Associated Engineering

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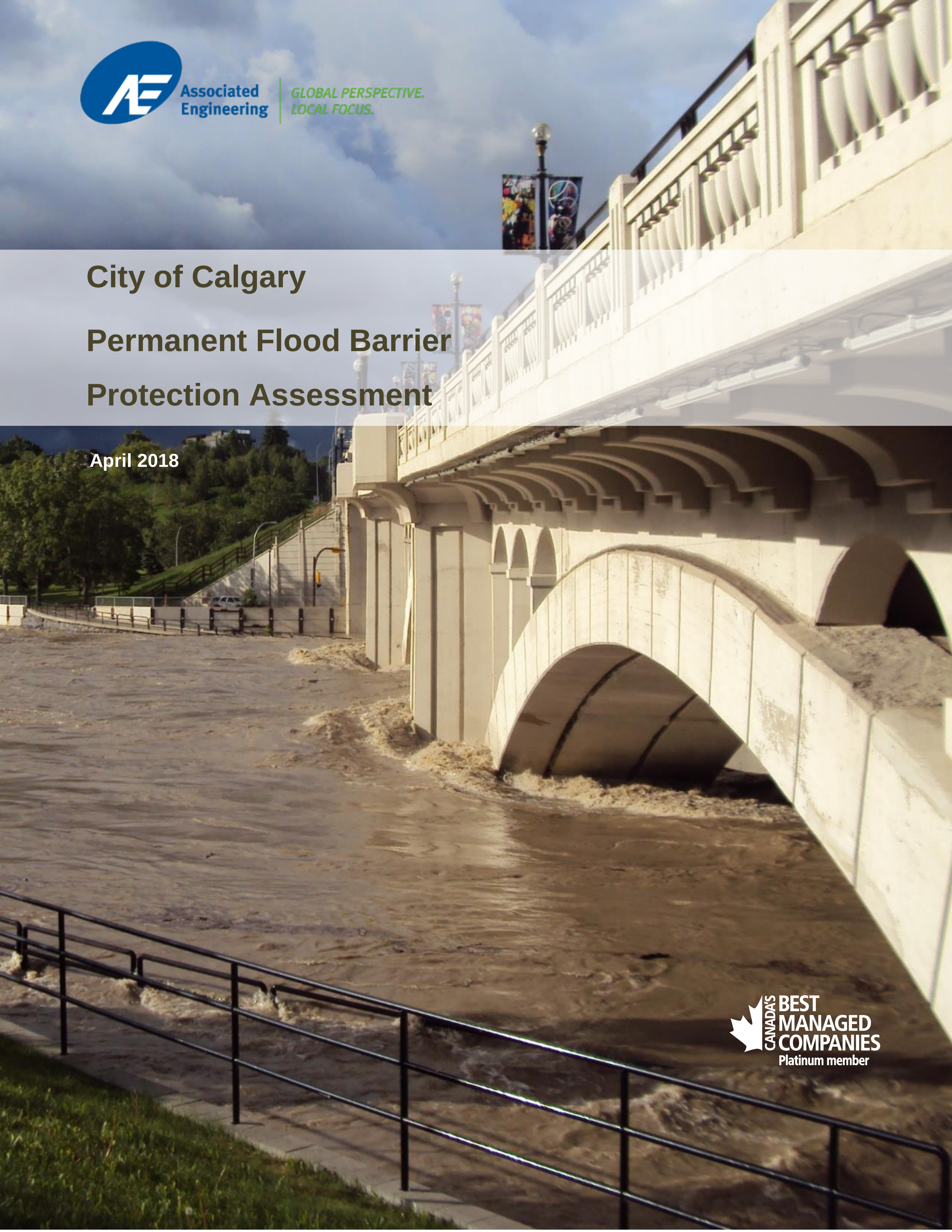
City of Calgary

Permanent Flood Barrier Protection Assessment

April 2018



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Executive Summary

Floodplain mapping undertaken by The City of Calgary (The City) identified that many communities within The City are at risk of flooding during river flood events on the Bow and Elbow Rivers. Various flood protection defenses have been built throughout The City's history, but these do not provide complete city-wide flood protection. River flood events in Calgary that are caused by precipitation in the Rocky Mountains are difficult to forecast with certainty and occur rapidly. This affords The City limited time to implement emergency flood protection measures and creates challenges in decision making. In an effort to improve flood defences, The City has been investigating measures to reduce flood damage risk through the construction of local flood protection barriers.

Following the 2013 flood, The City made a dedicated effort to improve its flood defences. Key milestones that initiated this project include the following:

- **May 2013** - The City issued a request for proposal to review the existing flood defences, and develop and prioritize conceptual level flood protection measures on the Bow River, Elbow River and Nose Creek as part of the *"Calgary River Flood Protection Conceptual Design"* (hereafter referred to as the Study).
- **June 2013** - The City experienced severe flooding on the Bow and Elbow Rivers representing one of Canada's worst natural disasters.
- **August 2013** - The City commissioned an expert panel on river flood mitigation. The panel recommended that The City investigate the viability of local barriers either in combination with, or as an alternative to, other structural and non-structural flood mitigation concepts (City of Calgary - Expert Management Panel, 2014).
- **September 2013 -** The City engaged Associated Engineering (AE) to undertake the Study.

The goal of the Study is to assist The City in evaluating the merits of implementing permanent, local flood protection using a Triple Bottom Line (TBL) approach. This analysis considers the economic, social and environmental benefits, and costs associated with implementing local, permanent flood protection, while recognizing the unique characteristics and challenges of each neighborhood. The City will incorporate the findings of this Study into an overall flood protection strategy.

AE's scope of work consisted of the following:

- Assess flooding mechanisms and existing flood risk:
  - Review available reports on hydrology, hydraulic modelling and flood inundation mapping to identify riverbank spill points and assess overland flood risk (Section 2).
  - Assess the condition and adequacy of existing flood protection barriers (Section 2).
  - Conduct hydrogeological modelling to understand subsurface flow regimes (Section 3).
  - Develop and review groundwater inundation mapping (Section 3) to assess groundwater flood risk.

- Conduct a TBL Analysis to evaluate benefits and costs of flood protection:
    - Estimate the flood damages expected for multiple high river flow conditions, as well as those averted by local flood protection barriers, which represent the benefits of implementing flood protection (Section 4).
    - Propose conceptual level flood protection barriers and estimate their costs (Section 5).
    - Calculate and compare economic, social and environmental benefits, and costs associated with the proposed flood protection barriers (Section 6).
- Interpret the TBL Analysis:
    - Identify the flood protection level that provides the greatest benefit relative to investment cost for flood protection at each vulnerable area. (Section 6).
    - Prioritize flood protection solutions based on the benefits they provide relative to their cost (Section 6).
    - Refine the conceptual designs selected for implementation (Section 8).

This Study determined that permanent flood protection is technically feasible but costly, and comes with large social and environmental costs. In many locations, permanent flood protection barriers require obstruction of river views and easements over private land. The TBL analysis indicated that local flood protection barriers with the highest benefit/cost ratios are located in the communities of Bowness, Sunnyside, Downtown and Fish Hatchery sites. The analysis also revealed that groundwater and stormwater flood protection is expensive and only beneficial in a few communities.

The results of the analysis performed in this Study have been incorporated into the Flood Mitigation Measures Assessment (FMMA) conducted by The City. The FMMA assessed the benefits of flood mitigation upstream of Calgary, as well as within The City. The FMMA recommended the following:

- Support flood mitigation upstream of Calgary including: The Province's Springbank Off-stream Reservoir project for the Elbow River, and the continuation of the Provincial TransAlta operational agreement for the Bow River.
- Develop and implement a funding plan for community level mitigation including permanent barriers that will complement an upstream reservoir and provide shorter term protection for communities at the greatest risk. The communities at the greatest risk are Sunnyside, Inglewood, Bowness, and Downtown.

Based on these findings, AE developed refined conceptual designs for the complementary barriers. The following table summarizes the recommended local flood protection measures identified for the complementary barriers in this Study:

Table 1-1
Recommended Local Flood Protection Measures

Site	Proposed Level of Service	Overland Flood Protection Length (m)	Groundwater Flood Protection Seepage Trench Length (m)	Capital Cost Estimate
Bowness	1:20 year	3016	N/A	$24.6 Million
Sunnyside	1:20 year	653	1800	Overland: $8.2 Million Groundwater: $4.7 Million
Downtown West	1:200 year	626	N/A	$14.9 Million
Downtown East	1:200 year	776	N/A	$10.7 Million
Fish Hatchery	1:75 year	564	N/A	$4.1 Million

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1 Introduction

1.1 BACKGROUND

Floodplain mapping undertaken by The City of Calgary (The City) identified that many communities within The City are at risk of flooding during river flood events on the Bow and Elbow Rivers. Various flood protection defenses have been built throughout The City's history but these do not provide complete city wide flood protection. River flood events in Calgary are difficult to forecast with certainty and occur rapidly. This affords The City limited time to implement emergency flood protection measures and creates challenges in decision making. In an effort to improve flood defences, The City has been investigating measures to reduce flood damage risk through the construction of local flood protection barriers.

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1.2 STUDY OBJECTIVES & SCOPE OF WORK

The goal of the Study is to assist The City in evaluating the merits of implementing permanent, local flood protection using a Triple Bottom Line (TBL) approach. This analysis considers the economic, social and environmental benefits, and costs associated with implementing local, permanent flood protection, while recognizing the unique characteristics and challenges of each neighborhood. The City will incorporate the findings of this Study into an overall flood protection strategy.

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    - Conduct hydrogeological modelling to understand subsurface flow regimes (Section 3).
    - Develop groundwater inundation mapping to assess groundwater flood risk (Section 3).
    - Review groundwater inundation mapping to identify sites to be considered for flood protection (Section 3).
- Conduct a TBL Analysis to evaluate benefits and costs of flood protection:
    - Estimate the flood damages expected for various high river levels, as well as those averted by proposed flood protection, which represent the benefits of implementing flood protection (Section 4).
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    - Refine the conceptual designs selected for implementation (Section 8).

1.3 STUDY AREA

The study area encompasses the floodplains of the Bow and Elbow Rivers throughout Calgary city limits. The Ghost Reservoir and the Glenmore Dam regulate flow on the Bow and Elbow Rivers, respectively. Within The City limits, three creeks discharge into the Bow River, downstream of the Elbow River - Nose Creek, Fish Creek and Pine Creek. The Western Headworks Division diverts water away from the Bow River for irrigation and conveys flow to the Western Irrigation District's Chestermere Lake. The study area is illustrated within Figure 2-1. All Figures have been included within **Appendix A**.

1.4 BACKGROUND DATA

The City provided AE with a significant amount of background data for the Study. This information included GIS data, reports, studies and drawings and is listed in **Appendix B**.

The background information served as the basis for this report. At the time of the preparation of this report, The City planned to implement additional flood protection measures, which were not considered in this Study:

- Bonnybrook Wastewater Treatment Plant flood barrier
- Heritage Drive SE flood barrier
- West Eau Claire Park flood barrier
- Centre Street Bridge gates
- Memorial Drive (west of Centre Street) flood barrier
- ENMAX Substation 32 flood barriers.
- Deane House flood barrier

1.5 RELEVANT COMPLETED AND CONCURRENT WORK

There have been a number of previous studies which investigated flood risk within The City. Some of the more relevant studies are summarized below. Additional relevant studies are noted in **Appendix B**.

- *City of Calgary Flood Study - Volume - Bow River* (Montreal Engineering Company Limited, 1973)
- *City of Calgary Floodplain Study* (Alberta Department of the Environment, 1983)
- *City of Calgary Floodplain Study - Summary Report* (Alberta Department of the Environment, 1984)
- *The Inglewood Floodplain Management Study* (AGRA Earth & Environmental Limited, 1994)
- *East Village Flood Reduction Study - Phase 2* (AGRA Earth & Environmental Limited, 1995)
- *Bow and Elbow River Updated Hydraulic Model Project - Hydrology Study* (Golder Associates, 2010)
- *Bow and Elbow River Updated Hydraulic Model Project - Hydraulic Modelling and Inundation Mapping* (Golder Associates, 2012)
- *Basin-Wide Hydrology Assessment and 2013 Flood Documentation* (Golder Associates, 2014)
- *Hydraulic Model and Flood Inundation Mapping Update* (Golder Associates, 2015).

