion annually) Damage to critical infrastructure and disruption of critical services – water, wastewater, energy, health services, etc.	**4 (High)**
	Secondary economic impacts associated with lost output and value added due to direct damages to buildings and infrastructure, and disruption to the provision of goods and services (estimated lost economic output and GDP amount to $2.1 billion and $0.9 billion annually, respectively)	**4 (High)**
	Damage to trees and forests resulting in loss of ecosystem services (damages are about $6 million annually)	**2 (Low)**
Determinants of Vulnerability	Presence and accessibility of suitable shelter Construction materials (e.g., brick vs wood frames) and building design (e.g., addition of fasteners, ties, anchors) Prevalence of buildings with large, expansive roofs and walls Prevalence of mobile homes Condition and age and type of buildings and infrastructure Proportion of electricity T&D and ICT network underground Tree density and proximity to property and infrastructure	

[40] Tornadoes are classified into three broad groups based on their estimated wind speeds and resultant damage: "weak" includes EF0 and EF1 [wind speeds of 105-177 kph]; "strong" includes EF2 and EF3 [wind speeds of 178-266 kph]; and "violent" includes EF4 and EF5 [wind speeds of 267 to over 322 kph].

[41] Based on damage path statistics reported for all tornadoes in the United States over the period 2007-2013 in Elsner, J. et al., 2014, Tornado Intensity Estimated from Damage Path Dimensions, PLoS ONE 9(9): e10757.

[42] Note that all estimated damages reported here account for the likelihood of built and natural assets and people being located within the path of the tornado, but not the likelihood of the tornado occurring.

#16: Freezing Rain, Ice Storm (Climate Hazard, Increasing)

Description	Rain that freezes on impact to form a coating of clear ice (glaze) on the ground and on exposed objects	
Climate Driver(S)	More severe weather, milder winters	
Threshold:	A day with 10-11 mm of freezing precipitation affecting the entire Region	
Historic Likelihood	7.5 mm (5-10 mm) freezing precipitation in a day (1:20 year daily maximum freezing precipitation level)[43] Unknown annual probability of 10.5 mm (7-14 mm) of freezing precipitation in a day, but less than 5%	**2 (Unlikely)**
Future Likelihood	10.5 mm (7-14 mm) freezing precipitation in a day (1:20 year daily maximum freezing precipitation level) 5% annual probability of 10.5 mm (7-14 mm) of freezing precipitation in a day	**3 (Possible)**
Potential Consequences	Safety risks (traffic accidents, falls, down power lines) – injuries and potential loss of life (welfare losses from accidents and injuries amount to about $2-3 million annually) Reduced mobility (walking, other active transport), particularly for elderly and less abled	**2 (Low)**
	Damage to building envelopes due to ice loading (damages estimated at about $120 million annually, mainly from tree branches impacting buildings) Damage to infrastructure and potential impairment of services (e.g., when covered with ice power lines are weighted and can be damaged) and disruption to business activity and daily life (damages to electricity T&D infrastructure estimated at about $10 million annually) Road and pavement maintenance costs (sanding, salting)	**4 (High)**
	Disruption to road transport network Secondary economic impacts associated with lost output and value added due to direct damages to buildings and infrastructure, and disruption to the provision of goods and services (notably power)	**4 (High)**
	Damage to forest and tree canopy in population centers, resulting in impairment or temporary loss of ecosystem services, as well as increased clean-up costs (estimated damages and ecosystem service losses amount to $100 million annually)	**2 (Low)**
Determinants of Vulnerability	Condition and age of buildings and infrastructure Prevalence of outdoor, overhead electricity wires (versus underground cables) Tree density and proximity to property and infrastructure Road and pavement maintenance regime	

[43] Historic and future values for freezing precipitation are based on Jeong, D. et al., 2019, Projected changes to extreme freezing precipitation and design ice loads over North America based on a large ensemble of Canadian regional climate model simulations, Natural Hazards and Earth Systems Science, 19, 857-872 and Canon, A. et al., 2020, Climate Resilient Buildings and Core Public Infrastructure, An assessment of the impact of climate change on climatic design data in Canada, Infrastructure Canada.

#17: Heavy Snowfall (Climate Hazard, Decreasing)

Description	A snowfall event that exceeds Environment Canada's alert parameters for issuing a snowfall warning (when 10 cm or more of snow falls within 12 hours or less)	
Climate Driver(S)	More severe storms	
Threshold:	Historic 1:50-year snowfall event (12 cm in 12 hours) [44]	
Historic Likelihood	12 cm snowfall in 12 hours (1:50 snowfall event) 2% annual probability of 12 cm snowfall in 12 hours in any given year	**2 (Unlikely)**
Future Likelihood	Decreasing likelihood 1-2% annual probability of 12 cm snowfall in 12 hours in any given year	**2 (Unlikely)**
Potential Consequences	Increased safety risks (traffic accidents, falls, acute cardiac arrest, down power lines) – injuries and potential loss of life (welfare losses estimated at about $70 million annually, mainly due to exacerbation of cerebro- or cardio-vascular episodes, and to a lesser extent, accidents) Reduced mobility (walking, other active transport), particularly for elderly and disabled	**2 (Low)**
	Damage to building envelopes due to snow loading (damages estimated at about $80 million annually, mainly from tree branches impacting buildings) Damage to electricity transmission and distribution system and potential impairment of services (power outages) and disruption to business activity and daily life (damages estimated at about >$5 million annually) Road maintenance costs (removal, sanding) Strain on stormwater and drainage systems during spring season	**3 (Moderate)**
	Disruption to road transport network Economic impacts associated with lost revenues and delays due to infrastructure impacts, notably utility impacts and power outages	**3 (Moderate)**
	Damage to tree canopy, resulting in loss of ecosystem services, as well as increased clean-up costs (damages and loss of ecosystems services estimated at about $60 million annually)	**2 (Low)**
Determinants of Vulnerability	Prevalence of outdoor electricity wires (versus underground cables) Tree density and proximity to property and infrastructure Prevalence of flat roofs and snow shedding materials Engineering design standard, condition and age of buildings roofs Snow clearing and sanding service levels	

[44] Historic values are based on data from the Edmonton International Airport weather station; future values are based on Canon, A. et al., 2020, Climate Resilient Buildings and Core Public Infrastructure, An assessment of the impact of climate change on climatic design data in Canada, Infrastructure Canada.

#18: Hailstorm with Large Hail (Climate Hazard, Increasing)

Description	Precipitation in the form of lumps of ice mainly associated with thunderstorms	
Climate Driver(S)	More severe storms	
Threshold:	One "very large hail day" (i.e., with hailstones > 4cm) impacting about 7-8% of Region[45]	
Historic Likelihood	1 large hail day every 6-7 years (3.5-5 large hail days over period 1971-2000) ~14% annual probability of large hail day occurring historically	**4 (Likely)**
Future Likelihood	Increasing likelihood. About 1 additional large hail day per season (1 large hail day every 5-6 years) ~18% annual probability of large hail day occurring	**4 (Likely)**
Potential Consequences	Increased safety risks - injuries and in extreme cases potential loss of life, including from road traffic accidents	**2 (Low)**
	Damage to building envelopes (roof, shingles, siding, gutters, windows), outdoor structures and roof-mounted equipment (e.g., solar panels) (damages to buildings are estimated at about $80 million annually) Damage to public infrastructure and potential impairment of services (including power outages and telecommunication disruptions) and disruption to business activity and daily life (damages to electricity T&D infrastructure are estimated at >$5 million annually) Damage to vehicles	**3 (Moderate)**
	Disruption of transportation routes and access, and disruption of public and private sector goods & services Damage to crops, reducing farm incomes	**3 (Moderate)**
	Damage trees, plants and flower beds, resulting in impairment of ecosystem services, and clean-up costs (damages and loss of ecosystem services are estimated at >$5 million annually)	**2 (Low)**
Determinants of Vulnerability	Design, materials, condition and age of building envelopes and other external systems (e.g., roof top HVAC) Proportion of electricity T&D and ICT network underground Prevalence of garages and indoor parking spaces	

[45] Historic and future values based on Brimelow, J. et al., 2017, The changing hail threat over North America in response to anthropogenic climate change, Nature Climate Change, DOI: 10.1038/NCLIMATE3321. The spatial extent of impact is based on the average size of severe thunderstorms in North America, and specifically, the diameter of the "rain spout", which is assumed to traverse the Edmonton Metropolitan Region from west to east.

#19: Air Quality – Ground Level Ozone (Climate Hazard, Increasing)

Description	Acute and chronic exposure to ground level ozone (O3) is associated with higher mortality and morbidity (illness and disease) than expected (i.e., in the absence of O3 exposure) in the population. Maximum daily summer temperature is used as a proxy for potential exposure of the ERM population to ambient ground-level 03.	
Climate Driver(S)	Increasing summer temperatures, more hot days and drier conditions	
Threshold:	8 parts per billion by volume (ppbv) increase in 1-hour concentrations of ground level O3 in the Region[46] This represents close to a 40% increase in the average July-August 1-hour average concentration between 1990-2020 (≅ 20 ppbv)[47].	
Historic Likelihood	21.2°C = mean maximum daily summer temperature 4-5% annual probability of a mean maximum daily summer temperature of at least 24°C in any given year[48,49]	**3 (Possible)**
Future Likelihood	24°C = mean maximum daily summer temperature 60% annual probability of a mean maximum daily summer temperature of at least 24°C in any given year	**5 (Almost Certain)**
Potential Consequences	Negative health impacts resulting in increased mortality, injuries, and mental illness, as well as reduced quality of life, associated with health effects (excess deaths attributable to increased O3 levels estimated at about 10-15 annually, with corresponding welfare losses of $105 million) Reduction in summer outdoor recreation and outdoor events	**4 (High)**
	Reduced economic output and value-added (direct and indirect loss of economic output and value added estimated at $85 million and $35 million, respectively)	**4 (High)**
	Reduced survivability of tree seedlings and increased susceptibility to diseases, pests and other stresses	**2 (Low)**
Determinants of Vulnerability	Prevalence of vulnerable populations: Older adults (65+ year); Infants and young children; Pregnant women; People with pre-existing medical conditions, illness or chronic conditions People who exercise outdoors People performing strenuous work outdoors People experiencing homelessness Background concentrations of O3 and pre-cursors from anthropogenic sources Tree species; some species are more susceptible to harm than others	

[46] For example, Boyd et al. (2020) found a 1-degree Celsius change in daily summertime temperature was associated with a 2.9 [0.12 to 6.51] parts per billion by volume (ppbv) increase in 1-hour O3 concentrations (Boyd et al., Costing Climate Change Impacts on Human Health across Canada, Final Report, December 2020).
[47] Data from the Alberta Air Data Warehouse, Edmonton Central Station, Core Long-term Program, Ozone.
[48] The likelihood estimates relate to the change in temperature that is driver the change in O3 concentrations.
[49] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative; the change in O3 levels is a function of projected increases in maximum daily summer temperature.

#20: Shifting Ecoregions (Climate Hazard, Increasing)

Description	Alberta's grasslands, parkland and boreal regions are anticipated to shift northward with climate change. The natural regions that surround communities in the Region will no longer look the same in the future, providing different ecosystem services, and making them a different place to live.	
Climate Driver(S)	Changing seasons and ecosystems	
Threshold:	A shift from mainly mixed woodland/parkland to parkland/grasslands in the Region[50]	
Historic Likelihood	n/a	n/a
Future Likelihood	Unknown, as it depends on disturbances to the landscape (to create windows for change) as well as changes to the climate envelope of each ecoregion	**3 (Possible)**
Potential Consequences	Welfare losses arising from changes to values people derive from the provision of ecosystems services (cultural, recreation, habitat, aesthetics, etc.) as the landscape alters	**3 (Moderate)**
	Some species will shift their ranges northward as the ecoregions shift; other species (many plants) may not be able to make the shift Potential die-off of temperature sensitive species (e.g., fish) Loss of ecosystem services (pollination, water filtration, recreation, stormwater attenuation, carbon sequestration, aesthetics, etc.) provided by mixed woodland/central parkland Changes to risk of natural disturbances, like drought, wildfire Potential die-off of native/current vegetation species which could increase debris from storms and increase wildfire risk	**4 (High)**
Determinants of Vulnerability	Non-native vegetation Ability of species to migrate with changing ecoregions Dependence of livelihoods and wellbeing on the ecosystem services provided by mixed woodlands/central parklands	

[50] Schneider, R., 2013, Alberta's Natural Subregions Under a Changing Climate: Past, Present and Future, Report prepared by Department of Biological Sciences, University of Alberta for the Biodiversity Management and Climate Change Adaptation Project, 97p.

#21: Long-Term Water Shortage (Climate Hazard, Increasing)

Description	A severe low flow event in the North Saskatchewan River (NSR) (<25 cubic metres per second) could compromise water intakes and lead to potentially major water supply interruptions across the Region. Climate projections indicate a shift in the magnitude and timing of low flows in the NSR in the future (**Error! Reference source not found.**)[51]. Whereas historically, minimum river flows occurred in winter, i n the future they occur in late summer and fall. This is due to the loss of glacier and mountain snowpack runoff and increased precipitation in winter and spring.	
Climate Driver(S)	Warmer temperatures, lower snowpack	
Threshold:	A monthly average flow rate less than 25 m^3 per second reducing ability to reliability and sustainability draw water from the North Saskatchewan River, and other natural water sources	
Historic Likelihood	A monthly average flow rate of less than 25 m^3 per second has an annual probability of about 35%-40%[52]	**4 (Likely)**
Future Likelihood	A monthly average flow rate of less than 25 m^3 per second has an annual probability of about 5%	**3 (Possible)**
Potential Consequences	Increased economic costs to secure temporary alternative supplies Reduced economic output and value-added for water-intensive sectors, notably the petrochemical sector and Industrial Heartland	**5 (Very High)**
	Stress on natural systems and green infrastructure Loss of/damage to irrigated natural assets – sporting fields, trees, etc. Potential die-off of aquatic species and ecosystems	**4 (High)**
Determinants of Vulnerability	Water-intensity of power supply Water-intensity/dependance of regional economy, businesses and industries Availability and quality of infrastructure (e.g., water and sanitation, water storage, reservoirs, wells, water quality) Per capita residential and total water demand Plans and strategies (e.g., water management planning)	

[51] Source: Sauchyn, David; Soumik Basu, Muhammad Rehan Anis, Yuliya Andreichuk, and Samantha Kerr (2021) High-Resolution Climate Change Projections for the City of Edmonton, Final Report to Alberta EcoTrust and the City of Edmonton.

[52] Sauchyn, D., et al., High-Resolution Climate Change Projections for the City of Edmonton, Final Report prepared by PARC for the City of Edmonton, May 2021.

#22: Supply Chain Disruption (Climate Hazard, Increasing)

Description	Climate change is anticipated to increase the frequency, intensity and spatial distribution of acute supply chain disruptions caused by extreme weather that could damage production facilities and infrastructure. Climate change is also expected to create chronic (long-term) changes to supply chains and may give rise to new, not previously encountered risks. All of these supply chain impacts will have financial, competitiveness and reputational consequences for businesses in the ERM. A Supply Chain Risk Index created for the City of Edmonton is used as a proxy for upstream and downstream supply chain disruption affecting the region because of global climate change[53].	
Climate Driver(S)	Multiple climate impact-drivers, regionally, nationally and internationally	
Threshold:	Supply chains upstream (inputs from suppliers) and downstream (outputs to customers) of businesses in the Region experience disruption (e.g., delays in receiving inputs, reduced quality of inputs, increased costs, impaired access to customers and markets, etc.)	
Historic Likelihood	Projected supply chain risk for the Region is "very low" on average across all sectors (GDP weighted average across all 2-digit NAICS industries)[54]	**1 (Rare)**
Future Likelihood	Projected supply chain risk for the Region is "low" on average across all sectors (GDP weighted average across all 2-digit NAICS industries)	**2 (Unlikely)**
Potential Consequences	Loss of benefit consumers derive from consumption of goods and services resulting from reduced supply or quality of goods, and/or increases in price[55]	**3 (Moderate)**
	Increased logistics costs Reduced output and value added Reputational loss for businesses Higher financing and insurance costs Reduced investment by businesses in Region Loss of Region's market share	**5 (Very high)**
Determinants of Vulnerability	Dependence of businesses on climate-sensitive (e.g., agricultural products) material inputs that are not easily substituted Concentration of suppliers of critical material inputs in the same location or Region Dependence of critical supply chains on unique infrastructure, such as single port or land or air route Extent to which key businesses or sectors rely on a single supplier for a critical material input Concentration of customers in the same location or Region Economic diversity of Region	

[53] The Supply Chain Risk Index is explained in Boyd, R., Zukiwsky, J. and Kwan, C., 2022. Climate resilient business guide: future-proofing your business for a changing climate. Final Report prepared by All One Sky Foundation for the City of Edmonton.

[54] For some industries the risks are "high" to "very high" (e.g., agriculture, construction, wholesale trade, transport & warehousing)

[55] Strictly speaking, the benefit lost is referred to as "consumer surplus" –i.e., the difference between a consumer's maximum willingness to pay for a good or service and the price actually paid.

#23: Longer Construction Season (Climate Opportunity, Increasing)

Description	Projected increases in spring and fall temperatures will extend the length of the construction season. An extended season could reduce construction costs and lead to quicker completion of projects. An Opportunity Index is used as a proxy for an increase in the length of the construction season in the Region *attributable* to climate change; the Index comprises projected changes to the following climate variables: mean spring temperature, mean fall temperature, length of the frost-free season. An Index value of 10 = maximum change in beneficial climate conditions or best-case.	
Climate Driver(S)	Longer frost-free season, increased spring and fall temperatures	
Threshold:	A doubling of climate conditions conducive to a longer construction season, with a 30% increase in the frost-free season	
Historic Likelihood	Opportunity Index = 3.3 (median)[56] 1-2% annual probability of Opportunity Index = 6.8	**2 (Unlikely)**
Future Likelihood	Opportunity Index = 6.8 (median) 51% annual probability of Hazard Index = 6.8	**5 (Almost Certain)**
Potential Consequences	Increased productivity and economic output Increased efficiency and reduced costs of summer construction projects – roads, buildings, utilities, etc. Increased demand for construction supplies, materials and personnel	**3 (Moderate)**
Determinants of Vulnerability	Economic dependance on construction sector (accounted for about 8% of Region's direct value-added in 2021) Employment dependence on the construction sector (accounted for about 10% of Region's labour force aged 15 and older and 12% of direct employment income in 2021)	

[56] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative (mean seasonal temperatures), and data downloaded from the Climate Data Canada portal (frost-free season).

#25: Longer Summer Recreation and Tourism Season (Climate Opportunity, Increasing)

Description	Warmer temperatures, particularly in spring and fall will increase opportunities for summer outdoor tourism and recreation across the Region. An Opportunity Index is used as a proxy for an increase in the length of the summer recreation and tourism season in the Region *attributable* to climate change; the Index comprises projected changes to the following climate variables: mean spring temperature, mean fall temperature, length of the frost-free season. An Index value of 10 = maximum change in beneficial climate conditions or best-case.	
Climate Driver(S)	Longer frost-free season, increased spring and fall temperatures	
Threshold:	A doubling of climate conditions conducive to a longer summer recreation and tourism season, with a 30% increase in the frost-free season	
Historic Likelihood	Opportunity Index = 3.3 (median)[57] 1-2% annual probability of Opportunity Index = 6.8	**2** **(Unlikely)**
Future Likelihood	Opportunity Index = 6.8 (median) 51% annual probability of Hazard Index = 6.8	**5** **(Almost Certain)**
Potential Consequences	Improved quality of life and well-being from warmer temperatures and increased ability to spend time outdoors and enjoy outdoor events and attractions	**3** **(Moderate)**
	Increased tourism visitation and economic benefits for hotels, restaurants, attractions, festivals and events, etc.	**3** **(Moderate)**
Determinants of Vulnerability	Economic dependance on tourism and recreation sector Employment dependence on tourism and recreation sector Supply, quality, affordability and equitable access of supporting infrastructure	

[57] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative (mean seasonal temperatures), and data downloaded from the Climate Data Canada portal (frost-free season).

#25: Longer Agricultural Growing Season (Climate Opportunity, Increasing)

Description	A model relating changes in farmland values[58] to changes in an Index of agricultural-related climate variables is used to define this impact scenario. The Index comprises projected changes to the following climate variables: mean seasonal temperatures, mean annual precipitation, frost-free days, and growing degree days[59]. Through the 2050s a higher Index value is beneficial for agriculture[60].	
Climate Driver(S)	Longer, warmer growing season	
Threshold:	An improvement in mean climate conditions resulting in a 1.5%-2% improvement in farmland values in the Region	
Historic Likelihood	Index = 3.2 (median) <1% annual probability of Index = 6.7[61]	**1** **(Rare)**
Future Likelihood	Index = 6.7 (median) 55% annual probability of Index = 6.6	**5** **(Almost Certain)**
Potential Consequences	Improved quality of life and well-being, particularly for agricultural workers and local farmers	**2** **(Low)**
	Positive changes to crop yields, and opportunities for warm weather crops, with corresponding changes in net farm income (farmland values in the Region are estimated to increase by about $0.3 billion by 2055)	**3** **(Moderate)**
Determinants of Vulnerability	Dependency of ERM on agriculture sector for employment Contribution of agriculture sector to regional economic output and GDP Prevalence of pests and disease Crop type (e.g., heat tolerance, diversification) Prevalence of shelter for livestock Reliance of ERM on locally supplied food stuffs and prevalence of food insecurity	

[58] Farmland values are indicative of the (present value) of the stream of economic surplus (whether from crops, livestock or both) the land is expected to yield over time.

[59] These climate variables are all independent variables in the impact-model used for the costs of inaction analysis.

[60] Note that this Index which suggests climate change by mid-century will be beneficial for the sector does not account for all challenges climate is likely to present agricultural productivity and economic surplus, such as water availability and extreme events like windstorms, hailstorms, heatwaves, flooding, etc.

[61] Historic and future likelihood estimates based on climate projection data provided by the Prairie Adaptation Research Collaborative.

APPENDIX D

Consequence Scoring Rubrics

Consequence Scoring Rubric for Climate Hazards: Public Health, Safety, and Wellbeing

Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
Minimal health effects Insignificant/negligible impacts to quality of life and livability within the region, including impacts to food security, culture, and/or community amenities Not likely to result in evacuation, shelter in place orders or people stranded		Moderate health effects including with less than 10 fatalities and fewer than 25 injuries or illnesses Moderate negative impacts to quality of life and livability within the Region, including impacts to food security, culture, and/or community amenities Some community evacuations and displacement with fewer than 100 people evacuated, sheltered in place or stranded		Significant and widespread health effects including over 50 fatalities, and/or 100 injuries or illnesses Widespread and long-term negative impacts to quality of life and livability within the Region, including impacts to food security, culture, and/or community amenities Widespread community evacuations and displacement with over 500 people evacuated, sheltered in place or stranded

Consequence Scoring Rubric for Climate Hazards: Economic

Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
Insignificant economic losses/reductions in economic output Minimal disruption of important businesses/economic sectors Few if any job losses and/or reductions in productivity Minimal costs to municipalities in the Region		Potential direct and indirect economic losses of around $100 million Medium-term (days-weeks) disruption of many important businesses/economic sectors, affecting the movement of people, goods and services to, from and within the Region Some job losses and/or reduced productivity impacting some economic sectors. Moderate reduction in diversity, competitiveness and prosperity of the Region Costs to municipalities is manageable within existing “reserve funds"		Potential direct and indirect economic losses of over $400 million Long-term (months-years) disruption of many important businesses/economic sectors, affecting the movement of people, goods and services to, from and within the Region Widespread job losses and/or reduced productivity impacting many important economic sectors across the Region. Long-term reduction in diversity, competitiveness and prosperity of the Region Costs to municipalities in the Region is far beyond available "reserve funds"

Consequence Scoring Rubric for Climate Hazards: Built Environment

Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
Minimal damage to infrastructure and assets across the Region Insignificant/very short-term interruption of services – water supply, energy, telecommunications, etc.		Moderate damage to infrastructure and assets across the Region including transportation networks (roads, rail, active transport, airport, etc.), water infrastructure (treatment plants, supply lines, sewage, etc.), energy infrastructure (supply, generation, distribution), and buildings (residential, commercial, industrial), including affordable housing Some interruption of services, but minimal impact on critical services – water supply, energy, telecommunications, etc.		Widespread and severe damage to infrastructure and assets across the Region including transportation networks (roads, rail, active transport, airport, etc.), water infrastructure (treatment plants, supply lines, sewage, etc.), energy infrastructure (supply, generation, distribution), and buildings (residential, commercial, industrial), including affordable housing Significant and long-term interruption of more than 3 critical services – water supply, energy, telecommunications, etc.