The City and the Government of Alberta have undertaken a number of projects that impact or utilize the findings of this Study. The projects with the greatest impacts upon flood risk within The City are the large scale works being considered on both the Bow and Elbow Rivers, upstream of Calgary. On the Elbow River, the Government of Alberta has committed to the Springbank Off-Stream Reservoir, identified in the "*Flood Mitigation Measures for the Bow, Elbow and Oldman River Basins*" study (AMEC Environment & Infrastructure, 2014). On the Bow River, the Government of Alberta and TransAlta have reached a temporary five-year agreement to modify operations at several TransAlta facilities for flood mitigation. These projects have significant implications upon the results and recommendations of this Study.

The Government of Alberta commissioned the "*Provincial Flood Damage Assessment Study*" (IBI Group, 2015) to develop a rapid assessment tool for estimating flood damages. This tool was used to develop a flood damage estimate for The City of Calgary under the "*Provincial Flood Damage Assessment Study City of Calgary: Assessment of Flood Damages*" (IBI Group, 2015). The depth/damage curves (Section 4.2.2) from that project were used in this Study.

The City of Calgary undertook the Flood Mitigation Options Assessment (FMOA) (IBI Group & Golder Associates Ltd., 2017). Findings from this Study contributed to the FMOA, which is discussed further in Section 6. The damage estimates developed within this Study were calibrated to the results obtained in the FMOA. The findings from this Study also contributed to the Flood Mitigation Measures Assessment (FMMA) (City of Calgary, 2016) undertaken by The City.

2 Existing Flood Risk

2.1 FLOOD MECHANISMS

The City is vulnerable to flooding during the following hydrological events:

Winter Events	High River Flow Events	Rainfall Events
• Ice Jam Related Flooding	• Overland Flooding • Groundwater Flooding • Stormwater Flooding Due to Outfall Gate Closure	• Stormwater Flooding Due to a High Intensity Rain During a Low River Level

2.1.1 Winter Events

2.1.1.1 Ice Jam Related Flooding

The City undertook the "*Ice Regime of the Bow River within The City of Calgary, Alberta*" (Northwest Hydraulic Consultants Ltd., 2017) study which identified the following:

- Most ice jams arise during freeze-up in the reaches between Cushing Bridge and the Crowchild Trail bridge as thickened ice accumulations form during the more severe cold periods.
- Forecasting ice conditions requires an understanding of individual ice processes, and at this point, understanding some of the processes is too rudimentary to forecast ice-related outcomes with any degree of confidence.
- Ice does not play a dominant role in shaping the planform of the Bow River or cause extensive bed and bank scour.
- Open water conditions will define the erosion protection requirements rather than ice forces

Based on the above noted findings, AE used open water conditions to design erosion protection requirements.

2.1.2 High River Flow Events

2.1.2.1 Overland Flooding

Much of the Bow and Elbow Rivers' catchments upstream of Calgary are within the foothills and Rocky Mountains as shown within Figure 2-2 in **Appendix A**. This is described in a paper entitled "*Quantifying baseflow and water-quality impacts from a gravel-dominated alluvial aquifer in an urban reach of a large Canadian river*" (Cantafio & Ryan, 2014) in which the flow in the Bow River is characterized as follows:

> *An assessment of historical discharge measurements along the Bow River between its headwaters and Calgary confirmed that flow does not increase significantly along the Calgary-region reach during either low or high flow conditions.*
>
> *Based on 30-year-mean-discharge data (where available), the majority of the mean discharge recorded at Calgary during both the low and high flow periods was generated in the Rocky Mountains (92 and 95 %, respectively).*
>
> *…it is evident that almost all of the [Bow] river flow in the prairie reaches is generated in the Rocky Mountains.*

Although some contribution to high river levels in Calgary can be due to local rainfall, the majority of high river flows are understood to be due to upstream contributions as noted above.

Flood events develop and propagate quickly due to the steep mountainous topography of the headwaters. The temporal and spatial variability of rainfall and corresponding hydrological conditions that contribute to high runoff events originating in the Rocky Mountains and the close proximity of catchment boundaries make flood events difficult to forecast. The relatively rapid runoff response and difficulties in prediction make overland flood events challenging to respond to within Calgary, particularly with temporary measures.

2.1.2.2 Groundwater Flooding

"The geology of The City of Calgary is generally comprised of a surficial layer of finer grained material (silts/clays/organics), underlain by moderate to highly permeable sands and gravels, with sandstone bedrock at depth" (Moran, 1986). The highly permeable sand and gravel layer allows for significant groundwater migration. This suggests flooding due to groundwater seepage during river flood events is likely.

The City's surficial geology indicates that, in certain areas, mitigation of overland flooding and groundwater seepage must be considered together to be effective. Therefore, this Study provides results from hydrogeological analyses, groundwater inundation mapping, groundwater flood damage estimation, as well as conceptual designs for groundwater flood protection.

2.1.2.3 Stormwater Flooding Due to Closed Outfall Gates

Local flood protection barriers can obstruct stormwater drainage. Overland flood protection prevents overland runoff from discharging directly to the river. Additionally, in anticipation of high river levels, stormwater outfall gates are closed to prevent the river backwatering into The City's stormwater collection system causing flooding.

This highlights the risk of stormwater flooding during a combined high river and rainfall event. When the outfall gates are closed, stormwater runoff is unable to discharge to the river and could result in flooding on the land side of the flood protection barrier. Damage estimates due to a combined high river/rainfall event were not included in the scope of this Study. However, AE estimated the cost of providing stormwater flood mitigation to accompany overland flood protection.

2.1.3 Stormwater Flooding Due to High Intensity Rainfall During a Low River Level

Rainfall flooding during a low river level was not assessed as the Study is focused on river related flooding.

2.2 FLOOD RISK MANAGEMENT

Flood risk is managed in Calgary through a combination of:

- Floodplain Mapping
- Municipal Regulation
- Provincial Regulation
- Permanent Flood Protection Barriers
- Emergency Response Procedures.

2.2.1 Floodplain Mapping

In 1983 the Alberta Department of the Environment delineated and subdivided the floodplain of the Bow and Elbow Rivers as contained in the "*City of Calgary Floodplain Study*" (Alberta Department of the Environment, 1983). Within this Study, the floodplain (or flood hazard area) was separated into the Floodway; Flood Fringe; and Overland Flow areas using The City of Calgary Land Use Bylaw 1P2007 definitions as follows:

- **Floodway** - The river channel and adjoining lands indicated on the Floodway/Flood Fringe Maps that would provide the pathway for flood waters in the event of a flood of a magnitude likely to occur once in one hundred years.
- **Flood Fringe** - Those lands abutting the floodway, the boundaries of which are indicated on the Floodway/Flood Fringe Maps that would be inundated by floodwaters of a magnitude likely to occur once in one hundred years.
- **Overland Flow** - Those lands abutting the Floodway or the Flood Fringe, the boundaries of which are indicated on the Floodway/Flood Fringe Maps that would be inundated by shallow overland floodwater in the event of a flood of a magnitude likely to occur once in one hundred years.

2.2.2 Municipal Regulation

The City's "*Land Use Bylaw 1P2007*" restricts development within the Floodway and requires that the main floor of buildings within the Flood Fringe must be constructed at or above the designated flood level. The bylaw defines the designated flood level as the "theoretical level, indicated on the Floodway/Flood Fringe Maps, to which water would rise in the event of a flood of a magnitude likely to occur once in one hundred years" (City of Calgary, 2014).

2.2.3 Provincial Regulation

In 2014, the Government of Alberta passed "*Bill 27 – Flood Recovery and Reconstruction Act*" (The Legislative Assesmbly of Alberta, 2013). This act amended the "*Municipal Government Act*" (Government of Alberta, 2016). The changes to the Municipal Government Act restrict development within the Floodway as indicated below:

693.1(1) The Lieutenant Governor in Council may make regulations

a. controlling, regulating or prohibiting any use or development of land that is located in a Floodway within a municipal authority, including, without limitation, regulations specifying the types of developments that are authorized in a Floodway;

b. exempting a municipal authority or class of municipal authorities from the application of all or part of this section or the regulations made under this subsection, or both;

Bill 27 gives the Provincial Government authority to control development within designated Floodways and overrule municipal decisions in this regard.

The Government of Alberta outlines further restrictions within their "*Flood Risk Management Guidelines for Location of New Facilities Funded by Alberta Infrastructure*" (Alberta Infrastructure, 2013). This mandates that certain facilities funded by Alberta Infrastructure be constructed outside of the 1:100, 1:500 or even the 1:1000 year inundation extents.

The Government of Alberta also manages the production of flood hazard studies and mapping under the provincial Flood Hazard Identification Program. The Government of Alberta is currently updating the flood hazard mapping for the Bow and Elbow Rivers in Calgary, and this could lead to a revised delineation of the Floodway, Flood Fringe or Overland Flow areas.

2.2.4 Permanent Flood Protection Barriers

The existing permanent barriers do not provide consistent levels of protection throughout the city. AE conducted a desktop and condition assessment of overland flood protection infrastructure including an estimation of the current level of service provided by these structures as discussed in Section 2.5.

2.2.5 Emergency Response Procedures

The City implements emergency response measures when weather and flow forecasts predict flooding. These measures can require placement of temporary barriers. Deployment of barriers is intended for critical locations. Further deployment is limited because barriers can be labour intensive to construct and are difficult to implement given the minimal notice of a flood event afforded to The City.

2.3 HYDROLOGY/HYDRAULICS

Historical flow data for the Bow River has been collected by Environment Canada at the Reconciliation Bridge (formerly known as the Langevin Bridge) and downstream of the Glenmore Dam on the Elbow River. Daily maximum, average and minimum flow data is presented within Figure 2-3 in **Appendix A**.

There are several hydrology/hydraulic reports for the Bow and Elbow Rivers. These studies are shown within the following table:

Table 2-1
Hydrology and Hydraulic Studies

Set	Hydrology Study	Hydraulic Study
1983 Study	*City of Calgary Floodplain Study* (Alberta Department of the Environment, 1983)	*City of Calgary Floodplain Study* (Alberta Department of the Environment, 1983)
1985	*City of Calgary Probable Maximum Flood Inundation Study* (Moneco Consultants Ltd., 1985)	*City of Calgary Probable Maximum Flood Inundation Study* (Moneco Consultants Ltd., 1985)
1994		*The Inglewood Floodplain Management Study* (AGRA Earth & Environmental Limited, 1994)
Pre 2013 Hydrology/Hydraulic Study	*Bow and Elbow River Updated Hydraulic Model Project - Hydrology Study* (Golder Associates, 2010)	*Bow and Elbow River Updated Hydraulic Model Project - Hydraulic Modelling and Inundation Mapping* (Golder Associates, 2012)
Post 2013 Hydrology/Hydraulic Study	*Basin-Wide Hydrology Assessment and 2013 Flood Documentation* (Golder Associates, 2014)	*Hydraulic Model and Flood Inundation Mapping Update* (Golder Associates, 2015)

The Post 2013 Hydrology Study estimated flow rates for several return periods on the Bow and Elbow Rivers. These flow rates are summarized as follows:

Table 2-2
River Flow Rate (m^3/s) by Return Period

Return Period (years)	Bow River Above Confluence with Elbow River	Bow River Below Confluence with Elbow River	Bow River Below Confluence with Nose Creek	Bow River Below Confluence with Fish Creek	Bow River Below Confluence with Pine Creek	Bow River Below Confluence with Highwood River	Elbow River Below Glenmore Dam
2	369	433	439	478	482	687	63.9
5	659	802	816	902	915	1,390	143
10	927	1,160	1,180	1,320	1,340	2,080	234
20	1,230	1,500	1,540	1,740	1,770	2,980	275
50	1,660	2,150	2,210	2,530	2,570	4,230	494
100	2,020	2,820	2,910	3,360	3,400	5,610	803
200	2,390	3,520	3,650	4,270	4,320	7,200	1,130
500	2,920	4,610	4,820	5,770	5,840	9,820	1,690
1000	3,340	5,610	5,920	7,220	7,300	12,240	2,270

The Post 2013 Hydrology/Hydraulic Studies identified a significant increase in flows and inundation extents when compared to the Pre-2013 Hydrology/Hydraulic Studies.