Consequence Scoring Rubric for Climate Hazards: Natural Environment

Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
Insignificant alteration or negative impacts to natural living systems in the Region, including watershed health, land, water quality, air quality, wildlife, and/or ecosystem function/services. Very localized impacts covering less than 1% of the Region. Natural systems can easily recover.		Moderate damage or disturbance to natural living systems in the Region, including watershed health, land, water quality, air quality, wildlife, and/or ecosystem function/services. Impacts affecting less than 10% of the Region. Ecological recovery possible in a reasonable time		Widespread, long-term and potentially irreversible, damage or disturbance to natural living systems in the Region, including watershed health, land, water quality, air quality, wildlife, and/or ecosystem function/services. Impacts are widespread affecting greater than 50% of the Region. Recovery, if at all, is very long-term, taking greater than 10 years.

APPENDIX E

Risk Assessment Results

Climate Impact Scenario		Likelihood Score	Consequence Score	Risk Score	Risk Level in Matrix
Climate Hazards	**Consequence Type**				
Increased space cooling demand	Economic	5	5.0[62]	25.0	Very High
Outbreak of invasive species & pests	Economic	5	4.3	21.5	Very High
Air quality—ground level ozone	Economic	5	4.0[63]	20.0	Very High
Air quality—ground level ozone	Health, safety & wellbeing	5	4.0	20.0	Very High
Air quality—wildfire smoke	Health, safety & wellbeing	4	5.0	20.0	Very High
Outbreak of invasive species & pests	Natural environment	5	4.0	20.0	Very High
Air quality—wildfire smoke	Economic	4	4.0	16.0	Very High
Extreme heat—impacts to public health	Economic	4	4.0[64]	16.0	Very High
Long-term water supply shortage	Economic	3	5.0	15.0	Very High
Extreme heat—impacts to public health & workforce	Health, safety & wellbeing	4	3.7	14.8	Very High
Summer (meteorological) drought	Economic	3	4.8	14.4	Very High
Summer (meteorological) drought	Natural environment	3	4.7	14.1	Very High
Heavy precipitation & stormwater flooding (rural)	Economic	3	4.6	13.8	Very High
Extreme heat—impacts to built & natural environment	Natural environment	4	3.4	13.6	Very High
Long-term water supply shortage	Natural environment	3	4.3	12.9	Very High
Increased space cooling demand	Built environment	5	3.0[65]	15.0	High
Freezing rain, ice storm	Built environment	3	4.0	12.0	High
Hailstorm—large hail	Built environment	4	3.0[66]	12.0	High
Heavy precipitation & stormwater flooding	Built environment	3	4.0	12.0	High

[62] Changed from a "built environment" consequence (as per workshop) to an "economic" consequence during the evaluation of workshop results.
[63] Average consequence score of 4.7 from workshop was lowered to 4.0 during evaluation of the results; supported by an update to the quantitative modelling performed for the costs-of-inaction analysis.
[64] Average consequence score of 2.6 from workshop was raised to 4.0 during evaluation of the results, which is in line with the results from the costs-of-inaction analysis.
[65] Average consequence score of 4.6 from workshop was lowered to 3.0 during evaluation of the results, as the consequence rating at the workshop was based more on "economic" concerns than "built environment" concerns.
[66] Average consequence score of 3.9 from workshop was lowered to 3.0 during evaluation of the results.

Climate Impact Scenario		Likelihood Score	Consequence Score	Risk Score	Risk Level in Matrix
Climate Hazards	**Consequence Type**				
Summer (meteorological) drought	Built environment	3	4.0	12.0	**High**
Freezing rain, ice storm	Economic	3	4.0[67]	12.0	**High**
Hailstorm—large hail	Economic	4	3.0[68]	12.0	**High**
Heavy precipitation & stormwater flooding (urban)	Economic	3	4.0[69]	12.0	**High**
Air quality—wildfire smoke	Natural environment	4	3.0	12.0	**High**
Shifting natural ecoregions	Natural environment	3	4.0	12.0	**High**
Heavy precipitation & stormwater flooding	Health, safety & wellbeing	3	3.9	11.7	**High**
Wildland fire (rural & urban)	Health, safety & wellbeing	3	3.9	11.7	**High**
Wildland fire (rural)	Built environment	4	2.8	11.2	**High**
Supply chain disruption	Economic	2	5.0	10.0	**High**
River & creek flooding	Economic	2	4.8	9.6	**High**
River & creek flooding	Built environment	2	4.7	9.4	**High**
Wildland fire (urban)	Built environment	2	4.4	8.8	**High**
River & creek flooding	Natural environment	2	4.4	8.8	**High**
Wildland fire	Economic	2	3.9	7.8	**High**
River & creek flooding	Health, safety & wellbeing	2	3.9	7.8	**High**
Outbreak of invasive species & pests	Health, safety & wellbeing	5	2.5	12.5	**Moderate**
Air quality—ground level ozone	Natural environment	5	2.0[70]	10.0	**Moderate**
Extreme heat—impacts to built & natural environment	Economic	4	2.4	9.6	**Moderate**
Outbreak of invasive species & pests	Built environment	5	1.9	9.5	**Moderate**

[67] Average consequence score of 3.5 from workshop was raised to 4.0 during evaluation of the results, which is in line with the results from the costs-of-inaction analysis.
[68] Average consequence score of 3.7 from workshop was lowered to 3.0 during evaluation of the results, which is in line with the results from the costs-of-inaction analysis.
[69] Average consequence score of 3.3 from workshop was raised to 4.0 during evaluation of the results, which is in line with the results from the costs-of-inaction analysis.
[70] Average consequence score of 3.0 from workshop was lowered to 2.0 during evaluation of the results.

Climate Impact Scenario		Likelihood Score	Consequence Score	Risk Score	Risk Level in Matrix
Climate Hazards	**Consequence Type**				
Severe windstorm, wind gust	Built environment	3	3.1	9.3	Moderate
Wildland fire (rural & urban)	Natural environment	3	3.1	9.3	Moderate
Air quality—wildfire smoke	Built environment	4	2.3	9.2	Moderate
Severe windstorm, wind gust	Economic	3	3.0[71]	9.0	Moderate
Reduced winter recreation	Built environment	4	2.1	8.4	Moderate
Reduced winter recreation	Economic	4	2.1	8.4	Moderate
Extreme heat—impacts to built & natural environment	Built environment	4	2.0	8.0	Moderate
Hailstorm—large hail	Natural environment	4	2.0	8.0	Moderate
Freeze thaw cycles	Built environment	4	1.9	7.6	Moderate
Hailstorm—large hail	Health, safety & wellbeing	4	1.8	7.2	Moderate
Supply chain disruption	Health, safety & wellbeing	2	3.0	6.0	Moderate
Heavy snowfall	Built environment	2	2.8	5.6	Moderate
Heavy snowfall	Economic	2	2.6	5.2	Moderate
Tornado	Built environment	1	4.0	4.0	Moderate
Tornado	Economic	1	4.0	4.0	Moderate
Tornado	Health, safety & wellbeing	1	3.6	3.6	Moderate
Shifting natural ecoregions	Health, safety & wellbeing	3	2.5	7.5	Low
Freezing rain, ice storm	Health, safety & wellbeing	3	2.4	7.2	Low
Severe windstorm, wind gust	Health, safety & wellbeing	3	2.3	6.9	Low
Summer (meteorological) drought	Health, safety & wellbeing	3	2.2	6.6	Low
Severe windstorm, wind gust	Natural environment	3	2.2	6.6	Low
Reduced winter recreation	Health, safety & wellbeing	4	1.6	6.4	Low
Reduced space heating demand	Economic	5	1.1	5.5	Low
Freezing rain, ice storm	Natural environment	3	1.8	5.4	Low

[71] Average consequence score of 2.0 from workshop was raised to 3.0 during evaluation of the results, which is in line with the results from the costs-of-inaction analysis.

Climate Impact Scenario		Likelihood Score	Consequence Score	Risk Score	Risk Level in Matrix
Climate Hazards	**Consequence Type**				
Reduced space heating demand	Built environment	5	1.0	5.0	Low
Heavy snowfall	Health, safety & wellbeing	2	2.4	4.8	Low
Freeze thaw cycles	Health, safety & wellbeing	4	1.1	4.4	Low
Heavy snowfall	Natural environment	2	2.1	4.2	Low
Extreme cold	Built environment	3	1.1	3.3	Low
Extreme cold	Economic	3	1.0	3.0	Low
Extreme cold	Health, safety & wellbeing	3	1.0	3.0	Low
Tornado	Natural environment	1	2.0	2.0	Very Low

APPENDIX F

Climate Adaptation Planning Considerations Details

Theme 1: Consistent Public Education

Why is this relevant for a regional plan:

- Regionally consistent messaging reduces confusion and avoids conflicting information and mistrust.
- The Region is highly diverse, and communications needs to be targeted and available to those most vulnerable.
- Rationalizes effort and resources to develop these materials together and share.

Key Region policy areas supported by the priority measures in this theme:

Communities & Housing
Natural Living Systems
Agriculture

Table F-1 Theme 1 Adaptation Measures with Relevant Risk Identified

Number	Adaptation Measures Description
1-1	Develop protocol for coordinated emergency alert and action communication materials that are accessible and targeted to different audiences in the Region. • Utilize various communication channels (**digital and non-digital**), such as storyboards, infographics, and infomercials, to raise awareness about potential hazards and appropriate actions to take during emergency events. • Establish effective Region wide communication systems to disseminate alerts, evacuation notices, and updates on risk levels to residents in the affected areas and surrounding regions. • Develop communication materials in different languages and foster partnerships with trusted messengers to support communication with vulnerable groups.
1-2	Develop regional public education program on climate-related emergency preparedness. • **Wildland fire** preparedness and prevention, FireSmart program, evacuation procedures, and wildfire safety measures. • Reduce the risk of collisions with wildlife due to decreased visibility from **wildfire smoke** by enhancing signage and communications. • Public safety education on dangers associated with **river and creek flooding, extreme heat** and **wildfire smoke**. • Establish regional residential **stormwater flood** resilience programs that include education and financial support for homeowners. This can involve promoting and assisting with the installation of backflow valves, raising electrical and mechanical systems above flood levels, implementing downspout disconnection and routing measures, and other flood mitigation measures.
1-3	Develop public education campaign discussing higher risks areas. • Include education on climate projections and highest climate risks for the Region. Acute events (such as wildland fire, flood and wildfire smoke) are closely align with adaptation measure 1-2 but education should have a strong focus on chronic events (such as invasive species and shifting ecoregions). • Identification of **invasive species**, their potential ecological and economic consequences, and best practices to prevent their introduction and spread. Partner with educational institutions, community organizations and local media to promote. Collaborate with greenhouses to educate staff and customers on the use of non-invasive plants. • Foster understanding and support for conservation efforts and adaptive natural area management practices in the context of **shifting ecoregions**. Engage with local communities, landowners, and stakeholders. Promote public involvement in citizen science initiatives and monitoring programs.

Theme 2: Collaborative Disaster Preparedness

Why is this relevant for a regional plan:

- Disasters cross jurisdictional boundaries with impacts cascading across the Region.
- Communities can pool resources, share information, and ensure consistency.
- Pre-established tools and agreements between communities facilitates a more rapid response in the Region without having to wait on provincial processes.

Key Region policy areas supported by the priority measures in this theme:

Economic Competitiveness
Transportation Systems
Agriculture

Integration of Land Use and Infrastructure
Communities & Housing

Table F-2 Theme 2 Adaptation Measures with Relevant Risk Identified

Number	Adaptation Measures Description
2-1	Develop a regional program to build resilience to supply chain disruptions. • Implement strong communication strategies to minimize panic buying and ensure accurate information reaches the public during supply chain disruptions. • Promote the Region as a less risky place to do business due to its resilience and preparedness. Highlight the Region's efforts to mitigate supply chain disruptions and its commitment to supporting businesses and maintaining a stable economy.
2-2	Develop rapid regional response and evacuation protocols for people and livestock. • Establish a comprehensive regional evacuation protocol that facilitates safe and efficient emergency response coordinated across the Region. Evacuees move throughout the Region and resources should be coordinated and shared. Regional coordination should be rapid, and mechanisms put in place to prevent delays by having to first coordinate with the Province or the Federal Government. • Prevent public from accessing at-risk areas (e.g., flood-prone) by utilizing signage on roadways and highways to warn and provide clear directions for evacuation routes. • Consider evacuation and supports for livestock and other agricultural needs.
2-3	Develop and enforce regional wildland fire risk reduction and rapid response plan. • Enforce Fire Smart standards throughout the Region to promote fire-resilient communities including implementing regulations, guidelines, and education programs for **wildland fire and wildfire smoke** hazards. • Utilize historical wildland fire data and mapping to identify trouble areas prone to recurrent fires to prioritize prevention and mitigation efforts, facilitate early intervention, and inform land-use planning strategies to minimize fire risks. • Develop regional rapid response protocols that outline the roles, responsibilities, and coordination mechanisms among various agencies and stakeholders involved in wildfire suppression and emergency management including standardized training for Incident Command System (ICS).
2-4	Develop comprehensive regional emergency management and business continuity plans in the case of a catastrophic event with the loss of critical services (e.g., tornado, wildland fire). • Create a comprehensive regional emergency management plan that outlines roles, responsibilities, and coordination mechanisms among different jurisdictions, agencies, and stakeholders for response and recovery of a loss of critical services from a catastrophic event (i.e., **tornado, wildland fire**). • Develop a regional business continuity plan for maintaining essential services (e.g., water supply), protecting infrastructure, and facilitating the recovery of businesses in the aftermath of a loss of critical service from a catastrophic event (i.e., **tornado, wildland fire**). These plans should involve collaboration between local governments, emergency management agencies, businesses and organizations representing vulnerable groups. • Ensure proper regional resourcing for disaster response by allocating sufficient resources and funding to support emergency management activities, including search and rescue operations, debris removal, and infrastructure repairs.