Implementations of upstream flood mitigation projects such as the Glenmore Dam Infrastructure Improvements, Springbank Off-Stream Reservoir and proposed solutions assessed through the Bow River Water Management Project would impact hydrological estimates. With the implementation of upstream water management facilities and changes to regulated flow management, predicted flow rates in Table 2-2 above and corresponding Water Surface Elevations (WSELs) would be reduced. Implementation of upstream flow attenuation would therefore reduce the benefit of local flood protection. AE incorporated the effects of the proposed upstream mitigation within this Study. This is discussed further within Section 6.3.5.

2.4 OVERLAND FLOOD RISK AREAS

AE reviewed the overland inundation extents to identify areas that warranted flood protection. The Bow River within City limits and the Elbow River from downstream of the Glenmore Dam to the City limits were reviewed.

AE reviewed the 20, 50, 100, 200, 350, 500 and 1000 year overland inundation extents, provided in the "*Hydraulic Model and Flood Inundation Mapping Update"* (Golder Associates, 2015), in conjunction with a list of critical infrastructure and vital services identified by The City, through the use of the "Flood Impacted Roadways - 100 Year Return Period Flood Event" drawings (City of Calgary, 2016). The following sites were identified as locations vulnerable to overland flooding and as such, were selected to be evaluated for flood protection using permanent flood barriers through the TBL benefit-cost analysis.

- Bowness North
- Bowness South
- Montgomery North
- Montgomery South
- Point McKay
- Crowchild
- Sunnyside
- Memorial West
- Memorial East
- Bridgeland
- Sunalta
- Downtown
- Inglewood
- Fish Hatchery
- Deerfoot at 17 Avenue SE
- Inglewood Golf Club
- Bonnybrook
- Heritage Drive
- Deerfoot at Southland
- Riverbend North
- Riverbend South
- Quarry Park
- Douglas Glen
- Douglasbank
- Deer Run
- Britannia
- Elboya
- Manchester
- Rideau and Roxboro
- Erlton
- Elbow Park South
- Elbow Park North
- 5 Street SW (Mission)
- East Mission
- St. Mary's High School
- MacDonald Bridge

Refer to **Appendix C** for a complete set of figures delineating spill lines and areas vulnerable to overland flooding for the above noted return periods. A similar assessment was conducted for vulnerability to groundwater flooding as discussed in Section 3.6. Flood damages (Section 4) and overland flood protection designs (Section 5) were developed for each site identified above.

2.5 EXISTING FLOOD BARRIER INVENTORY

In conjunction with The City, AE developed an inventory of existing flood barriers within Calgary. The full list of infrastructure with available documentation is presented within **Appendix D**.

2.6 EXISTING FLOOD PROTECTION BARRIER CONDITION ASSESSMENTS

As a part of the assessment of the existing flood risk, The City identified six existing flood protection barriers to be assessed in greater detail. AE performed a condition assessment of these six barriers, depicted in Figure 2-4 in **Appendix A**. The assessment consisted of a review of available engineering information and a field assessment of the condition of the structures. Little information exists about the design intent of most of these barriers. For those where design information was not available, they were assessed for conformance to the design criteria for proposed structures outlined within Section 5.2. Geotechnical field work was not included in these assessments and would be required to validate the permeability and stability of the infrastructure. The following barriers were assessed:

- Bowness Road Berm
- Montgomery Berm
- Sunnyside Berms
- Bridgeland Berm
- East Village/Riverwalk Dyke
- Inglewood Barrier

2.6.1 Bowness Road Berm

The berm near Bowness Road NW, on the right bank of the Bow River, extends from Bowness Road to Bowness Crescent for a total length of about 100 m. The riverside toe of the berm appears to form the top of the river bank with no setback. No record information was available for the Bowness Road Berm.

A site review of the berm conducted on June 19, 2014 provided the following observations:

- No observable settlement of the berm crest, nor were there signs of slope instability on either the landside or the riverside of the berm. See Photos 2-1, 2-2 and 2-3 for typical photos of the berm.
- The berm crest is narrower than the dyke design criteria identified in Section 5.2, which may indicate a concern with stability. Confirming whether stability is a concern would require an assessment of the material composition of the berm.
- Large trees are growing within the berm which may affect the integrity or impermeability of the structure.
- Side slopes vary from 1.5H to 1V to 5H to 1V. Some sections of the berm are steeper than the recommended design criteria and some are flatter.
- The typical crest width is 1.5 m, which is narrower than the recommended design criteria.

Photo 2-1

Photo 2-2

Photo 2-3

2.6.2 Montgomery Berm

An existing berm extends in front of Bow View Manor; between Montgomery Road and the TransCanada Highway, for 390 m on the left bank of the Bow River. The berm is not set back from the river bank. No record information was available for the Montgomery Berm.

A site review of the berm conducted on June 19, 2014 provided the following observations:

- No observable settlement of the berm crest. See Photos 2-4 and 2-5 for typical photos of the berm.
- Localized failure approximately 3 m in length on the riverside slope, possibly due to erosion of the riverbank toe. See Photo 2-6 of the localized slope failure.

AE recommends remediation of the localized failure through an analysis of the existing soils and design of appropriate bank protection.

- Side slopes vary from 1.5H to 1V to 4H to 1V. Some sections of the berm are steeper than the recommended design criteria and some are flatter.
- The typical crest width is 3 m, which meets the recommended design criteria.

Photo 2-4

Photo 2-5

Photo 2-6

2.6.3 Sunnyside Berms

There are multiple existing berms between 24 Street NW and Centre Street S on the left bank of the Bow River, extending for 4 km. In most cases, the berms are aligned immediately alongside the river bank, and serve as pathways or multi-use trails. No record information was available for the berms. A site review of the berm conducted on January 28, 2014 provided the following observations:

- Large diameter trees are present in the side slope. Large diameter trees could impact the stability of the slope however, it is not visibly apparent as to whether these affect the integrity of the berm in this location. Additional subsurface investigation would be required to verify any impacts or concerns with the integrity of the berm. See Photos 2-7 and 2-8 for typical photos of the berm.
- Side slopes vary from 1H to 1V to 4H to 1V. Some sections of the berm are steeper than the recommended design criteria and some are flatter.
- The typical crest width ranges between 1 and 4 m. Some sections of the berm are narrower than the recommended design criteria and some are wider.

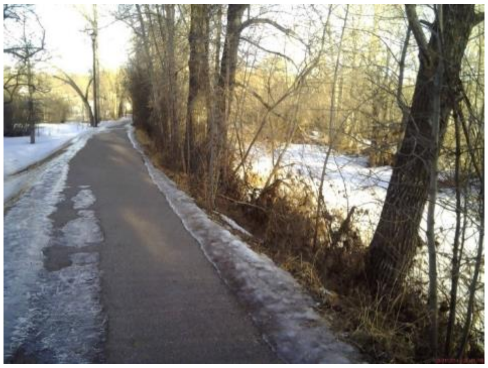

Photo 2-7

Photo 2-8

2.6.4 Bridgeland Berm

An existing berm extends for a length of about 60 m along the left bank of the Bow River between the Reconciliation Bridge (formerly known as the Langevin Bridge) (4 Street NE) and the 5 Avenue Flyover. The riverside toe is offset about 4 m from the top of the riverbank. No record information was available for the Bridgeland Berm.

A site review of the berm conducted on May 20, 2014 provided the following observations:

- No observable settlement of the berm crest. See Photos 2-9 and 2-10 for typical photos.
- Side slopes vary from 1.5H to 1V to 5H to 1V. Some sections of the berm are steeper than the recommended design criteria and some are flatter.
- The typical crest width ranges between 1 and 5 m. Some sections of the berm are narrower than the recommended design criteria and some are wider.

Photo 2-9

Photo 2-10

2.6.5 East Village/Riverwalk Dykes

Calgary Municipal Land Corporation’s ‘Riverwalk’ extends along the right bank of the Bow River from 3 Street SE to 6 Street SE for 1750 m. The gradual landside slope of the dyke allows for easy equipment access onto the dyke for inspection, maintenance and repair.

Riverwalk consists of a constructed earth-fill dyke, topped with a number of landscaped features including a concrete promenade, asphalt bike trails, rolled-face curb and gutter, trees and shrubs. Riverwalk was constructed in 2012.

A site review of Riverwalk conducted on May 15, 2014 provided the following observations:

- No observable settlement of the berm crest, nor signs of slope instability was evident on either the landside or the riverside of the dyke. See Photos 2-11 and 2-12 for photos of Riverwalk.
- Culvert immediately west of the Reconciliation Bridge (formerly known as the Langevin Bridge) is situated within the dyke, as shown in Photo 2-13. This is not shown on the available drawings. The culvert through the dyke represents a vulnerability. The City should examine the culvert for opportunities to incorporate backflow prevention or temporary blockage.

- Design drawings do not include measures to control groundwater seepage.
- Design drawings identify side slopes of 3H to 1V, which is flatter than the recommended design criteria.
- Design drawings identify a crest width of 5 m, wider than the recommended design criteria.

Photo 2-11

Photo 2-12

Photo 2-13

2.6.6 Inglewood Flood Barrier

The Inglewood Flood Barrier is located in the residential community of Inglewood. The structure is a combination of concrete flood walls and earth fill dykes along the right bank of the Bow River from New Bow Lane SE to 15 Street SE, with a total length of 450 m. Phased construction of the wall commenced in 2003 and was completed in 2008.

As noted on the construction drawings provided by The City, the earth-fill sections of the barrier consist of compacted, low permeability clay fill beneath varying amounts of topsoil. Design drawings of the clay core identify side slopes of 3H to 1V, which is flatter than the recommended design criteria. The typical crest width is 1 m, which is narrower than the recommended design criteria.

The concrete sections of the barrier consist of a reinforced, 250 mm thick vertical concrete wall, with a 1.3 m long riverside toe and toe key extending 450 mm deep below the footing. In some locations, the riverside and landside faces of the wall are clad with architectural stone. Joints along the wall are sealed with waterstops. There are locations where access over the concrete wall to the river bank is provided with stairs on either side of the wall, with a landing on the wall top. In two instances, access is provided to the riverbank via hinged, lockable timber lag gates in the concrete flood wall.

Although there is a toe on the flood protection wall footing, this has been implemented for stability as opposed to seepage control. The design drawings do not include measures to control seepage.

A site review of the Inglewood Barrier on May 15, 2014 and follow up assessment on November 14, 2015 provided the following observations:

- Cracks were observed in the concrete wall facing on both landside and riverside faces, but only in locations where the wall is clad with architectural stone (red arrows in photos). In some cases, the cracks extend from the visible bottom of the wall (where it meets the ground) to the top of the wall. However, no evidence could be found of crack propagation through the entire wall which, had it been found, could suggest settlement or wall movement following loading. Thus, the cracks are presumed to be a result of shrinkage cracking of the architectural facing and not due to a structural issue. See Photos 2-14, 2-15 and 2-16.

Photo 2-14

Photo 2-15

Photo 2-16

- No observable settlement of the concrete wall along its length.
- No observable leaning, signs of overturning, or horizontal movement.
- Holes appear in the earth fill dyke at 66 New Street, very likely due to burrowing animals. Residents have indicated that these holes are dug by Richardson Ground Squirrels. The University of Lethbridge indicates that the burrows can go as deep as 1 m and can extend up to 10 m in length (http://research.uleth.ca/rgs/burrow.cfm). These holes did not appear to be deep enough to impact the clay core of the dyke.
- Black rubber gate seal on one gate is starting to peel away from the gate frame, as evidenced in Photo 2-17.