Theme 3: Supporting Our Most Vulnerable

Why is this relevant for a regional plan:

- Resources for family and community services are limited within municipalities; cross-regional collaboration can alleviate the strain on these organizations.
- Creating and strengthening partnerships can facilitate the sharing of resources during emergencies.
- Adaptation actions should be targeted to equity-deserving groups as this is the foundation for resilience of the entire community.

Indicators of Vulnerability			
Socioeconomic Status	Household Composition & Disability	Minority Status & Language	Housing & Transportation
Below Poverty Unemployed Income No High School Diploma	Aged 65 or Older Aged 17 or Younger Disability Single-Parent Household	Minority Speak English “Less than Well” Recent Immigrant	Multi-Unit Structures Mobile Homes Unhoused No Vehicle

Key Region policy areas supported by the priority measures in this theme:

Communities & Housing

Table F-3 Theme 3 Adaptation Measures with Relevant Risk Identified

Number	Adaptation Measures Description
3-1	Develop a comprehensive map that highlights the locations of outdoor fountains, resilience hubs, cooling zones, and other resources accessible to vulnerable populations across the Region. This is relevant during **extreme heat**, and or taking shelter from **ice storm/hailstorm**, as well as **wildfire smoke**. • Ensure the map and related information are easily accessible to the entire population, including vulnerable groups. • Mapping of locations accessible for all residents is also helpful, but mapping and communication is needed for locations that will provide access and services for the unique needs of vulnerable groups.
3-2	Develop programs to respond to vulnerable populations in extreme heat by fostering regional partnerships across social organizations or services. • Establish partnerships to distribute resources, offer assistance programs, and coordinate outreach efforts to ensure vulnerable individuals receive the necessary support. • Implement programming that specifically caters to vulnerable populations, providing necessary water and supplies to ensure their well-being during extreme heat events. • Establish a "neighborhood connectors" program to foster community support, encouraging neighbors to check in on vulnerable populations and offer assistance. • Planning can extend to other climate hazards, but extreme heat was identified as the highest risk to address first.
3-3	Establish shelters for vulnerable populations during **wildfire smoke** events. • Create designated shelters to provide refuge for vulnerable populations that cater to the daily needs of vulnerable individuals during periods of poor air quality caused by wildfire smoke. • Plan for adequate capacity, accessibility, and transportation options to facilitate the relocation and accommodation of vulnerable populations.

Theme 4: Protecting Our Natural Environment

Why is this relevant for a regional plan:

- Watersheds, ecosystems, and natural areas cross municipal boundaries.
- Actions in one part of the watershed or ecosystem impacts another part, potentially having unintended consequences.
- Natural areas provide a multitude of ecosystem services, which cannot be fully replaced once removed.
- Natural areas provide protection from multiple climate hazards and support other theme areas.

Key Region policy areas supported by the priority measures in this theme:

Natural Living Systems
Integration of Land Use & Infrastructure
Agriculture

Table F-4 Theme 4 Adaptation Measures with Relevant Risk Identified

Number	Adaptation Measures Description
4-1	Develop regional policies for natural asset planning and maintenance. • Implement regional policies and initiatives to protect existing wetlands, enhance riparian zones, and restore naturalized streams to support ecological resilience. • Promote the planting and conservation of drought-resilient vegetation and species in collaborate with relevant stakeholders, including conservation organizations or biologists. • Develop and implement wetland and riparian strategies that address the impacts of drought and ensure sustainable water management in collaboration with the North Saskatchewan Watershed Alliance (NSWA) and other relevant organizations. • Develop strategies for co-existence with wildlife to plan for shifting ecoregions. • Restoration of ecosystem form and function as a mitigation (carbon storage) and resilience action.
4-2	Develop a regional **invasive species** management plan. • Identify priority invasive species, establish monitoring and early detection systems, and outlines strategies for prevention, control, and eradication. • The plan should involve collaboration among neighboring regions to target species that have been identified as invasive in adjacent areas and support joint efforts to manage their populations.
4-3	Allocate resources and establish regional funds to support riparian restoration projects, including tree planting and habitat enhancement along watercourses to mitigate **extreme heat** on the aquatic environment. • Focus on riparian restoration efforts to encourage tree growth and increase shading along watercourses, streams, and stormwater management facilities. • Plant vegetation that is resilient and adapted to thrive in warmer climate conditions, particularly species that provide canopy cover and shade to reduce heat stress on aquatic habitats. • Promote education on the connection between fish health and extreme heat, raising awareness about the impacts and implementing measures to protect vulnerable fish populations.

Theme 5: Managing Water Scarcity

Why is this relevant for a regional plan:

- A regional approach allows for an **equitable** distribution of water.
- Ensures **consistent** water conservation standards and water restrictions across the Region.
- Promotes **collective efforts** to mitigate the impacts of drought conditions.

Wetland conservation and restoration plays a critical role in managing water scarcity, which is captured in **Theme 4 Protecting our Natural Environment**. Many measures do apply across themes. Efforts to reduce duplication does not preclude recognizing the multiple benefits a measure may have.

Key Region policy areas supported by the priority measures in this theme:

Economic Competitiveness
Community & Housing

Natural Living Systems
Agriculture

Table F-5 Theme 5 Adaptation Measures with Relevant Risk Identified

Number	Adaptation Measures Description
5-1	Develop regional strategies to achieve sustainable and equitable water distribution during **drought or water scarcity** events. • Establish regional policies that govern water allocation and management, ensuring efficient and equitable distribution of water resources across municipalities and industries. • Collaborate with relevant stakeholders, including provincial authorities, to develop consistent guidelines for water usage during drought conditions. • Create a regional water-sharing agreement that allows for the transfer of water resources between municipalities during times of drought or water scarcity. This agreement should outline the terms and conditions for sharing water to ensure fair and sustainable access for all communities involved.
5-2	Promote consistent water conservation and efficiency measures across the Region. • Provide incentives to adopt lower resource consumption practices, such as water recycling and rain harvesting systems. • Offer financial incentives, education programs, and rebates to encourage the installation of water-saving technologies and practices in homes and businesses across the Region.
5-3	Develop water management guidelines and promote water reuse and conservation. • Develop regional guidelines for water reuse, outlining best practices and standards for implementing water recycling systems at various scales, from residential to commercial and industrial including agriculture. • Encourage, incentivize, and support industrial facilities to adopt water reuse practices to reduce reliance on freshwater sources and alleviate pressure on water supplies during droughts. • Improve regional building and development standards to include guidelines and/or incentives for water conservation, promoting the use of efficient appliances, rainwater harvesting systems, and low-impact development techniques like bioswales and green roofs.

Theme 6: Designing Resilient Infrastructure

Why is this relevant for a regional plan?

- Municipalities working together can **pool resources** and share information to develop climate-informed standards in alignment with updated national standards and building codes.
- Regional standards will ensure **consistency** which encourages industry capacity building and allows for promotion of the Region as resilient and safe for investment.

This theme applies to **all infrastructure types**. Stormwater management standards are included in Theme 7 but are related to this theme. In addition to stormwater, the initially focus on highest risks include:

- Enhanced regional resilient building standards to align with and leverage the progress on emission reduction efforts in buildings.
- Extreme heat and preserving indoor air quality in buildings to support health and wellbeing.
- Enhance drainage capacity of major transportation routes to reduce vulnerability to supply chain disruptions.

Key Region policy areas supported by the priority measures in this theme:

Community & Housing
Transportation Systems

Economic Competitiveness
Integration of Land Use & Infrastructure

Table F-6 Theme 6 Adaptation Measures with Relevant Risk Identified

Number	Adaptation Measures Description
6-1	Develop regional building standards to manage **extreme heat**. • Advocate for province-wide adoption of higher building and energy codes. • Collaborate across the Region to establish resilient building standards that specifically address the increased demands for air cooling and associated energy demands. This can include setting energy efficiency requirements <u>for HVAC systems</u>, promoting the use of advanced technologies that reduce energy consumption (e.g., <u>heat pumps</u>) and promoting <u>passive or nature-based solutions</u> (e.g., shade from trees, green roofs, white/light roofs and exteriors). • Integrate these standards into local regulations and permit approvals to encourage or incentivize new constructions and major renovations comply. • Establish a <u>regional award/certification/rating system</u> that recognizes and rewards buildings that exceed the minimum standards, encouraging developers and owners to go beyond the baseline requirements.
6-2	Develop regional building standards to manage reduced **air quality**. • Establish a regional building standard for new construction and retrofit to address any gaps in provincial standards, focusing on ensuring indoor air quality is effectively managed and protected against wildfire smoke. • Implement these standards for all regional building to provide refuge as clean air centers.
6-3	Enhance regional transportation design standards for culverts and bridges to protect major access/egress routes. • Establish a regional climate-adjusted road and highway design standard for new construction and retrofit of local roads using climate-informed intensity-duration-frequency (IDF) curves for drainage design. • Advocate for a provincial climate-adjusted road and highway design standard for new construction and retrofit of local roads using climate-informed intensity-duration-frequency (IDF) curves for drainage design.

Theme 7: Raising the Bar on Flood Management

Why is this relevant for a regional plan?

Province	Regulatory Flood
BC	200-yr adjusted for climate change
AB	**100-yr**
SK	500-yr
MB	100-yr, 700-yr Winnipeg
ON	> of 100-yr or Regional Storms
NFLD	100-yr adjusted for climate change
Remaining	100-yr

Source: Developing a Canadian Standard for New Flood-Resilient Residential Communities (2017), Intact Center for Climate Adaptation

- A regional approach to flood resilience enables municipalities to collectively increase standards and zoning policies.
- A unified voice is better able to advocate to the province for higher flood design standards to better align with other provinces and territories.
- Regional consistency prevents development from being relocated from areas with higher standards to lower standards within the Region.

Key Region policy areas supported by this theme:

Integration of Land Use & Infrastructure
Community and Housing
Natural Living Systems

Table F-7 Theme 7 Adaptation Measures with Relevant Risk Identified

Number	Adaptation Measures Description
7-1	Rapidly develop **regional river and creek flood** hazard maps to accelerate mapping progress in smaller watercourses. • Provincial flood hazard mapping is of high value and high quality, but it is time consuming to meet the mapping standards. The pace of developing flood maps is also limited by availability of Provincial resources. • River and creek flood hazard mapping should be developed to guide management policies and actions. Somewhat simplified processes for mapping could be used for mapping smaller watercourses to rapidly accelerate progress.
7-2	Develop higher, climate-informed regional **river flood** design standards and zoning changes. • Advocate for the adoption of higher regional flood design standards that exceed the current provincial standards. This can include a 200-year flood design standard with freeboard and preventing future development in the flood fringe. • Collaborate with relevant authorities and refer to established standards, such as those provided by BC (British Columbia) guidelines, to ensure consistency and best practices for flood design standards.
7-3	Develop a regional **river and creek flood** management plan. • Develop and implement comprehensive regional flood preparedness plans include proactive measures such as early warning systems, floodplain management strategies, infrastructure improvements and conservation/restoration of natural drainage systems to mitigate the impacts of flooding. • Engage with local communities, vulnerable groups, stakeholders, and experts to identify and prioritize actions that enhance resilience, including the implementation of flood-resistant building standards, land-use planning to minimize exposure to flood-prone areas, and the establishment of emergency response teams.
7-4	Develop a regional stormwater design standard using climate-adjusted IDF curves to mitigate **localized flooding**. • Update regional engineering standards to ensure that stormwater infrastructure can accommodate heavy rainfall to reduce flooding and potential washout of culverts, roads, and bridges.
7-5	Develop a regional low impact development (LID) standard to mitigate **localized flooding**. • Develop regional guidelines and standards for low-impact development practices, focusing on reducing stormwater runoff and promoting water conservation during drought periods. • Encourage and promote the use of permeable surfaces, green roofs, rain gardens, and other sustainable stormwater management techniques to retain water on-site and replenish natural water sources.