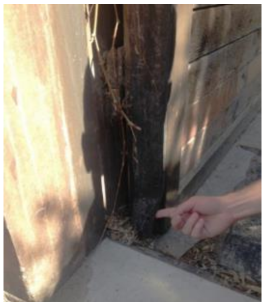

Photo 2-17

Photo 2-18

- Some landscaping and garden features have been placed alongside the concrete wall and earth fill dyke. In one case, an outdoor patio had been cut into the landside of the earth fill dyke, extending to the landside shoulder of the berm crest (Photo 2-18). This does not appear to affect the clay core of the dyke. No evidence could be found of waterstop or sealant peeling, cracking or drying. See Photos 2-19 and 2-20 showing the waterstops.
- No observable signs of slope instability on either the landside or the riverside of the dyke.

Photo 2-19

Photo 2-20

2.6.6.1 Summary

The two gates in the wall serve as vulnerabilities to flooding because they require manual closure.

There is no dedicated maintenance access in place, so City access to the barrier must cross private property with permission from residents. The City should examine opportunities to establish a maintenance access procedure and coordinate this with residents.

2.6.6.2 Potential Barrier Improvements

In 2015/2016 AE assessed the feasibility of raising the existing barrier. The findings of this analysis are included in the “*Inglewood Flood Barrier Assessment Findings and Recommendations”* (Associated Engineering, 2016) and summarized as follows:

- Raising the existing flood barrier to the current 1:100 year level of protection will require removal and replacement of the wall at 6 properties.
- Barriers at the other 12 properties can be raised to the 1:100 year level of service or higher. This is further detailed in the above noted memo.

The findings of this memo were incorporated into the flood protection conceptual designs.

3 Groundwater Modelling and Inundation Mapping

3.1 SUMMARY

AE conducted groundwater modelling and created groundwater flood inundation mapping as part of the Study to estimate groundwater flood risk due to high river levels and the costs associated with groundwater flood protection. As a part of this exercise, AE:

- Conducted hydrogeological modelling and analysis
- Developed groundwater inundation extents and depths
- Identified areas at risk of groundwater flooding
- Used the results to design proposed flood protection.

The groundwater modelling and inundation mapping exercise included three major components:

3.1.1 Modelling Setup

AE created groundwater transmissivity models for three critical river reaches in Calgary. To create these models, AE identified and incorporated:

- Typical stratigraphy for floodplain areas in The City based on a review of existing borehole logs which are mapped in Figure 3-1 in **Appendix A**.
- Typical hydraulic conductivity values.
- Hydrographs to represent floods 20, 50, 100, 200, 350, 500 and 1000 year return periods.

AE selected a two-dimensional modelling methodology because it provides results on vertical elevation and horizontal extents away from the river. A three-dimensional model would require significant effort to setup, given the large study area and it would yield limited accuracy without being able to input more detailed subsurface information than what is currently available.

3.1.2 Modelling Results

Review of the groundwater modelling yielded two major findings:

- Two separate wetting fronts were observed while modelling some scenarios. While overland flow was propagating away from the river, the groundwater profile did not propagate fully beneath the extents of the overland flow. This is further discussed in Section 3.3. An example of this is shown in Figure 3-4.
- In certain scenarios and locations, the model predicted that groundwater would rise to surface despite the presence of proposed overland flood protection. This finding indicated that, in certain areas, groundwater was a significant contributor to flood damages and that mitigation of overland flooding on its own may not be sufficient to prevent damages in these locations.

3.1.3 Groundwater Inundation Mapping

AE extracted two-dimensional groundwater profiles from the model and related them to the existing digital elevation model information to develop groundwater inundation mapping across The City. These surfaces were used to identify locations where flooding was expected to affect basements or reach the ground surface. AE prepared groundwater flood depth surfaces for multiple river flood event return periods for the existing condition with no overland flood protection in place and a mitigated scenario with overland flood protection in place. The groundwater inundation mapping is provided in **Appendix E**.

The remainder of this section discusses the groundwater modelling and inundation mapping exercise in greater detail.

3.2 MODELLING SETUP

Groundwater modelling was conducted using SEEP/W [1]. To facilitate this analysis, AE created typical cross sections at representative river reaches in The City. The major input parameters of the groundwater model consist of:

- Subsurface conditions
- Hydraulic conductivity
- River geometry
- Flood hydrographs.

3.2.1 Subsurface Conditions

The City provided forty-five reports which contained subsurface information within Calgary. These reports were reviewed and summarized within a technical memorandum entitled "*City of Calgary Flood Mitigation – Summary of Existing Test Hole Information*" (Thurber Engineering Ltd., 2015) to develop a typical stratigraphy for the floodplain areas in Calgary. The recommended baseline soil profile, based on this review, was a stratigraphy with three lithological units summarized as follows:

0-2 m deep:	fine grained fluvial overbank sediments (Silty/Sandy Unit)
2-6 m deep:	coarse grained fluvial channel deposits (Sand/Gravel Unit)
6 m depth:	bedrock (Bedrock Unit).

The three lithological units were assumed to be homogenous throughout the floodplain of the study area for this analysis. Subsurface conditions do vary across the City and this would affect the rate of movement of groundwater. To quantify the significance of the variance, site specific field investigations would need to be conducted in the areas of interest.

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[1] SEEP/W is a finite element software product that can be used to model the movement and pore-water pressure distribution within porous materials" (Geo-Slope Office, 2001)

3.2.2 Hydraulic Conductivity

Throughout Calgary, both lithology and hydraulic conductivity (k) vary significantly. To represent this variability, AE developed a range of values for each of the three lithological units based on a literature review. The range was divided into a low, expected and high hydraulic conductivity scenario for each lithological unit. Refer to the following table for details.

Table 3-1
Hydraulic Conductivity (k)

Lithological Unit	Scenario	Hydraulic Conductivity (k) (m/day)	Reference
Silty/Sandy Unit	Low	0.00073	(Thurber Engineering Ltd., 2014)
Silty/Sandy Unit	Expected	0.17	(Associated Engineering, 2015a)
Silty/Sandy Unit	High	200[2]	(Cantafio & Ryan, 2014)
Sand/Gravel Unit	Low	35	(Baker, et al., 2011)
Sand/Gravel Unit	Expected	430	(Associated Engineering, 2015a)
Sand/Gravel Unit	High	881	(Meyboom, 1961)
Bedrock Unit	All	0.8	(Baker, et al., 2011)

SEEP/W also allows the user to adjust the Hydraulic Conductivity Ratio, which is the ratio of the hydraulic conductivity in the vertical direction to the hydraulic conductivity in the horizontal direction. AE reviewed literature for appropriate ratios in the expected subsurface layers. The Hydraulic Conductivity Ratios used are as follows:

- Silty/Sandy Unit: 0.1 (Capuano & Jan, 1996)
- Sand/Gravel Unit: 0.5 to 0.8 (Todd, 1980)
- Bedrock Unit: 0.5 (Domenico & Schwartz, 1990).

3.2.3 River Geometry

AE developed three different river cross sections to represent conditions across The City. These cross sections have been illustrated within Figure 3-2 in Appendix A and represent the following river reaches:

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[2] AE noted the potential presence of paleo channels within background reports and lithological logs. While these channels were not modelled, the hydraulic conductivity was increased from 172.8 m/day to 200 m/day in the silty/sandy unit to represent an increased conductivity due to the possible presence of these channels.

- Bow River upstream of the Elbow River
- Bow River downstream of the Elbow River
- Elbow River downstream of the Glenmore Reservoir.

To generate these three representative cross sections, AE:

- Extracted typical bank geometry within each river reach using representative cross sections.
- Averaged the channel width, bank height, bank slope and thalweg depth, and created several composite cross sections for each reach.
- Developed and utilized an average cross section for each reach.
- Applied the subsurface stratigraphy identified in Section 3.2.1 to each representative cross section.

AE extracted representative depth/flow rating curves from each of the three river reaches noted above from the Post 2013 Hydraulic Model. These were combined into a representative curve for each reach.

3.2.4 Flood Hydrographs

Flow hydrographs were converted to stage vs. time curves for use within SEEP/W as described below and illustrated within Figure 3-3 in **Appendix A**.

- **Flow/Time Hydrographs** - The City provided AE with flow hydrographs[3] for the 20, 50, 100, 200, 350, 500 and 1000 year return periods for the Bow River upstream of the Elbow River, and the Elbow River downstream of the Glenmore Dam. AE assumed that the Bow River flow downstream of the Elbow River would be the sum of the two hydrographs.

Stage/time relationships were developed using the flow/time hydrographs and depth/flow rating curves. AE used the stage/time relationships to simulate the typical rise in the Bow and Elbow Rivers within the two-dimensional cross sections. This resulted in stage/time curves for the 1:20, 50, 100, 200, 305, 500 and 1000 year river levels for each of the three modelled reaches.

3.3 MODELLING RESULTS

Groundwater modelling results for the various scenarios are included in **Appendix F**. AE generated two major findings. These findings are described as “dual wetting fronts” and “full saturation” which are described in the following sections.

3.3.1 Dual Wetting Fronts

Modelling results indicated that the horizontal location of a flood barrier, relative to the top of bank, significantly affected the groundwater propagation results. In order to understand the impacts, AE modelled a flood barrier at three locations: 5, 200 and 400 m away from the bank.

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[3] Flow Hydrographs were based upon information within the “*Bow River and Elbow River Basin-Wide Hydrology Assessment and 2013 Flood Documentation*” (Golder, 2014).

The simulation with the flood barrier setback 5 m from the riverbank provided insight on groundwater effects when overland flooding does not occur. The simulations with the flood barrier setback 200 and 400 m from the riverbank allowed overland flooding to occur on the river side of the barrier and allowed AE to analyse the relative groundwater propagation during overland flooding. Refer to Figure 3-4 in **Appendix A** for a depiction of these results.

Under the high hydraulic conductivity scenario, overland flow would result in rapid advancement of the phreatic surface and the groundwater levels. However, under the expected and low hydraulic conductivity scenarios, AE observed the development of two separate wetting fronts. The silty/sandy surface layer resisted the infiltration of overland flow and allowed for a dry area underneath the extents of the overland inundation. The relationship between the propagation of the phreatic surface and the propagation of overland is highly sensitive to the depth, duration and extent of overland inundation and the hydraulic conductivity of the soil.

3.3.2 Groundwater Migration

With an overland flood protection barrier in-place, groundwater can migrate to surface on the land side of the flood barrier. The degree to which the water migrated to the surface is dependent on the head differential across the flood barrier.

The model predicted the most significant depth of groundwater flooding to be on the Elbow River where the bank height is relatively low. At and above the 1:200 year return period on the Elbow River, model results demonstrated that groundwater on the land side of the flood barrier would reach the surface under expected and high hydraulic conductivities. AE referred to this as “full saturation”. In locations where this occurs, further assessment should be undertaken to quantify the duration and volume of groundwater flooding. This analysis would support a decision as to whether to include groundwater seepage control with overland flood protection.

3.4 COMPARISON OF MODEL RESULTS TO FIELD OBSERVATIONS

The Canadian Creosote Site is a contaminated site located west of downtown and on the right bank of the Bow River. Test holes and/or monitoring wells have been installed at the site to monitor contamination, and to record groundwater levels. AE reviewed the groundwater levels recorded at these monitoring wells during the June 2013 flood event to compare these groundwater levels to modelled groundwater results. The locations of the three monitoring wells are shown in Figure 3-5 in **Appendix A**.

AE noted that the recorded groundwater levels varied significantly between the three monitoring wells. The recorded readings at two of the three wells were lower than the modelled results. This is too limited a data set to validate the groundwater modelling results. However, this indicates that the groundwater inundation mapping developed by AE is either appropriate or slightly conservative. The recorded and modelled groundwater surface elevations are summarized as follows:

Table 3-2
Canadian Creosote Site – Groundwater Levels Review Comparison

Monitoring Well Name	Distance from Top of Riverbank (m)	Groundwater Surface Elevation (m)				
		June 2013 Recorded Level	50 Year Flood, Expected k Scenario	50 Year Flood, High k Scenario	100 Year Flood, Expected k Scenario	100 Year Flood, High k Scenario
MW11-06	115	1046	1049.44	1049.85	1049.67	1050.18
MW94-4	16	1051.25	1050.34	1051.33	1050.85	1051.84
MW10-19	33	1047.2	1049.91	1050.54	1050.07	1051.22

3.5 GROUNDWATER INUNDATION MAPPING

AE utilized the two-dimensional groundwater modelling results to estimate groundwater depths and extents throughout the floodplains in The City for the 20, 50, 100, 200, 350, 500, and 1000 year river levels using advanced GIS techniques. The groundwater model profiles were used to develop surfaces which were compared to existing ground elevations to generate estimated depths of groundwater and extents of groundwater intrusion. These groundwater depths were mapped to identify locations where the groundwater was expected to impact basements[4] and reach the ground surface.

3.5.1 Scenarios

AE created groundwater inundation mapping for two different scenarios:

- **Existing Scenario** - This scenario represented the extents of groundwater inundation without the presence of any proposed overland or groundwater seepage protection. These results were used to estimate the potential groundwater flooding damages which could be incurred in a high river event under existing conditions. This scenario was used to estimate the groundwater flooding damages under existing conditions.
- **Mitigated Scenario** - This scenario represented the extents of groundwater inundation with proposed overland flood protection in place. This scenario was used to estimate potential residual groundwater flood damages with proposed overland flood protection in-place.

AE created groundwater inundation mapping for the expected and high hydraulic conductivity conditions for each of the above noted scenarios for each return period. Groundwater mapping was not developed for the low hydraulic conductivity condition as the model results may underestimate groundwater impacts. After reviewing the inundation mapping, AE and The City agreed to apply the inundation mapping using the expected hydraulic conductivity values identified in Section 3.2.2 to estimate flood damages.

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[4] Basements were assumed to be impacted at a depth of 1.4 m below ground. This is based on the assumption that basements would start to flood when the groundwater level reached 1 m depth on the outside of the foundation wall, and that the basements are typically 2.4 m deep and equipped with sump pumps.

3.5.2 Limitations

The groundwater inundation mapping developed within this Study is intended to be used as a guide to identify areas warranting further investigation. The inundation extents were developed based upon typical stratigraphy, geometry and hydraulic conductivity values and have not been supported with field information or verification. Furthermore, the inundation extents were based upon three typical cross sections for the Bow and Elbow Rivers. The inundation depths and extents could vary significantly when updated with more subsurface data and more representative cross sections along the rivers. AE therefore recommends that The City gather site specific subsurface information and undertake further groundwater modelling where flood protection is being considered.

3.6 GROUNDWATER FLOOD RISK AREAS

AE reviewed the groundwater inundation extents to identify areas at risk due to flooding. All areas were reviewed along the Bow River between the Bearspaw Dam and the southern City limit; and along the Elbow River between the Glenmore Dam and the confluence with the Bow River.

The following sites were assessed to be at risk of groundwater related flooding, and as such were identified to be analyzed for groundwater flood protection through the TBL benefit-cost analysis.

- Bowness North
- Bowness South
- Montgomery North
- Montgomery South
- Crowchild
- Sunnyside
- Bridgeland
- Sunalta
- Downtown
- Fish Hatchery
- Inglewood Golf Club
- Bonnybrook
- Heritage Drive
- Riverbend North
- Quarry Park
- Douglasbank
- Britannia
- Elboya
- Rideau and Roxboro
- Erlton
- Elbow Park South
- Elbow Park North
- 5 Street SW (Mission)
- East Mission
- St. Mary’s High School
- MacDonald Bridge
- Inglewood

Refer to **Appendix E** for a complete set of figures identifying areas vulnerable to groundwater flooding for the 20, 50, 100, 200, 350, 500 and 1000 year return periods. Flood damages (Section 4) and groundwater flood protection designs (Section 5) were developed for each site identified above.

4 Flood Damage Estimation

4.1 SUMMARY

AE estimated flood related damages for use in the TBL analysis. These flood damage estimates included:

- Economic, social and environmental impacts
- Losses incurred for the 1:20, 50, 100, 200, 350, 500 and 1000 year return periods.

Damages averted by proposed flood protection projects were considered to be benefits within the TBL analysis. Averted damages were calculated by subtracting the damages remaining after flood protection projects were constructed (also referred to as residual damages) from the estimated damages under existing conditions. This approach assumes that the proposed flood protection infrastructure would be completely effective and not subject to breach or failure during the corresponding event.

AE estimated damages associated with overland flooding, groundwater flooding and socio-environmental impacts.

4.1.1 Damage Estimates

Overland flooding damage estimates were developed by applying modelled flood depths to depth-damage curves assigned to all affected buildings throughout Calgary.

To estimate damages associated with groundwater flooding, AE used groundwater inundation surfaces developed as part of this Study by applying modelled flood depths to depth-damage curves assigned to all affected buildings throughout Calgary. Damage estimates were developed for the existing condition and a mitigated condition in which there is overland flood protection in place.

4.1.2 Socio-Environmental Factors

Socio-environmental factors included in the analysis were traffic delays due to flooding of roads, aesthetic impacts of proposed flood protection, loss of parkland during construction and indirect damages [5].

The remainder of this section discusses flood damage estimation in greater detail.

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[5] Indirect damages included impacts such as loss of business, administrative costs, loss of profit, inconvenience and costs associated with displacement during and after the flood event.

4.2 DAMAGE ESTIMATES

4.2.1 Flood Inundation Surfaces

The City provided AE with flood mapping inundation surfaces developed in 2015 (Golder Associates, 2015). for areas inundated by overland flooding. Groundwater inundation surfaces were developed by AE in this Study as discussed in Section 3.

4.2.2 Depth-Damage Curves

The City provided AE with depth-damage curves developed as a part of the "*Provincial Flood Damage Assessment Study*" (IBI Group, 2015) that estimate damages per unit area based on flood depth, for various building types, and are separated into structure and content curves. However, these depth-damage curves were not assigned to all buildings considered in this Study. To utilize the depth-damage curves for this Study, AE amalgamated the provided depth-damage curves into residential, commercial and industrial categories which were applied to all properties in the study area. These curves are shown in Figure 4-1.

For groundwater flood damage estimates, AE assumed that basements would be affected by groundwater as it reached 1.4 m below ground and that the maximum depth of groundwater related flooding above ground would be 0.3 m above the main floor elevation of a building. To more accurately estimate the predicted depth of groundwater flooding above surface, a three-dimensional groundwater model would be required.

4.2.3 Damage Calculations

AE evaluated the depth of overland inundation at each property and assigned a corresponding unit area damage from the depth-damage curves. Unit area damages were multiplied by the building floor area to determine overland damages.

Buildings categorized as either garages or out buildings were not assigned depth related damages. Instead, AE assigned a fixed cost of $15,000 for each of these buildings within the inundation extents.

As discussed in Section 3, the lateral extent of groundwater flooding to surface or basements is, in many areas, less than that of overland inundation. In these areas, flood damage would be caused by overland flooding and not groundwater flooding. The properties that were deemed to incur groundwater damages were predominantly in areas of isolated groundwater flooding and along the fringe of the overland inundation extents.

Groundwater damage estimates were calculated for an existing condition, with no overland flood protection and a mitigated condition in which there is overland flood protection in place, to understand the residual flood damage risk after implementing overland flood protection.

4.3 SOCIO-ENVIRONMENTAL DAMAGE ESTIMATES

As part of this study, AE quantified several social and environmental impacts incurred as a result of flooding as well as the implementation of overland flood protection projects, which are discussed in Section 5. The socio-economic factors considered included:

- Indirect damages
- Traffic delays due to flooding or closure of roads
- Aesthetic impacts of flood protection projects impeding a view of the river in both public areas and on private property
- Loss of parkland during construction
- Gain of riparian area through buyouts of private property to accommodate flood protection barriers.

5 Flood Protection Design Approach

5.1 SUMMARY

AE created conceptual level flood protection designs for the communities identified within Sections 2.6 and Section 3.6. This section describes the design approach. These designs were:

- Developed for the 1:20, 50, 100, 200, 250, 500 and 1000 year return periods.
- Completed with cost estimates for use within the TBL analysis.
- Used to inform estimation of socio-environmental impacts of implementing flood protection.

The conceptual designs included overland flood protection, stormwater management to mitigate drainage impeded by overland flood protection, and groundwater seepage control.

5.1.1 Overland Flood Protection

AE considered earth fill dykes, flood walls and semi-permanent barriers for overland flood protection conceptual designs. Earth fill dykes were proposed where space permitted and flood walls were proposed where space was limited. Semi-permanent barriers were proposed in locations where regular access was required through the flood protection. In some locations land acquisition would be required for overland flood protection.

To enable stormwater to discharge to the river while stormwater outfall gates are closed and overland runoff is obstructed by overland flood protection, AE estimated the costs of pump stations to discharge stormwater to the river.

5.1.2 Groundwater Flood Protection

AE considered two different types of permanent groundwater flood protection: seepage collection trenches and cut off walls. For either solution, groundwater pump stations would be required on the land side of the overland flood protection to enable groundwater on the land side to be discharged to the river.

The remainder of this section discusses the design approaches for overland and groundwater flood protection in greater detail.

5.2 OVERLAND FLOOD PROTECTION

5.2.1 Types of Overland Flood Protection

AE considered three different types of overland flood protection within the conceptual designs:

- **Earth Fill Dykes** – Where space permits, these are the most cost-effective type of overland flood protection and have relatively low maintenance costs. Earth fill dykes were proposed as the primary form of flood protection where space was available. They are built with compacted low permeability fill material and can have varying side slopes and crest widths. For the purposes of conceptual design, a standard dyke section was used throughout the study area.
- **Flood Walls** – Where there is insufficient space for an earth fill dyke, flood walls were considered. For the purposes of conceptual design, the flood walls were considered to be cast-in-place concrete with standardized dimensions relative to height. Concrete flood walls are more expensive than earth fill dykes and incur greater lifecycle costs, although these occupy a smaller footprint above ground.
- **Semi-Permanent Barriers** – These are barriers that can be easily deployed in the event of a potential flood but otherwise permit access and regular use of an area. Where overland flood protection is required to cross a road or pathway, and permanent solutions are not feasible, semi-permanent barriers were considered. There are a number of semi-permanent barrier types available which range from traditional stop logs to self-raising buoyant varieties.

5.2.2 Earth Fill Dyke Design

AE developed a standard earth fill dyke cross section for the purposes of the TBL analysis. This standard cross section was developed in accordance with the existing dyke best practices outlined in the following documents:

- "*Dike Design and Construction Guide Best Management Practices for British Columbia*" (Golder Associates Ltd, Associated Engineering British Columbia Ltd., 2003)
- "*Dam Safety Guidelines*" (Canadian Dam Association, 2013).

AE developed the typical dyke cross section with input from Thurber Engineering, considering the typical stratigraphy (Section 3.2.1) and geometry (Section 3.2.3), as well as the need to provide a stable, low permeability barrier. This section is shown in Figure 5-1 in **Appendix A** it includes side slopes of 2.5H:1V and a 3 m wide crest to accommodate maintenance vehicles.

AE proposed dykes such that the slope between the dyke's river side toe and the toe of the river bank was a minimum of 2.5H to 1V. This was done to account for potential stability issues with the river banks.

5.2.3 Flood Wall Design

AE developed a standard cast-in-place concrete flood wall cross section for the purposes of the TBL analysis. This cross section was designed to resist various potential failure mechanisms. The section used within the TBL analysis is presented within Figure 5-2 in **Appendix A**. During preliminary design, various forms of flood walls should be considered to identify the optimal solution for each specific area. Options in addition to a cast-in-place concrete wall include sheet piles, secant piles or the use of precast concrete walls.

AE proposed flood wall alignments such that the slope between the top of wall footing on the river side and the toe of the river bank was 2.5H to 1V. This was done to account for potential stability issues with the river banks.