APPENDIX G

Cost of Climate Change: Methods

1. Approach

Quantifying the economic consequences of climate change across the range of potentially impacted human and natural systems requires the application of multi-model, multi-sector approaches. Typically, modelling approaches vary across climate-sensitive systems—e.g., the methodology for quantifying and costing heat-related impacts to public health will differ from the approach for costing impacts to urban forests, which in turn will differ from the approach for costing impacts to roads, etc. When working with multiple different modelling approaches, best practice recommends performing the analyses within a common analytical framework driven by shared future socioeconomic and climate scenarios.[72]

Additionally, there is a wide spectrum of terms used to characterise the economic consequences of climate change impacts and adaptation strategies—e.g., direct costs, indirect costs, secondary costs, ripple-effects, macroeconomic impacts, private costs, social costs, externalities, side-effects, co-benefits, co-impacts, ancillary costs, market impacts, non-market impacts, tangible effects, intangible effects, net costs, and welfare costs. The range of terms, many of which overlap and are used interchangeably, can lead to confusion among practitioners and decision-makers.

For clarity when interpreting the results presented in Section 5, the common analytical framework used for the costing analysis including key cost terms is described, before defining the study's scope.

1.1 Analytical Framework for Estimating Costs of Climate Change

The costs of climate change were estimated following best practice[73] in three steps.

1. The first step involves: Estimating economic impacts today (for the purpose of this costing analysis, taken to be 2025), based on current exposures of human and natural systems in the Edmonton Metropolitan Region (Region), current vulnerabilities (the susceptibility of these systems to harm when exposed to different climate impact-drivers), and current climate conditions.
2. The second step involves: Estimating economic impacts in the future (specifically, in 2055 and 2085) under current climate conditions, but accounting for projected socioeconomic change—i.e., growth in the Region's human systems and the environment, growth in prices and wealth (e.g., higher property values and higher willingness-to-pay of individuals to avoid illness or risk of death), and anticipated changes in vulnerability (e.g., as shifts in the age distribution of the population affects baseline mortality rates). But, during this second step, the climate is held constant at baseline levels. In effect, current climate conditions are overlaid on a future society, such that the change in economic impact over time is driven solely by socioeconomic change.
3. The third step involves: Overlaying projected future climate change on top of a projected future Region. This generates an estimate of the overall scale of the challenge presented by the physical risks of climate change (in economic terms), which is also the pot of potential direct economic benefits from adaptation.
4. The outcomes of this process are illustrated in **Figure 1** for the impacts of high temperatures on labour output; projected annual average values are shown in the orange shaded boxes. The general methodology for calculating projected economic impacts is illustrated in **Figure 2** —again, using the exposure of workers to high

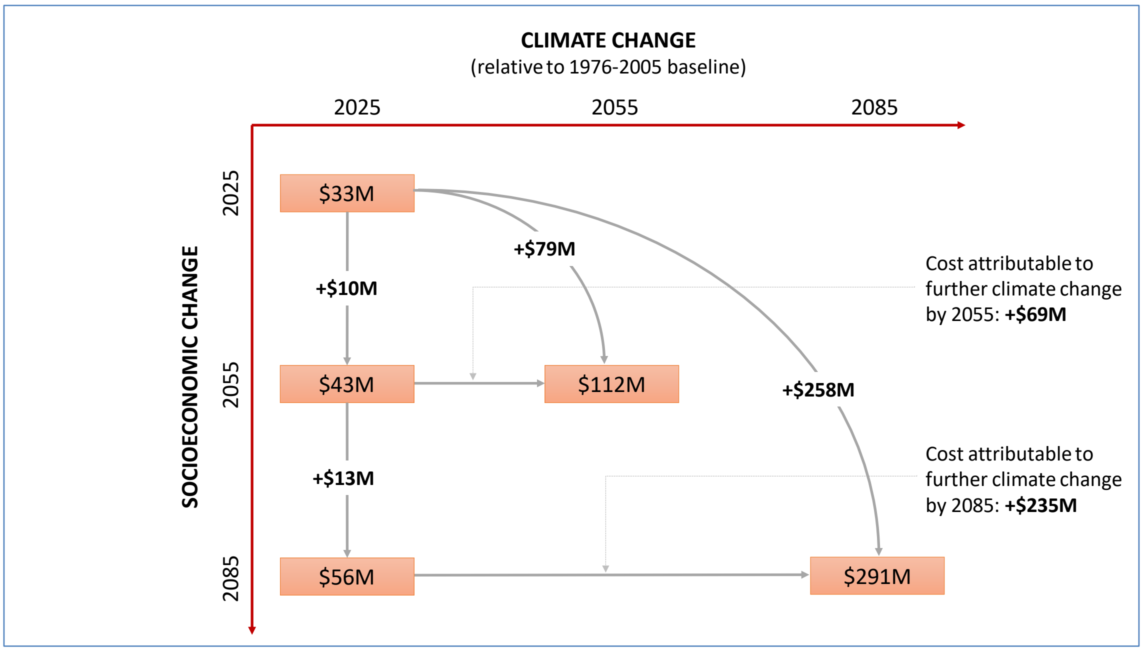
[72] Boyd, R., Gados, A. and Maynes, T., 2013: Economic Guidance for the Appraisal and Prioritization of Adaptation Actions, Technical Guidance Report prepared by C3 (Climate Change Central) for Natural Resources Canada, Ottawa, ON.

[73] See, for example, Boyd, R. and Markandya, A., 2021: Costs and benefits of climate change impacts and adaptation; Chapter 6 in Canada in a Changing Climate: National Issues Report, (Eds.) F.J. Warren and N. Lulham; Government of Canada, Ottawa, Ontario [https://changingclimate.ca/national-issues/chapter/6-0/]; and Boyd et al., 2013, *ibid*.

temperatures as an example. Similar calculations—driven by damage functions that relate biophysical impacts to changes in a climate variable—are performed for all system-climate hazard interactions included within the scope of the analysis.

5. This approach enables isolation of the incremental impact of further climate change from the influence of anticipated growth and development of the Region (with reference to **Figure 1**, +$79M by 2055 and +235M by 2085). It also enables analyses of alternative climate futures (emissions pathways) beyond mid-century on economic risks for the Region—though this was outside the scope of this study.

Figure 1: Illustration of Analytical Framework for Estimating the Projected Economic Impacts of Climate Change for the Region—Example of Labour Output



1.2 Scope: Impact Systems and Types of Costs Included

The human and natural systems included in the assessment are listed in **Table 1**. For each system, **Table 1** shows the climate variable(s) driving the estimated impacts—the so-called "climate impact-drivers". The corresponding economic consequences quantified in the study are also shown. Two broad types of economic consequences are assessed:

1. **Direct-Tangible Costs**. These costs arise from the direct biophysical impacts of climate impact-drivers, such as damage or disruption, to (tangible) goods and services that can be traded in a market and thus have an observed price as a basis for monetization (e.g., costs incurred to repair or replace damaged homes, the medical treatment costs for heat stress, etc.). This also includes business interruption costs, the costs of evacuation and temporary accommodation, etc. as a result of the direct damages caused by flooding[74]. Tangible costs are the familiar capital expenditures and "out-of-pocket" expenses.

2. **Direct-Intangible Costs**. These costs arise from direct biophysical impacts to (intangible) items not bought or sold in a traditional market and thus with no readily observable price as a basis for monetization (e.g., ecosystem services, stress or pain levels, travel delays, premature death). Economists have developed multiple

[74] The flood assessment literature refers to these latter costs as "indirect losses". However, the economic literature tends to treat them as direct, tangible costs to distinguish them from wider indirect and induced (secondary or cascading) impacts on the economy.

techniques to 'shadow price' these intangible (or non-market) impacts (e.g., the Value of a Statistical Life used to price the risk of premature death in a population[75]). Below, direct-intangible costs and welfare losses are used interchangeably—the latter term is more commonly used by economists.

Secondary-tangible costs were also estimated. These costs arise from the ripple effect of the direct tangible impacts on the wider economy as subsequent spending (both indirect and induced) is affected. Indirect impacts result from changes to upstream inter-industry purchases by the directly impacted economic sector(s) in the Region—e.g., a business that must temporarily close for repairs may cancel orders from its upstream suppliers. Induced impacts result from changes in the production of goods and services in response to changes in consumer income and household expenditures driven by the direct and indirect impacts (originating in the Region) as they ripple through the economy. For example, if a worker on an hourly wage at the aforementioned business is laid-off for a month during repairs, their income will decline, which may lead to reduced purchases of goods and services from other businesses in the Region. The most commonly measured secondary-tangible costs are reductions in projected gross-domestic product (GDP).

Regarding the secondary-tangible costs, they are sometimes erroneously viewed as a net gain for society. While some sectors, like remediation services and construction, might benefit from increased demand for clean-up and restoration services following an extreme weather event, this benefit should be viewed more as a transfer of resources towards sectors responding to the event and away from those that suffer damages as a direct result of the event. The costs incurred to restore assets to their pre-event state thus represents an "opportunity cost"—the opportunity cost refers to the forgone benefits from transferring expenditures away from the activities that would have occurred in the absence of damage from the climate-induced event. In short, these expenditures would not have been incurred in the absence of climate change impacts.

[75] For further details, see: Boyd, R., Eyzaguirre, J., Poulsen, F., Siegle, M., Thompson, A., Yamamoto, S., Osornio-Vargas, Erickson, A., and Urcelay, A., 2020: Costing Climate Change Impacts on Human Health Across Canada. Prepared by ESSA Technologies Ltd. For the Canadian Climate Institute.

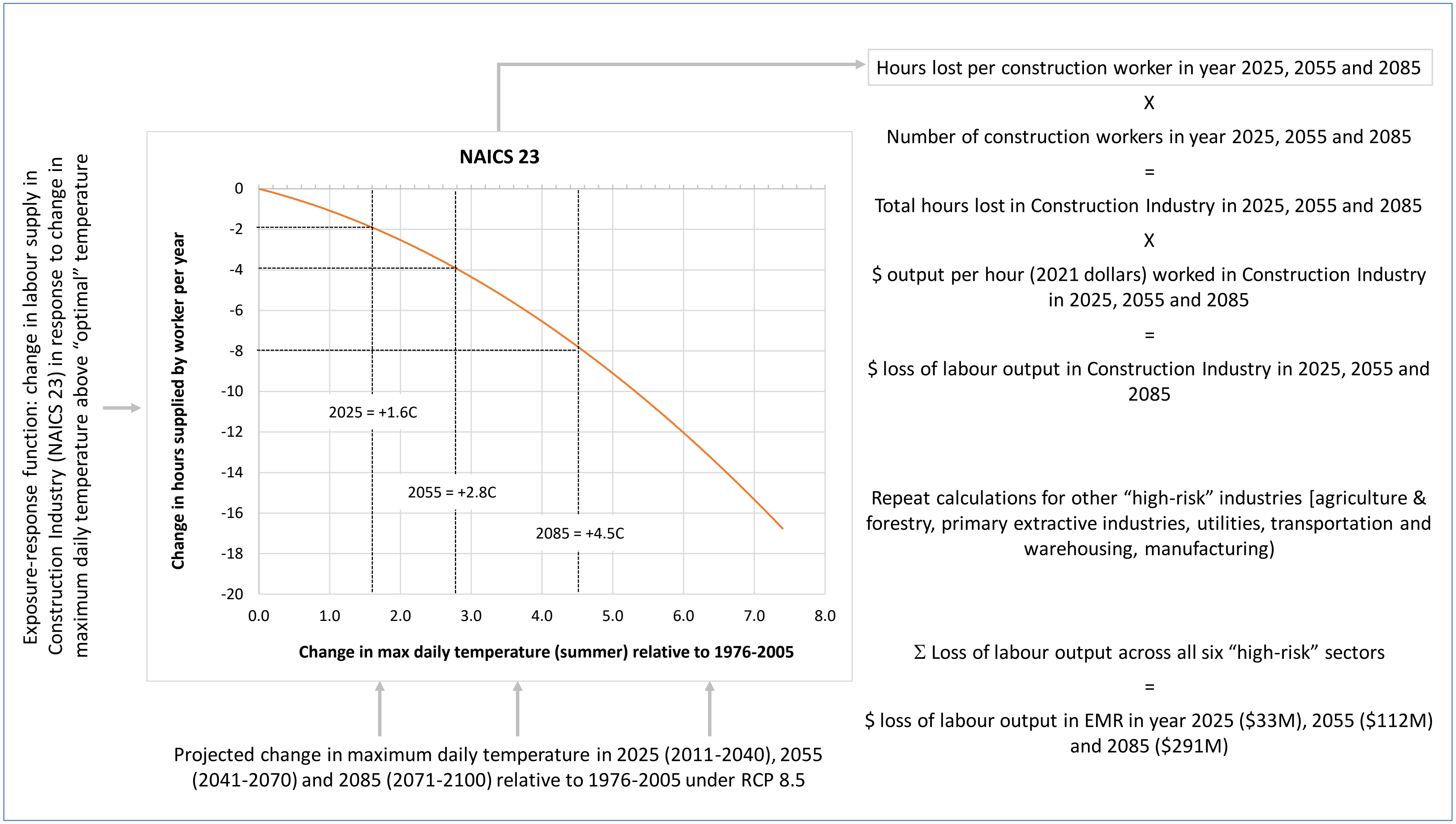
Table 1: Exposed Systems, Climate Impact-Drivers and Economic Consequences Included in the Analysis