5.2.4 Flood Protection Alignment Selection

Wherever possible, AE aligned proposed flood protection to avoid conflict with buildings, private property, and utilities and to be situated outside of the Floodway. However, land acquisition, Floodway encroachment and utility relocations would be required in certain situations. When proposing flood protection alignments, AE prioritized impacts as follows:

- Avoidance of existing buildings
- Avoidance of land acquisition
- Avoidance of utility impacts [6]
- Avoidance of Floodway encroachment.

Although new construction within the Floodway is prohibited, The City indicated that flood protection infrastructure could be considered within the Floodway if all other options are impractical, provided the Floodway infringement is minimized and the impacts on water levels can be quantified and mitigated. Quantification of the impacts on water levels was not considered during the TBL analysis. However, the impacts were considered once the level and location of recommended flood protection was selected as part of the refined conceptual designs. The confined flow analysis is discussed in Section 7.4.

Selection of a type of overland flood protection at a particular site was based upon the amount of public land available and the cost of land acquisition. For example, AE selected the most cost-effective option based upon a comparison of the costs of flood walls on public property versus earth fill dykes on private property. The results of the comparison indicated that:

- More cost effective to propose a flood wall on public land than an earth fill dyke on private property where property values were higher than $1,350/m^2.
- More cost effective to propose an earth fill dyke on private property than a flood wall on public property where property values were lower than $1,350/m^2.

Along the Elbow River, there is little space available for overland flood protection where buildings are often a few metres from the bank. Additionally, proposed upstream mitigation measures are expected to significantly reduce design flows on the Elbow River. Specifically, for flood protection along the Elbow River,

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[6] AE assigned a cost associated with each utility crossing for the overland flood protection conceptual designs. The design of the utility relocations required should be performed in preliminary design.

AE only examined flood protection alignments along the river to develop effective and continuous flood barriers.

5.2.5 Backflow Prevention

Stormwater infrastructure can provide a path for rivers to cause flooding by backwatering through storm outfalls. Prevention of backwater through storm outfalls can mitigate this concern. In order to preserve the integrity of the overland flood protection, backflow prevention is required on stormwater outfalls that the flood protection barrier crosses. Two types of backflow prevention were considered and are briefly described below:

- **Slide Gates** - Slide gates prevent backflow by closing the stormwater collection system. Slide gates can be operated manually or electronically. Electronic slide gates can be operated at site or remotely.
- **Flap Gates** - Flap gates prevent backflow through hydraulic pressure on the gate. When river levels rise, the gates close automatically. However, if water levels were to rise on the land side of the overland flood protection, such that they developed a hydraulic pressure greater than the pressure on the river side, the gates would open and allow drainage.

Each system has advantages and disadvantages as described as follows:

Table 5-1
Backflow Prevention

Gate	Pros	Cons
Slide Gate	• Open or closed status of the gate is known.	• Gates must be closed in anticipation of a forecasted high river event which may not actually occur. This gate closure leaves The City at risk of flooding during a rainfall event when the stormwater system is unable to discharge. • Gates require effort to open and close. This effort can be reduced by implementing electronic controls.
Flap Gate	• Gates open and close automatically based on river stage and internal water levels. • No power is required. • Stormwater discharge will occur by gravity whenever internal water levels exceed river levels.	• Gates can get stuck in the open position because of debris, ice or hinge failure and require maintenance and inspection. • Gates can be difficult to maintain if installed in long reaches of pipe.

AE recommends installation of both a slide and flap gate for each outfall to be included as a part of the design for overland flood protection projects. The flap gate will be allowed to operate regularly and the slide gate will be closed for emergencies or maintenance. Refer to Figure 5-3 in **Appendix A** for a depiction of this arrangement.

5.2.6 Erosion Protection

Erosion protection is often required for overland flood protection infrastructure. According to the "*Dike Design and Construction Guide Best Management Practices for British Columbia*" (Golder Associates Ltd, Associated Engineering British Columbia Ltd., 2003), the following hydraulic process can cause erosion of flood protection infrastructure:

- Action of water flow, including frictional erosion due to shear stress, direct impingement flow, eddying due to restrictions in the channel.
- Action of debris floods and debris flows.
- Wave action resulting in wave breaking and overtopping.
- Ice impact.

The two causes from the list noted above that will govern the design of erosion protection in the study area are water flow and ice impact.

5.2.6.1 Water Flow

AE proposed erosion protection for overland flood protection projects based upon the process below and considering the findings of the entitled "*Ice Regime of the Bow River within The City of Calgary, Alberta*" (Northwest Hydraulic Consultants Ltd., 2017) report.

- Determine whether the mean river reach velocity is greater than 2.5 m/s[7].
- Determine whether the overland flood protection is on the outside of a bend or a narrowing of the river. No erosion protection was considered for the insides of bends.
- Calculate the rip rap design velocity. AE assumed it would be 4/3 [8] of the mean river reach velocity.
- Determine the corresponding riprap class from the "*Design Guidelines for Bridge Size Culverts*" (Alberta Transportation, 2004) and the "*Standard Specifications for Bridge Construction*" (Alberta Transportation, 2013).

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[7] 2.5 m/s was based upon British Columbia's "*Chart for sizing rock riprap for bank protection*" (Province of British Columbia, Ministry of Environment, Water Management Branch, 1982)

[8] 4/3 was based upon British Columbia's "*Chart for sizing rock riprap for bank protection*" (Province of British Columbia, Ministry of Environment, Water Management Branch, 1982)

The following table summaries riprap class and its allowable velocity:

Table 5-2
Riprap Class Summary

Riprap Class[9]	Riprap Nominal Diameter mm)	Allowable Velocity (m/s)	Installation Depth (mm)
Class 1	300	3.0	600
Class 2	500	4.0	1000
Class 3	800	4.6	1600

It should be noted that, although other means of erosion protection could be considered, the conceptual level designs and cost estimates are based on the use of riprap. Further consideration for alternate erosion protection options should be considered during subsequent phases of design.

Erosion protection required for the stabilization of the existing river bank was not evaluated as part of this Study. During subsequent design phases the need for erosion protection on existing banks should be considered in areas of proposed improvements.

5.2.6.2 Ice Impact

Northwest Hydraulic Consultants (NHC) developed a report entitled "*Ice Regime of the Bow River within The City of Calgary, Alberta*" (Northwest Hydraulic Consultants Ltd., 2017). Within this report NHC indicated that:

> *It is expected that most ice force concerns will arise in the reaches between Cushing Pool and the Crowchild Trail bridge.*
>
> *The magnitude of these various ice forces scale with the thickness of the thermal ice, and so they will vary from year to year, depending on the severity of the winter. A 20 year ice force is recommended for design, and its application would result in the selection of Class II rock. Regardless, it appears that open water conditions would likely define the size of rock that would be required.*

Based on the analysis described here, a minimum of Class II riprap was proposed where required and the river velocity was assessed to determine if greater protection would be required.

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[9] Riprap class is defined within the "*Standard Specifications for Bridge Construction*" (Alberta Transportation, 2013).[10] Rates were adjusted in accordance to Engineering News-Record's Construction Cost Index (ENRCCI) historical rates. (Engineering News-Record, 2016)

5.2.7 Stormwater Flood Protection

5.2.7.1 Overland Flood Protection Impacts to Local Drainage

Overland flood protection can impede overland drainage paths to the river. Additionally, The City closes stormwater outfall gates to the river in anticipation of a high river level. This is done to prevent high river levels backing up the storm system causing flooding. To enable stormwater to discharge to the river while stormwater outfall gates are closed, AE estimated the costs of pump stations at each affected outfall to discharge stormwater to the river. Flood damages due to local rainfall were not assessed as a part of this Study.

5.2.7.2 Local Runoff Design Storm

For the purposes of this Study, stormwater flooding refers to flooding which occurs during a concurrent river and rainfall event. The probability of these two events happening at once depends on the degree to which these events are independent of each other.

- **Mutual Independence** - Two events are deemed mutually independent when the results of one event has no bearing upon the results of another event.
- **Mutual Dependence** - Two events are deemed mutually dependent when the results of one event dictates the results of another event.
- **Partial Dependence** - Two events are deemed partially dependent when the results of one event has a degree of influence on the results of the next.

The degree of independence between a rainfall and high river event in Calgary has not yet been accurately quantified. This complicates the selection of an appropriate rainfall runoff return period for stormwater management to accommodate overland flood protection.

However, as part of the "*Northwest Inner City Drainage Study – Sunnyside Review*" AE conducted the "*Historical Analysis Revision 1*" (Associated Engineering, 2015). This analysis plotted historical rainfall versus river flow and concluded that, historically, the two events appeared to be mutually independent. It was also found that there were very few combined events within the period of record. Based upon the findings of the historical analysis, The City recommended that a 1:5 year rainfall event should be accounted for in combination with a high river flood event.

This decision was partially based upon the extreme costs to pump and convey stormwater runoff during scenario in which outfall gates were closed. While the capacity of stormwater infrastructure varies around The City, it is typical for the minor system to have a 1:5 year capacity. Proposing a design event higher than the 1:5 year would require conveyance upgrades in addition to pumping infrastructure.

For this Study, a 1:5 year rainfall event was accounted for in conjunction with a high river event.

5.2.7.3 Stormwater Flood Protection Options

Mitigation of flooding from a rainfall event during a high river event is difficult because gravity discharge of runoff to the river is often not possible. When runoff flow to the river is impeded, there are only two means of providing protection against these combined events:

- **Storage** - The volume of rainfall runoff can be stored within ponds, underground facilities or acceptable surface storage.
- **Pumping** - The rainfall runoff can be collected and pumped directly to the river.

The stormwater storage volume required to attenuate the full rainfall volume is unlikely to be available. Therefore, combined river flood-rainfall events must be mitigated to some degree by pumping. Within this Study, pump stations were proposed at each outfall within the inundation extents where overland flood protection was proposed.

5.2.7.4 Stormwater Pump Station Sizing

Drainage pump stations were proposed to be located adjacent to affected outfalls and sized based upon modelled results of the 1:5 year storm of the contributing upstream catchments. AE assumed that 80% of the peak flow would be pumped and that 20% of the peak flow would be stored.

AE recommends that The City perform a more thorough analysis of stormwater management requirements during future design stages.

5.2.8 Limitations

- AE utilized private utility information made available in The City's basemapping. It is possible that additional private utilities exist in proximity to the proposed flood protection barriers. Subsequent design phases should include verification of the presence of existing utilities and liaison with utility owners to verify proximity or crossing agreement requirements.
- Cost estimates for acquisition of private property were calculated by cross referencing the footprint area of the conceptual design against The City's "assessed value" GIS layer. In subsequent phases of design, the feasibility and cost of acquiring a portion of the property requires further investigation. Negotiation costs for land acquisition were not included in the cost estimates.
- AE assumed that a conflict would exist in every instance where the proposed overland flood protection crossed an existing utility. This assumption is likely conservative.
- Environmental compensation (i.e., fish habitat compensation, tree replacement) and taxes are not accounted for in the cost estimates.

5.3 GROUNDWATER FLOOD PROTECTION

5.3.1 Types of Groundwater Flood Protection

The intent of groundwater flood protection is to reduce propagation of groundwater inland during a high river event. Propagation of groundwater could result in seepage into basements and inundation of low lying areas. AE considered two different types of permanent groundwater flood protection within the conceptual designs:

- **Seepage Collection Trenches** – Seepage collection trenches consist of a perforated groundwater conveyance system within a highly permeable collection trench. Perforated pipes would convey captured groundwater to an outfall which would drain by gravity if river levels are sufficiently low, or be pumped back to the river via a pump station while the outfall gates are closed.
- **Cut Off Walls** – Cut off walls consist of a physical barrier to groundwater flow. This barrier could be driven down to bedrock to stop groundwater from propagating inland. However, this barrier would also restrict natural groundwater flow from the land side to the river during non-flood event periods. A collection system on the land side of the wall would be required to convey inland groundwater to an outfall which would drain by gravity if river levels are sufficiently low or be pumped back to the river via a pump station while the outfall gates are closed. For this solution, the collection system and groundwater pumping stations would be smaller than those required for the seepage collection trenches as only the inland groundwater would need to be pumped.