Exposed human and natural systems	Climate impact-drivers	Economic consequences
Roads	High temperatures, heavy precipitation, freeze-thaw cycles	Damages
	High temperatures, heavy precipitation, freeze-thaw cycles	Delays (value of time)
Rails, including LRT	High temperatures	Damages
Active transport network	High temperatures, drought, extreme cold, freeze-thaw cycles, pluvial flooding	Damages
Buildings	Fluvial and pluvial flooding	Damages
	Fluvial and pluvial flooding	Indirect losses
	Hail storm, high winds, freezing rain, freeze-thaw cycles, heavy snow	Damages
	Heating degree days, cooling degree days	Energy costs
Electricity T&D (linear)	High temperatures, hail storm, high winds, freezing rain, heavy snow, pluvial flooding, NSR flooding, wildland fire	Damages
Potable water (linear)	Cold temperatures, drought, freeze-thaw cycles	Damages
Potable water (plant)	NSR flooding at Edmonton, extreme cold	Damages
Wastewater (linear)	Freeze-thaw cycles, pluvial flooding	Damages
Wastewater (plant)	NSR flooding at Edmonton	Damages
Drainage (linear)	Freeze-thaw cycles, pluvial flooding	Damages
City trees	High temperatures, drought, heavy snow, freezing rain, high winds, wildland fire, tornado, lightning	Damages Ecosystem services
Natural areas	High temperatures, drought, extreme cold, hail storm, high winds, freezing rain, heavy snow, pluvial flooding, river flooding, wildland fire, tornado	Damages Ecosystem services
Agriculture	Mean seasonal temperatures, mean annual precipitation, frost-free days, growing degree days	Farmland value
Labour	High temperatures	Lost output
Public health	Air quality (ground-level ozone) - mortality	Welfare losses
	Air quality (ground-level ozone) - mortality	Lost output
	Air quality (ground-level ozone) - morbidity	Welfare losses
	Air quality (smoke PM2.5) - mortality	Welfare losses
	Air quality (smoke PM2.5) - mortality	Lost output
	Air quality (smoke PM2.5) - morbidity	Welfare losses
	High temperatures - mortality	Welfare losses
	High temperatures - mortality	Lost output
	High temperatures - hospitalizations	Healthcare costs
	High temperatures - hospitalizations	Lost output
	Exacerbation of mental health disorders - multiple climate impact-drivers	Welfare losses
	Other public health and safety impacts - multiple climate impact-drivers	Welfare losses

1.2 Scope: Climate Scenarios and Timeframes

The base year selected for quantifying economic impacts is 2025; this year provides a benchmark against which future impacts are compared. This year was chosen as it is the central year of the 30-year meteorological averaging period or "climate normal" (2011-2040) between: (a) the climate baseline used for the climate risk assessment (1976-2005); and (b) two future 30-year averaging periods encompassing remainder of the century—i.e., the 2050s (2041-2070) and the 2080s (2071-2100).

Figure 2: Illustration of Calculations for Estimating the Projected Economic Impacts Of Climate Change for the Region—Example Of Labour Output



In addition to 2025, economic impacts are quantified for 2055 and 2085; the central years for the 2050s and 2080s time periods. For each of 2025, 2055 and 2085, economic impacts are calculated with respect to projected changes in climate variables relative to the 1976-2005 climate normal under a greenhouse gas concentration scenario with Radiative Forcing of 8.5 watts/m^2 by the end of the century—known as Representative Concentration Pathway (RCP) 8.5. Hence, estimated costs for 2025 are really the expected annual costs—for (say) roads—of climate change between 1976-2005 and 2011-2040. Likewise, estimated costs for 2055 represent the expected annual costs (for roads) of climate change between 1976-2005 and 2041-2070. Primary interest lies with the difference in estimated economic impacts between 2025 and 2055 and between 2025 and 2085; these differences represent the costs attributable to further climate change beyond what may be currently experienced in the Region.

When assessing climate-related economic risks it is prudent to consider the greatest plausible change scenario relative to the present, which in practice means working with the RCP 8.5 forcing scenario (i.e., the most conservative of global “no climate policy” scenarios). The primary justification for using the RCP 8.5 forcing scenario is that it represents a “worst case” scenario for projected climate change in the Region and thus should capture most climate-related risks. Uncertainties relating to whether the future unfolds along the RCP 8.5 forcing scenario or along a different, lower emission pathway and forcing scenario, are managed when subjecting adaptation strategies and measures to economic analysis.

All estimated economic impacts are reported in constant 2021 dollars.

APPENDIX H

Simulated Benefits and Costs of Investment in Different Adaptation Strategies

To shed light on the implications of different scenarios for investment in the adaptation strategies formulated in Section 4, the relationship between levels of spend on these strategies and the resulting benefits (projected costs avoided) and residual risks (projected costs remaining) were analyzed. Costs and benefits were simulated for the adaptation strategies listed in **Table H-1**:

Table H1 Adaptation Strategies and Actions Included in Assessment

Climate Hazard	Adaptation Strategy	Adaptation Actions (ref to Section 4)	Simulated Shared Investment* (per person/year)
Heavy rainfall and stormwater flooding	Structural measures/design standards[76]	6-3, 7-4, 7-5	$31
River and creek flooding	Comprehensive plan[77]	7-1 to 7-3	$32
River and creek flooding	Public awareness, communications and education	1-1, 1-2, 1-3	$77
Wildland fire	Comprehensive plan	2-2, 2-3	$23
Wildland fire	Public awareness, communications and education	1-1, 1-2, 1-3	$11
Wildfire smoke – public health & workforce	Building retrofits, structural/design standards	3-3, 6-2	$133
Extreme heat – public health	Comprehensive plan	3-1, 3-2	$75
Extreme heat – public health & workforce	Building retrofits, structural/design standards	6-1	$85
Severe windstorm, gusts, tornado	Comprehensive plan	2-4	$21

* These results are repeated from **Table H-2**

This investment analysis does not include adaptation strategies for natural environment (Theme 4 in Section 4) and drought (Theme 5 in Section 4), as there is no information currently available. More research and data collection are required to include these two themes in the analysis.

[76] This includes, for example, feasibility, engineering and design studies, culverts, detention / retention basins, diversions, flap gates, flood proofing, infrastructure protective measures, utility protection measures, water & sanitation system protective measures.
[77] This includes *inter alia* an early warning/alert protocol, emergency response and preparedness plans, a communications plan, and long-term preventative measures.

The following **"what if"** investment scenario was investigated for each climate hazard–adaptation strategy in **Table H-1**:

> ***What level of investment over the next 10 years (2025-2035) is required to reduce projected residual economic costs to at least 20% of the projected costs-of-inaction, if the adaptation strategy achieves an average (central) rate of return found in other economic studies (i.e., the central benefit-cost ratio in Table 5-3).***

Residual economic costs anticipated to remain even after implementing adaptation actions is a proxy for the **risk tolerance** of decision-makers—i.e., how much economic risk are they willing to accept. Decision-makers face a trade-off between higher levels of shared investment in adaptation, and lower levels of residual risk.

Assuming the adaptation strategies in **Table H-1** are carefully formulated to achieve at least an **average (central) rate of return** typical of similar strategies implemented in other jurisdictions, achieving the target level of residual economic losses will require the levels of total private and public investment (2021 dollars) in the Region over the next 10 years shown in **Table H-2.**

The following caveats should be borne in mind when viewing the results below:

- It is assumed that each adaptation strategy can achieve the target level of residual economic losses if the estimated level of investment is made; this **may not be technically feasible**.
- For some adaptation strategies—in particular, building retrofits, structural/design standards, and preventative measures within comprehensive plans that upgrade the building stock to mitigate heat and smoke risks—**the overall level of investment will be shared with other policy objectives—e.g., energy efficiency and climate mitigation**.
- For similar reasons, the **estimated levels of investment are not additive** across some of the adaptation strategies—especially those that target the same climate hazard. Many of the preventative measures included in the "comprehensive plans" will include building retrofits and design standards for new construction or asset renewals. Equally, adaptation measures included the strategies targeting one climate hazard will reduce risks attributable to other hazards; for example, green infrastructure to manage flood risks will also help alleviate public health and workforce risks from extreme heat.

Table H-2 Simulated Private and Public Investment to Achieve Residual Economic Risks Equal to 20% of the Projected Costs-of-Inaction

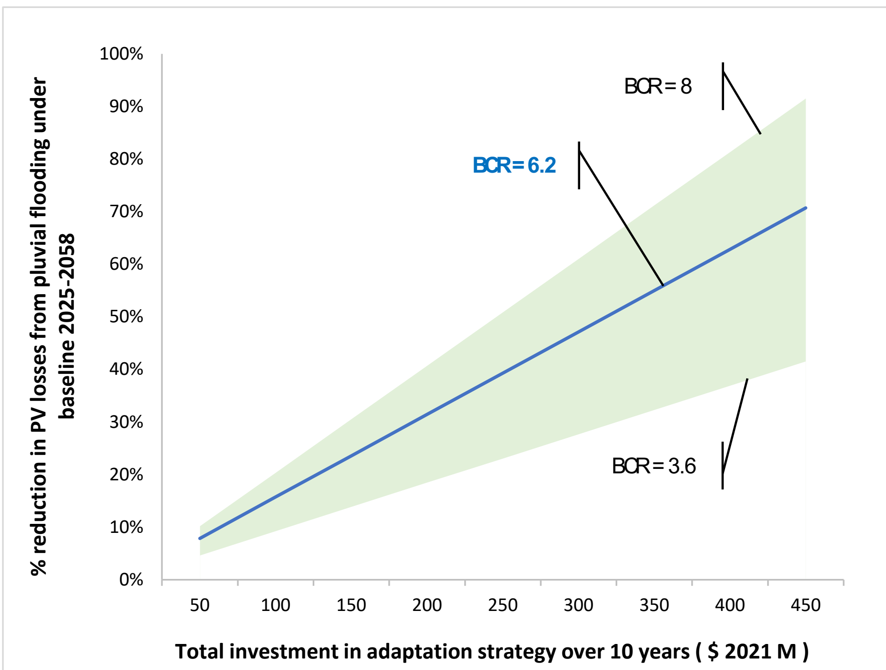
Total 10-year Shared Investment		Adaptation Actions (reference to Section 4)	Climate Hazard: Adaptation Strategy
$ 2021 M	$/Person/Year		
510	**31**	6-3, 7-4, 7-4	Heavy rainfall and stormwater flooding: Structural measures/design standards
540	**33**	7-1 to 7-3	River and creek flooding: Comprehensive plan
1,260	**77**	1-1, 1-2, 1-3	River and creek flooding: Public awareness, communications, education
370	**23**	2-2, 2-3	Wildland fire: Comprehensive plan
180	**11**	1-1, 1-2, 1-3	Wildland fire: Public awareness, communications, education
2,180	**133**	3-3, 6-2	Wildfire smoke – public health & workforce: Building retrofits, structural/design standards
1,225	**75**	3-1, 3-2	Extreme heat – public health: Comprehensive plan
1,400	**85**	6-1	Extreme heat – public health & workforce: Building retrofits, structural/design standards
350	**21**	2-4	Severe windstorm, gusts, tornado: Comprehensive plan

More detailed tables and associated graphs that drive the results presented in **Table H-2** are provided below.

Table H-3: Simulated Costs and Benefits of Different Levels of Investment to Address Losses from Stormwater Flooding with Structural/Design Standards

Total 10-year investment in adaptation (2025-2035)	Losses avoided per dollar invested	Present value benefits of investment	Reduction in present value of projected losses	Present value of residual direct losses after adaptation
$ 250 M $ 15 / person / year	$3.6	$ 885 M	23%	77%
	$6.2	**$ 1510 M**	**39%**	**61%**
	$8.0	$ 1955 M	50%	50%
$ 450 M $ 27 / person / year	$3.6	$ 1630 M	41%	59%
	$6.2	**$ 2775 M**	**71%**	**29%**
	$8.0	$ 3595 M	92%	8%

Figure H-1: Estimated Relationship Between Investment Levels and Reductions In Project Economic Costs: Stormwater Flooding - Structural/Design Standards

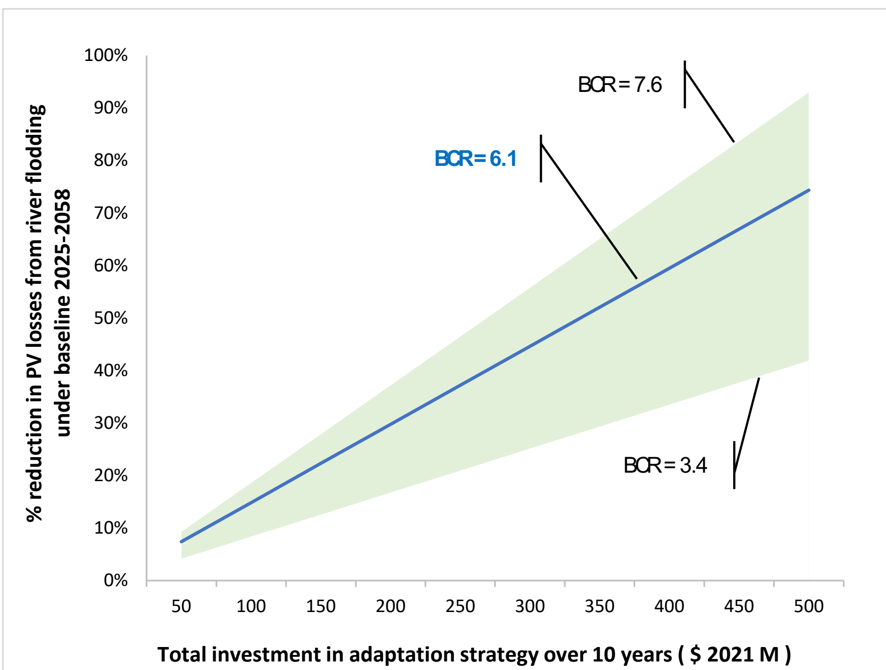


Note: The solid blue line denotes outcomes for the central benefit-cost ratio; the shaded green area indicates the range of outcomes between the low and high estimated benefit-cost ratio shown

Table H-4: Simulated Costs and Benefits of Different Levels of Investment to Address Losses from River and Creek Flooding Through a Comprehensive Plan, Including Emergency Response and Preparedness, and Long-Term Preventative Measures

Total 10-year investment in adaptation (2025-2035)	Losses avoided per dollar invested	Present value benefits of investment	Reduction in present value of projected losses	Present value of residual direct losses after adaptation
$ 250 M $ 15 / person / year	$3.4	$ 860 M	21%	79%
	$6.1	**$ 1525 M**	**37%**	**63%**
	$7.6	$ 1905 M	46%	54%
$ 500 M $ 31 / person / year	$3.4	$ 1720 M	42%	58%
	$6.1	**$ 3050 M**	**74%**	**26%**
	$7.6	$ 3815 M	93%	7%

Figure H-2: Estimated Relationship Between Investment Levels and Reductions In Project Economic Costs: River And Creek Flooding – Comprehensive Plan

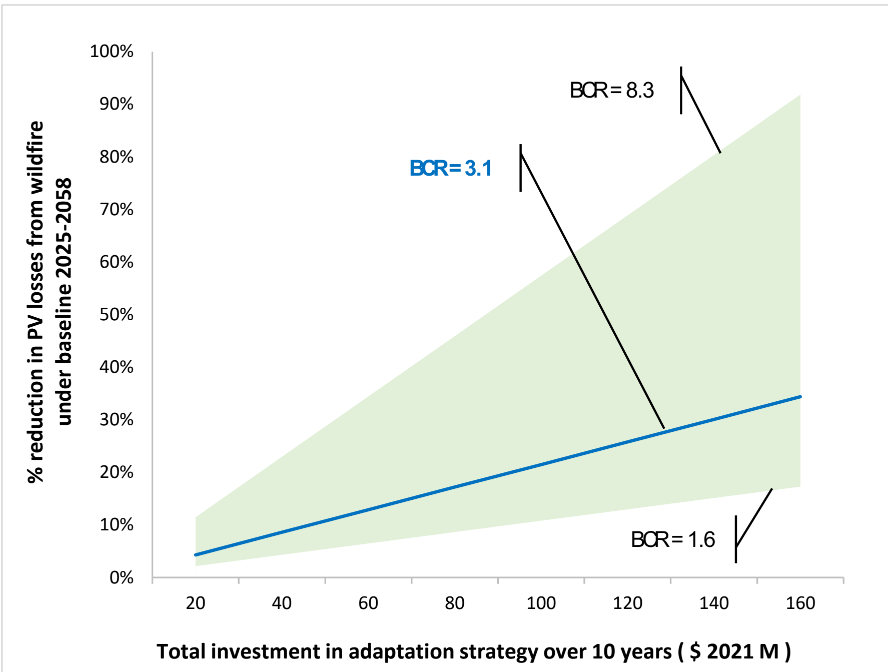


Note: The solid blue line denotes outcomes for the central benefit-cost ratio; the shaded green area indicates the range of outcomes between the low and high estimated benefit-cost ratio shown

Table H-5: Simulated Costs and Benefits of Different Levels of Investment to Address Losses From Wildland Fires Through a Comprehensive Plan, Including Emergency Response and Preparedness, and Long-Term Preventative Measures

Total 10-year investment in adaptation (2025-2035)	Losses avoided per dollar invested	Present value benefits of investment	Reduction in present value of projected losses	Present value of residual direct losses after adaptation
$ 80 M	$1.6	$ 125 M	9%	91%
	$3.1	**$ 250 M**	**17%**	**83%**
$ 5 / person / year	$8.3	$ 660 M	46%	54%
$ 160 M	$1.6	$ 250 M	17%	83%
	$3.1	**$ 495 M**	**35%**	**65%**
$ 10 / person / year	$8.3	$ 1325 M	92%	8%

Figure H-3: Estimated Relationship Between Investment Levels and Reductions In Project Economic Costs: Wildland Fire - Comprehensive Plan

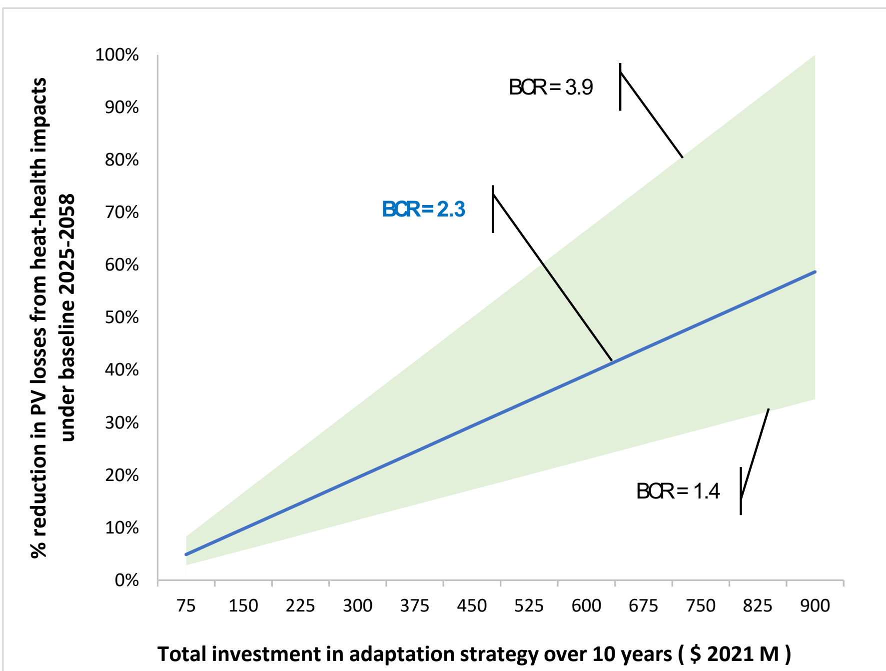


Note: The solid blue line denotes outcomes for the central benefit-cost ratio; the shaded green area indicates the range of outcomes between the low and high estimated benefit-cost ratio shown

Table H-6: Simulated Costs and Benefits of Different Levels of Investment to Address Losses from the Impacts of Heat on Public Health Through a Comprehensive Plan, Including Emergency Response and Preparedness, and Long-Term Preventative Measures

Total 10-year investment in adaptation (2025-2035)	Losses avoided per dollar invested	Present value benefits of investment	Reduction in present value of projected losses	Present value of residual direct losses after adaptation
$ 375 M $ 23 / person / year	$1.4	$ 505 M	14%	86%
	$2.3	**$ 865 M**	**24%**	**76%**
	$3.9	$ 1470 M	42%	58%
$ 825 M $ 50 / person / year	$1.4	$ 1115 M	32%	68%
	$2.3	**$ 1900 M**	**54%**	**46%**
	$3.9	$ 3235 M	92%	8%

Figure H-4: Estimated Relationship Between Investment Levels and Reductions In Project Economic Costs: Heat Impacts On Public Health - Comprehensive Plan

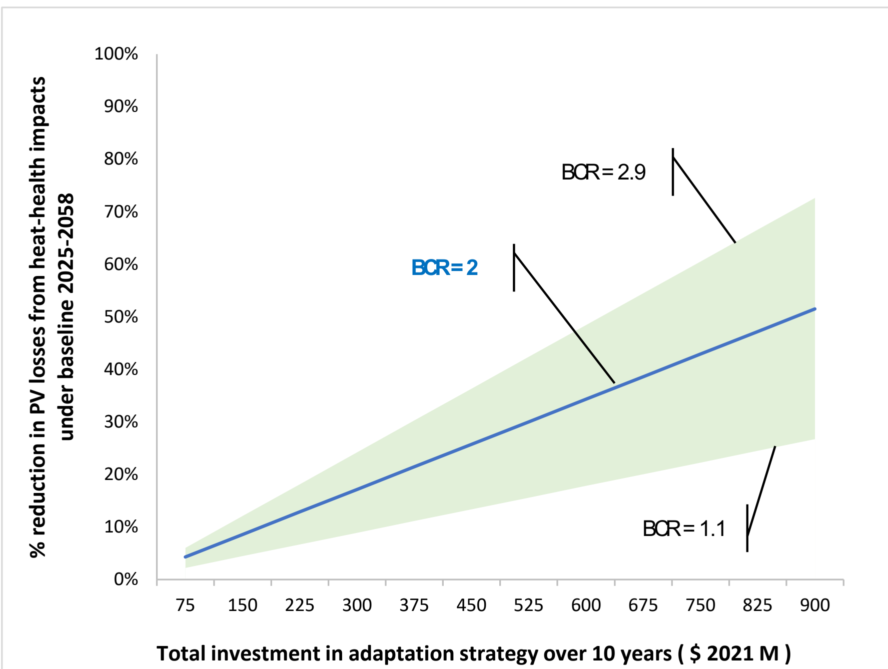


Note: The solid blue line denotes outcomes for the central benefit-cost ratio; the shaded green area indicates the range of outcomes between the low and high estimated benefit-cost ratio shown

Table H-7: Simulated Costs and Benefits Of Different Levels of Investment to Address Losses From The Impacts of Heat On Public Health Through Building Retrofits, Design and Standards

Total 10-year investment in adaptation (2025-2035)	Losses avoided per dollar invested	Present value benefits of investment	Reduction in present value of projected losses	Present value of residual direct losses after adaptation
$ 375 M $ 23 / person / year	$1.1	$ 395 M	11%	89%
	$2.0	**$ 755 M**	**21%**	**79%**
	$2.9	$ 1070 M	30%	70%
$ 825 M $ 50 / person / year	$1.1	$ 865 M	25%	75%
	$2.0	**$ 1665 M**	**47%**	**53%**
	$2.9	$ 2350 M	67%	33%