5.3.2 Flood Protection Design

Seepage collection trenches and cut off walls were modelled within SEEP/W.

5.3.2.1 Seepage Collection Trench Infiltration

A SEEP/W model was developed with typical stratigraphy, cross sections and hydraulic conductivity for three river reaches described in Section 3. As a part of the seepage collection trench model, the trench was modelled with a free outfall to represent pumping of flow as required. Flow into the trench was estimated per linear metre and used spatially to determine the required conveyance and groundwater pumping capacity.

Iterative modelling revealed that the flow per linear metre was highly dependent on the depth of trench, trench location relative to the river, hydraulic conductivity of the soils, and the driving head into the trench. The actual infiltration rates also vary depending on the trench alignment, local topography and stratigraphy.

5.3.2.2 Cut Off Walls

A SEEP/W model was developed with typical stratigraphy, cross sections and hydraulic conductivity for each of three river reaches as identified in Section 3. A cut off wall was introduced to the model to reduce groundwater propagation from the river. Cut off walls were modelled with depths of 2, 4 and 6 m with the 6 m depth representing a cut off wall installed down to bedrock.

Iterative modelling revealed that the cut off wall had little to no effect in mitigating river related groundwater unless it was extended down to bedrock. The highly permeable sand/gravel layer allowed significant propagation of groundwater under the cut off wall. In this case, the phreatic surface would eventually balance on either side of the cut off wall. Cut off walls extending to bedrock would greatly reduce groundwater migration; however, leakage through the cut off walls would have to be determined and managed on a case by case basis.

5.3.3 Groundwater Flood Protection Alignment

The proposed seepage collection trenches would be located adjacent to the proposed overland flood protection where possible. Cut off walls would be located directly under the overland flood protection.

Given that land acquisition was already considered within the overland flood protection cost estimates, no additional land acquisition cost was considered for seepage collection trenches or cut off walls.

5.3.4 Pump Station Sizing and Locations

Where possible, pump stations would be located every 100 m behind either the cutoff wall or seepage collection trench to limit the required pumping capacity at each location. The required pumping capacities are much larger for seepage collection trenches than for cut off walls. As such, AE assumed that pump stations for cut off walls could be incorporated into the land requirements for the overland flood protection. For seepage collection trenches, given the required larger pumping capacities, AE identified land requirements for pump stations. Where possible, AE proposed these pump stations to be located adjacent to overland flood protection on public land. Where land acquisition would be required, AE proposed a property buyout to accommodate the pump station.

5.3.5 Limitations

- AE estimated supply and installation costs per linear metre of cut off wall assuming a depth of 7 m, representing a 1 m embedment into bedrock. Costs associated with utility relocations were included within the unit rate of the cut off wall.
- The groundwater collection system behind the proposed cut off walls was sized with limited information, as modelling of non-flood period groundwater flows was not within the scope of this Study. AE assumed that a 450 mm perforated pipe would be adequate to convey inland groundwater flows and pump stations were sized to accommodate the flow that could be conveyed in these pipes. These requirements should be confirmed on a site specific basis in future designs.

5.4 CONSTRUCTION AND LIFE-CYCLE COST ESTIMATES

Cost estimates were developed for each conceptual design. Cost estimates are Class 5 in accordance with The City's "*Estimation & Contingency Standard*" (City of Calgary, 2012). These are included with the TBL results, further discussed in Section 6.

Cost estimates were prepared for each proposed pump station based upon a high-level pumping capacity vs. cost graph. The curves were initially obtained from "*Pumping Station Design Revised 3rd Edition*" (Jones, Sanks, Tchobanoglous, & Bosserman II, 2008) and modified to 2016 costs[10]. The curve was validated by capacities and cost estimates of reference projects. AE, in conjunction with The City, selected the average cost curve on the graph to estimate costs for the drainage pump stations. Refer to Figure 5-4 in **Appendix A**.

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[10] Rates were adjusted in accordance to Engineering News-Record's Construction Cost Index (ENRCCI) historical rates. (Engineering News-Record, 2016)

6 Triple Bottom Line Analysis

6.1 SUMMARY

A TBL analysis includes considerations for economic, social and environmental impacts. The purpose of this TBL analysis was to evaluate the benefits and costs of proposed flood protection projects considering the three aspects of the Triple Bottom Line. From this analysis, the optimal level of service at each site was determined and proposed improvements were able to be prioritized by understanding which improvements provide the best value relative to the cost of implementation. The benefits associated with a given flood protection improvement project were calculated to be the damages that the improvement project mitigates.

This section covers the development of the TBL analysis including the organization, calculations and interpretation of the results.

6.1.1 Organization

A separate TBL analysis was completed for each site. Inundation areas that are delineated at certain return period events may combine at higher flood levels. As a result, the estimated damages and costs for these sites are separate for low magnitude flood events, but are combined at higher magnitude flood events. The TBL analysis was organized to account for combination of flood extents.

6.1.2 Calculations

The TBL analysis required several calculations to estimate the average annual damage flood risk, determine the lowest river level at which flooding initially occurs and interpolate cost estimates for flood protection levels at which conceptual designs were not generated.

6.1.3 Interpretation of TBL Results

The results of the TBL analysis are presented in numerous graphs and tables which should be considered together when evaluating a particular site. The results are sensitive to variations in the upstream flow attenuation and the discount rate applied to future predicted flood damages.

The remainder of this section discusses the TBL analysis, the results and the findings in greater detail.

6.2 ORGANIZATION

6.2.1 Site Combinations

Flood protection sites were roughly delineated based upon overland inundation extents at the 1:100 year return period. However, there are cases in which multiple sites combine at return periods greater than the 1:100 year return period. Where that occurred, AE evaluated the results for those sites together for those particular river flood elevations. These site combinations also considered the ability of The City to install temporary barriers to maintain site delineation for higher return periods than would naturally occur.

There are three instances where sites were artificially separated even though the flood extents identified a site would become hydraulically connected. These three exceptions were made to simplify the TBL analysis. The three exceptions are:

- **Bow and Elbow Rivers** - The inundation extents for the Bow and Elbow Rivers combine at the 1:100 year return period just west of the Inglewood Bridge. Analyzing the Bow and Elbow Rivers combining would significantly complicate the TBL analysis without providing additional benefit. Therefore, AE, in agreement with The City, separated these sites for this analysis.
- **Elbow River between Sifton Boulevard and 9 Avenue SE** - The inundation extents along the left bank of the Elbow River combine at the 1:50 year return period and span a distance between Sifton Boulevard and 9 Avenue SE. However, the inundation extents narrow significantly west of 5 Street SW. Allowing all of the left bank of the Elbow River to combine would complicate the TBL analysis without providing additional benefit. Therefore, AE, in agreement with The City, separated these sites at this location for this analysis.
- **Mission/Stampede Park** - A large overland flow path between Mission and Stampede Park develops beginning at the 1:100 year return period. This overland flow path causes the Mission 5 Avenue Site and the Stampede Park site to combine. The City requested that for this analysis the Mission 5 Avenue site be evaluated independently, but that Stampede Park be evaluated as if the sites were combined.

Groundwater inundation extents often follow the overland inundation extents. However, in some cases groundwater inundation extents would not combine at the same return periods as overland inundation extents. Therefore, AE created separate site combinations for groundwater inundation.

6.2.2 TBL Scenarios

A TBL analysis was conducted evaluating the benefits and costs of implementing flood protection for each of six different TBL scenarios:

1. Overland flood mitigation.
2. Overland flood mitigation with residual groundwater flood damages.
3. Overland flood mitigation including stormwater flood mitigation with residual groundwater flood damages.

4. Groundwater flood mitigation assuming overland flood mitigation is in place.
5. Overland and groundwater flood mitigation.
6. Overland and groundwater flood mitigation including stormwater flood mitigation costs.

The purpose of the TBL scenarios was to isolate impacts to understand what factors are contributing to costs and benefits. The components that were included in each scenario are summarized as follows:

Table 6-1
TBL Scenarios

Scenario	Benefits						Costs					
	1	2	3	4	5	6	1	2	3	4	5	6
Overland Flooding Damage Estimates	x	x	x		x	x						
Existing Condition Groundwater Flooding Damage Estimates		x	x		x	x						
Mitigated Condition Groundwater Flooding Damage Estimates				x				x	x			
Socioenvironmental Damage Estimates	x	x	x		x	x						
Overland Flooding Protection Cost Estimates							x	x	x		x	x
Groundwater Flooding Protection Cost Estimates										x	x	x
Stormwater Flooding Protection Cost Estimates									x			x

6.3 CALCULATIONS

The following section describes the calculations and assumptions within the TBL analysis.

6.3.1 Integration

Flood damages are predicted to occur with a certain magnitude and frequency. To estimate the predicated average annual damage risk, AE integrated under a damage/probability curve using the backwards trapezoidal method.

6.3.2 Lowest Return Period of Flood Damage

The estimated average annual damages are sensitive to the identification of the lowest return period at which flood damage occurs. Refer to Figure 6-1 in **Appendix A** which shows the area below the curve at two different zero damage return periods. To identify this return period, AE calculated the elevation at which damages would first occur at each site. AE then estimated the return period associated with this elevation through linear interpolation.

6.3.3 Net Present Value of Future Predicted Impacts

The TBL analysis was conducted in present day dollars. This was necessary to evaluate immediate capital expenses against the life-cycle benefits and costs of the project. The overland and groundwater damages, and traffic delays were converted from average annual damages to a Net Present Value (NPV) based on the predicted frequency of various flood events and a selected discount rate.

The results of the net present value calculation are highly sensitive to the selected discount rate. In some cases, sites will be cost beneficial under the 0% discount rate and not cost beneficial under the 5% discount rate. The City selected the use of a 2.5% discount rate for the TBL analysis and requested that the 0% and 5% discount rates be used to depict the sensitivity of the results to variation in this parameter.

6.3.4 Interpolation of Cost Estimates

AE did not estimate flood protection cost estimates for all return periods. Cost estimates were linearly interpolated between bounding return period estimates. The cost estimates were extrapolated upwards using a line of best fit as shown on Figure 6-2 in **Appendix A**.

6.3.5 Updated Hydrology and Flood Frequency Equivalencies

AE initiated this Study utilizing the hydrology developed prior to the 2013 flood. During this Study, The City provided updated hydrology for the conditions following the 2013 flood. Following this, The City provided information on conditions considering future flow attenuation upstream of Calgary. To make use of the design work completed with the outdated hydrology in both instances, AE estimated the equivalent return periods between the three different hydrology calculations. The following table depicts the hydrology information that was referenced:

Table 6-2
Hydrology and Hydraulic Studies

Set	Hydrology Study	Hydraulic Study
Pre 2013 Hydrology/Hydraulic Study	*Bow and Elbow River Updated Hydraulic Model Project - Hydrology Study* (Golder Associates, 2010)	*Bow and Elbow River Updated Hydraulic Model Project - Hydraulic Modelling and Inundation Mapping* (Golder Associates, 2012)
Post 2013 Hydrology/Hydraulic Study	*Basin-Wide Hydrology Assessment and 2013 Flood Documentation* (Golder Associates, 2014)	*Hydraulic Model and Flood Inundation Mapping Update* (Golder Associates, 2015)
Attenuated Flows	(City of Calgary, 2016)	

6.3.5.1 Pre 2013 to Post 2013 Equivalencies

The Post 2013 Hydrology/Hydraulic Studies resulted in a significant increase in flows and inundation extents compared to the results of the Pre 2013 Studies.

6.3.5.2 Post 2013 to Attenuated Equivalencies

The City requested that AE consider the impacts of the Springbank Off-Stream Flood Storage Site[11] and use of the Ghost Reservoir for flow attenuation within the TBL analysis. While not a conventional hydrology study, these projects provide significant upstream attenuation, and alter the downstream hydrology in the Bow and Elbow Rivers. A site designed to the 1:100 year return period from the 2014 and 2015 (Table 6-2) studies would provide a higher level of service when considering the upstream flow attenuation. Providing upstream storage would significantly lower the benefit/cost ratios of local permanent barriers within the TBL analysis as the areas would be predicted to experience flooding on a less frequent basis.