Figure H-5: Estimate Relationship Between Investment Levels and Reductions In Project Economic Costs: Heat Impacts On Public Health - Building Retrofits, Design and Standards

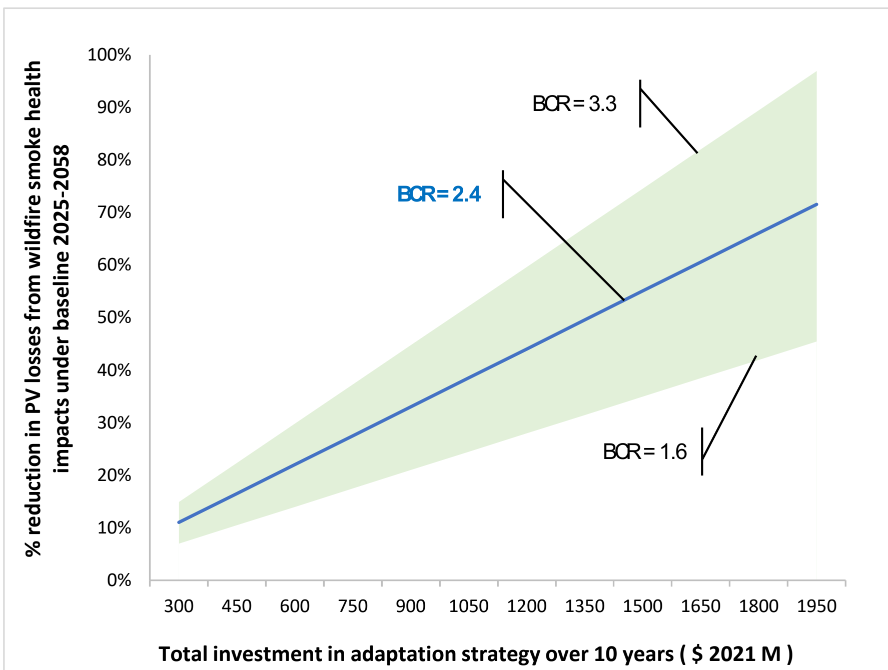


Note: The solid blue line denotes outcomes for the central benefit-cost ratio; the shaded green area indicates the range of outcomes between the low and high estimated benefit-cost ratio shown

Table H-8: Simulated Costs and Benefits Of Different Levels Of Investment to Address Losses From The Impacts Of Wildfire Smoke On Public Health Through Building Retrofits, Design And Standards

Total 10-year investment in adaptation (2025-2035)	Losses avoided per dollar invested	Present value benefits of investment	Reduction in present value of projected losses	Present value of residual direct losses after adaptation
$ 900 M $ 55 / person / year	$1.6	$ 1395 M	21%	79%
	$2.4	**$ 2195 M**	**33%**	**67%**
	$3.3	$ 2975 M	45%	55%
$ 1800 M $ 110 / person / year	$1.6	$ 2790 M	41%	59%
	$2.4	**$ 4390 M**	**66%**	**34%**
	$3.3	$ 5945 M	89%	11%

Figure H-6: Estimated Relationship Between Investment Levels and Reductions In Project Economic Costs: Wildfire Smoke Impacts On Public Health - Building Retrofits, Design and Standards

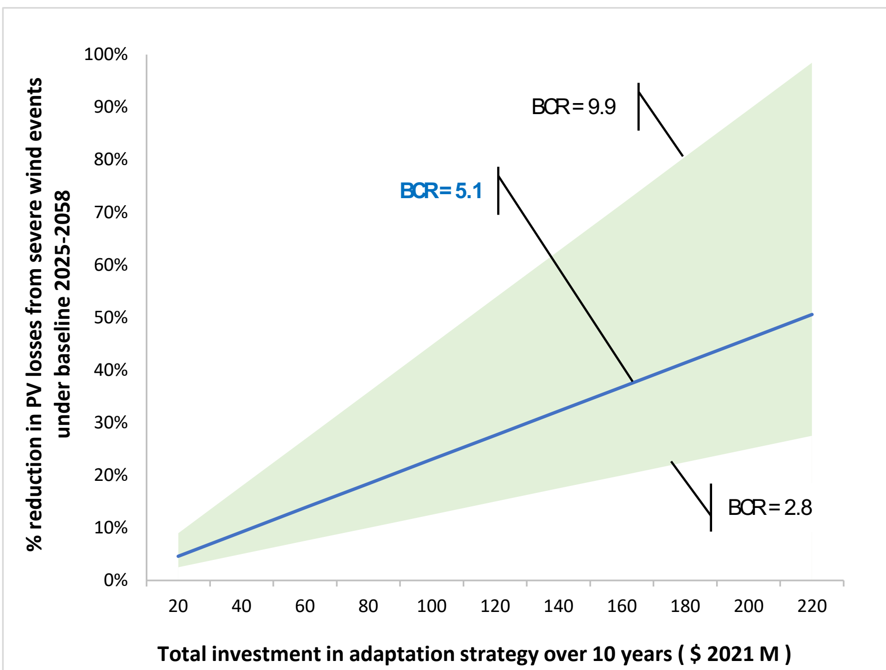


Note: The solid blue line denotes outcomes for the central benefit-cost ratio; the shaded green area indicates the range of outcomes between the low and high estimated benefit-cost ratio shown

Table H-9: Simulated Costs and Benefits of Different Levels of Investment to Address Losses from Severe Windstorms, Gusts, and Tornados Through a Comprehensive Plan, Including Emergency Response and Preparedness and Long-Term Preventative Measures

Total 10-year investment in adaptation (2025-2035)	Losses avoided per dollar invested	Present value benefits of investment	Reduction in present value of projected losses	Present value of residual direct losses after adaptation
$ 100 M	$2.8	$ 275 M	12%	88%
	$5.1	**$ 510 M**	**23%**	**77%**
$ 6 / person / year	$9.9	$ 995 M	45%	55%
$ 200 M	$2.8	$ 610 M	28%	72%
	$5.1	**$ 1125 M**	**51%**	**49%**
$ 13 / person / year	$9.9	$ 2185 M	98%	2%

Figure H-7: Estimated Relationship Between Investment Levels and Reductions In Project Economic Costs: Severe Windstorms, Gusts, and Tornados - Comprehensive Plan



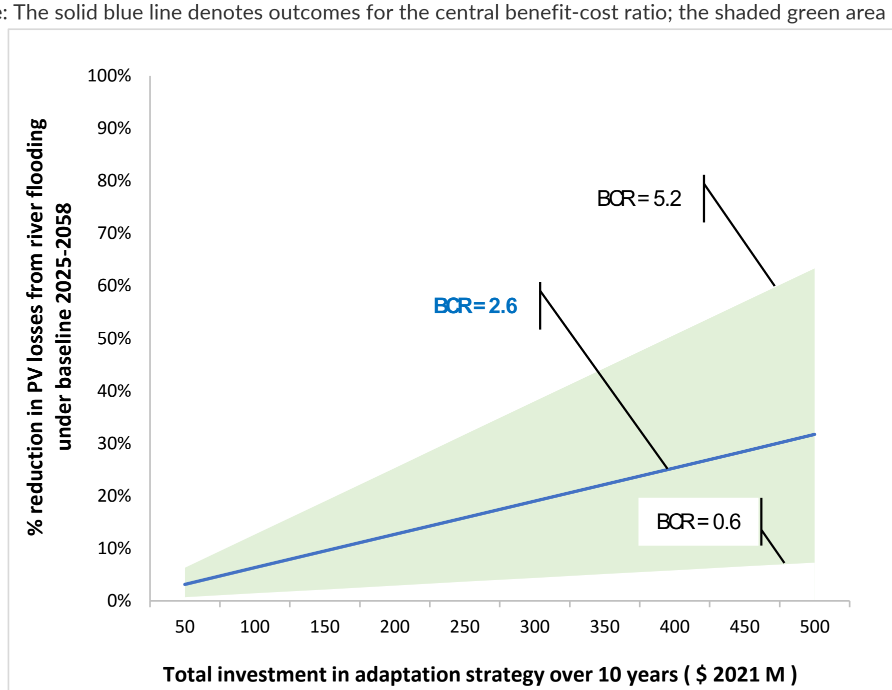
Note: The solid blue line denotes outcomes for the central benefit-cost ratio; the shaded green area indicates the range of outcomes between the low and high estimated benefit-cost ratio shown

Table H-10: Simulated Costs and Benefits of Different Levels of Investment to Address Losses from River and Creek Flooding Through Public Awareness Campaigns, Communications, Education, and Capacity Building

Total 10-year investment in adaptation (2025-2035)	Losses avoided per dollar invested	Present value benefits of investment	Reduction in present value of projected losses	Present value of residual direct losses after adaptation
$ 250 M	$0.6	$ 150 M	4%	96%
	$2.6	**$ 650 M**	**16%**	**84%**
$ 15 / person / year	$5.2	$ 1300 M	32%	68%
$ 500 M	$0.6	$ 300 M	7%	93%
	$2.6	**$ 1300 M**	**32%**	**68%**
$ 31 / person / year	$5.2	$ 2600 M	64%	36%

Figure H-8: Estimated Relationship Between Investment Levels and Reductions In Project Economic Costs: River and Creek Flooding - Public Awareness Campaigns, Communications, Education and Capacity Building

Note: The solid blue line denotes outcomes for the central benefit-cost ratio; the shaded green area

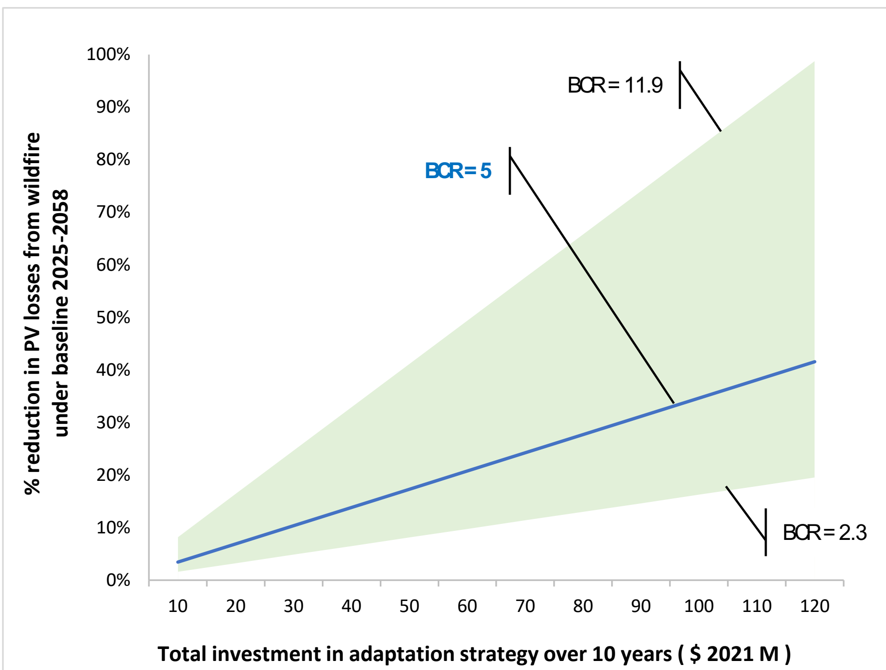


indicates the range of outcomes between the low and high estimated benefit-cost ratio shown

Table H-11: Simulated Costs and Benefits Of Different Levels Of Investment to Address Losses from Wildland Fire Through Public Awareness Campaigns, Communications, Education, and Capacity Building

Total 10-year investment in adaptation (2025-2035)	Losses avoided per dollar invested	Present value benefits of investment	Reduction in present value of projected losses	Present value of residual direct losses after adaptation
$ 50 M $ 3 / person / year	$2.3	115	8%	92%
	$5.0	**250**	**17%**	**83%**
	$11.9	595	41%	59%
$ 110 M $ 7 / person / year	$2.3	260	18%	82%
	$5.0	**550**	**38%**	**62%**
	$11.9	1,305	91%	9%

Figure H-9: Estimated Relationship Between Investment Levels and Reductions In Project Economic Costs: Wildland Fire - Public Awareness Campaigns, Communications, Education, and Capacity Building



Note: The solid blue line denotes outcomes for the central benefit-cost ratio; the shaded green area indicates the range of outcomes between the low and high estimated benefit-cost ratio shown