To date, updated inundation extents have not been developed for the scenario that includes upstream attenuation. Therefore, AE modified the 2015 HEC RAS model to reflect anticipated flow conditions based on expected attenuation, as provided by The City and noted in Table 6-3.

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[11] Refer to Appendix G of the "*Flood Mitigation Measures for the Bow, Elbow and Oldman River Basins*" report (AMEC Environment & Infrastructure, 2014).

Table 6-3
Peak Discharges along the Bow and Elbow Rivers Including Effects of the Springbank Off-Stream Storage Reservoir and Attenuation in the Ghost Reservoir

No.	River	Description	Flood Discharge												
			(m^3/s)												
			2 year	5 year	8 year	10 year	20 year	35 year	50 year	75 year	100 year	200 year	350 year	500 year	1000 year
1	**Bow River**	Downstream of Bearspaw Dam	369	378	400	415	640	946	1,222	1,520	1,744	2,280	2,627	2,864	3,340
2	**Bow River**	Downstream of Elbow River	433	521	570	585	810	1,116	1,392	1,690	1,914	2,709	3,506	4,013	5,080
3	**Bow River**	Downstream of Nose Creek	439	535	590	605	850	1,166	1,452	1,760	2,004	2,839	3,676	4,223	5,390
4	**Bow River**	Downstream of Fish Creek	478	621	680	745	1,050	1,396	1,772	2,130	2,454	3,459	4,536	5,173	6,690
5	**Bow River**	Downstream of Pine Creek	482	634	700	765	1,080	1,426	1,812	2,170	2,494	3,509	4,606	5,243	6,770
6	**Elbow River**	Downstream of Glenmore Dam	63.9	143	170	170	170	170	170	170	170	429	879	1,149	1,740

6.3.5.3 Limitations

Below are key assumptions AE incorporated into the modelling of the attenuated flows:

- AE assumed that the flow in the Bow River downstream of the Elbow River would be the sum of the flow in the Elbow River and the flow in the Bow River upstream of the Elbow River. Other inflows at Nose Creek, Fish Creek and Pine Creek were assumed to remain unchanged due to upstream attenuation.
- AE assumed that no damages would occur on the Elbow River during flow rates at or less than 170 m^3/s.
- AE assumed that the diversion capacity of the Springbank Off-Stream Reservoir would be 480 m^3/s.

6.4 TBL ANALYSIS RESULTS

The TBL results encompass a significant amount of information. Interpretation of this information should be conducted while considering all relevant information and scenarios for each site. The TBL Analysis results are located in appendices noted in Table 6-4.

Table 6-4
TBL Information Summary

Name	Description	Location
TBL Site Write-ups	Contains information on each site including interactions with existing infrastructure	Appendix G
TBL Graphs	Contains the TBL Graphs	Appendix H
TBL Graph Tables	Contains the tabular values for the TBL Graphs	Appendix H
TBL Component Tables	Contains detailed information regarding the values of each of the TBL components	Appendix H
TBL Summary Tables	Contains a summary of the Benefit/Cost ratios for each site	Appendix I
Attenuated TBL Summary Tables	Contains a summary of the Benefit/Cost ratios for each site under attenuated flow conditions	Appendix I
TBL Summary Tables - Discount Rate Sensitivity	Contains a summary of the Benefit/Cost ratios for each site under 3 varying discount rates: 0%, 2.5% and 5%	Appendix I

The TBL analysis findings were presented to and reviewed with The City in 2016.

The TBL analysis demonstrated that implementing permanent flood protection barriers in Calgary is technically feasible but costly as depicted in Figure 6-3. The barriers also require significant additional investment to protect from groundwater and stormwater flooding. Not only are the barriers financially expensive, there are large social and environmental costs. The flood barriers could obstruct river views and require easements over private land.

The TBL analysis indicated that some of the proposed local flood protection barriers with the highest benefit/cost ratios include Sunnyside, Inglewood, Downtown and Bowness. The analysis also revealed that neither groundwater nor stormwater flood protection is cost-beneficial, with the exception of a few locations.

The City incorporated the analysis performed in this Study into an overall flood protection strategy.

6.5 RECOMMENDATIONS FROM CITY FLOOD PROTECTION STRATEGY

The findings of this Study were incorporated into the Flood Mitigation Measures Assessment (FMMA) conducted by The City. The FMMA assessed the benefits of flood mitigation upstream of Calgary, as well as within The City. The FMMA recommended the following:

- Support flood mitigation upstream of Calgary including The Province’s Springbank Off-stream Reservoir project for the Elbow River as well as the continuation of the Provincial TransAlta operational agreement and a new reservoir for the Bow River.
- Develop and implement a funding plan for local flood mitigation including permanent flood protection barriers that will complement an upstream reservoir and provide shorter term protection for communities at the greatest risk. The areas at greatest risk are Bowness, Sunnyside, Downtown and the Fish Hatchery. These barrier projects are referred to as “Complementary Barriers”.

7 Refined Conceptual Design Approach for Complementary Barriers

7.1 SUMMARY

This section describes the approach used to refine the conceptual designs for the selected complementary barriers.

7.1.1 Level of Service for Selected Sites

In accordance with the recommendations from the FMMA, conceptual flood protection designs for the complementary barriers were refined to generate Class 4[12] cost estimates as opposed to the Class 5 estimates generated and applied in the TBL assessment. The refined conceptual designs take flood mitigation from the proposed Springbank Off-stream Reservoir project and operational changes made by TransAlta at the Ghost Reservoir into consideration.

The following levels of service were selected by The City for conceptual design:

- Overland flood protection for the Bowness site to the 1:20 year level or a river flow of 1230 m^3/s
- Overland flood protection for the Fish Hatchery site to the 1:75 year level or a river flow of 2241 m^3/s
- Overland flood protection for the Downtown site to the 1:200 year level or a river flow of 2390 m^3/s
- Overland and groundwater flood protection for the Sunnyside site to the 1:20 year level or a river flow of 1230 m^3/s.

All of the above noted designs also include an additional 0.5 m of freeboard.

7.1.2 Barrier Expansion

AE undertook a conceptual investigation into the feasibility of expanding the level of overland flood protection for the Bowness, Sunnyside and Fish Hatchery Sites in the future. The analysis considered the implications of expanding an earth fill dyke or flood wall after it is initially constructed. This exercise was intended to provide The City with flexibility to adapt to the potential effects of climate change or decisions not to proceed with flood mitigation upstream of Calgary.

7.1.3 Confined Flow Analysis

AE updated The City's hydraulic model to reflect the selected, proposed flood protection barrier projects to determine the resulting increase in flow depths on the Bow River. AE used the results of this analysis to determine the appropriate elevations for flood protection.

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[12] According to The City's "Corporate Project Management Framework Estimation & Contingency Standard" (City of Calgary, 2012).

7.1.4 Design Adjustment for Upstream Flow Attenuation

AE considered a scenario with upstream flood mitigation when identifying the required length and height of flood protection. This attenuated flow scenario significantly reduced flows along the Elbow River and reduced the extents of flood protection required for the Downtown site.

The remainder of this section discusses the refined conceptual design approach in greater detail.

7.2 SITE SELECTION AND LEVEL OF SERVICE

As discussed in Section 6.5, the FMMA recommended that The City implement permanent flood protection barriers at the four complementary barriers, Bowness, Sunnyside, Downtown and Fish Hatchery. The City instructed AE to refine the conceptual designs of the four complementary barriers and provide the following level of service at each site.

Table 7-1
Complementary Barrier Locations and Proposed Levels of Service

Site	Overland Flooding Level of Protection	Groundwater Flooding Level of Protection
Bowness	1:20 year	N/A
Sunnyside	1:20 year	1:20 year
Downtown	1:200 year	N/A
Fish Hatchery	1:75 year	N/A

7.3 FUTURE BARRIER EXPANSION

The design of the complementary barriers included consideration for future expansion. AE examined the impacts of expanding flood protection through the raising of an earth fill dyke, raising of a flood wall and installation of a retained dyke. These measures provide The City with flexibility given the uncertainty associated with implementation of the upstream flood mitigation solutions and the potential effects of climate change on river levels.

7.3.1 Earth Fill Dyke Expansion

Earth fill dykes can be expanded relatively easily by building up the original dyke structure to a higher elevation. This does not require any expandability design considerations at the time of original construction. To maintain the original 2.5:1 dyke side slopes that AE recommends, raising a dyke would also require a horizontal expansion. A horizontal expansion could extend from either side of the dyke, however, if possible, AE recommends expanding dykes to the land side to avoid further confining river flow and to avoid disturbing any existing erosion protection measures on the river side of the dyke. This horizontal expansion may require additional incidental costs such as private property purchase, tree removals, pathway relocations and stormwater drainage improvements. Refer to Figure 7-1 in **Appendix A** for a typical detail of an earth fill dyke expansion.

7.3.2 Flood Wall Expansion

Flood wall expansion is more challenging than dyke raising, as the flood wall footings are designed based on the height of a flood wall. A flood wall that is constructed without expandability considerations could not be raised to a higher design level without improvements to the flood wall footings. If it is likely that a proposed flood wall will be raised in the future, AE recommends that the wall footings be designed to the ultimate requirements initially, even if the initial wall height is lower than the ultimate elevation. This would result in an overall cost savings and the expansion would require less working area and disturbance to accommodate the expansion. Refer to Figure 7-2 in **Appendix A** for a typical detail of a flood wall expansion.

7.3.3 Expansion Using Retained Dykes

In some locations, it may not be possible to expand a dyke beyond its original footprint. In these cases, installing retaining walls to reduce the horizontal footprint of the dyke could be considered. Refer to Figure 7-3 in **Appendix A** for a typical detail of a dyke expansion with lock block retaining walls.

7.4 CONFINED FLOW ANALYSIS

The proposed barriers will prevent flooding but also constrict the flow of the Bow River. This confined flow will cause the water surface elevation to rise higher than without the barriers in place. A confined flow analysis was conducted such that the refined conceptual designs would consider these water surface elevation increases.

AE updated The City's HEC-RAS model to reflect the proposed designs. The proposed flood protection barriers were modelled as levees which were aligned with the river side toe of the proposed dyke. The modelling results are:

Table 7-2
Confined Flow Modelling Results

Site	Modelling Result
Bowness	Increased WSEL between 1 and 8 cms.
Sunnyside	Increased WSEL between 1 and 2 cms.
Downtown	Refer to text below.
Fish Hatchery	No Increase in WSEL.

It should be noted that the confined flow analysis adjacent to the Downtown site was particularly sensitive to the levee and ineffective flow area locations within the models. This sensitivity is because the Bow River diverts around Prince's Island adjacent to the proposed barriers within West Eau Claire Park. The City's hydraulic model is sensitive to the effective flow width within the first cross sections of the individual channels. Constricting the flow within Prince's Island Lagoon can greatly decrease the flows within the lagoon and increase the flows within the main channel. The flows within the channels are further complicated by transverse flow over Prince's Island. These flows have been estimated within the "*Hydraulic Assessment of Bow River Flood Levels near Prince's Island*" (Matrix Solutions Inc., 2016).

The modelling results generally indicated that flow depths increased upstream of the barrier constriction and decreased slightly downstream of the constriction. Refined designs included the following dyke elevation increases:

Table 7-3
Proposed Dyke Elevation Increases

Site	Proposed Dyke Elevation Increase
Bowness	10 cm
Sunnyside	5 cm
Downtown	10 cm
Fish Hatchery	0 cm

7.5 BACK FLOODING ANALYSIS

An attenuated flow scenario on the Bow and Elbow Rivers was analyzed to account for flow reductions because of the Springbank Off-Stream Reservoir and the TransAlta Ghost Reservoir flow modifications. The effects of attenuation on Elbow River flows are significant. The hydraulic grade line decreases on the Bow River from slightly upstream of the Elbow River confluence to The City limits. This reduction is due to the reduced flows in the Elbow River. This decrease in hydraulic grade line at the confluence affects the required flood protection length at the Downtown site.

In a scenario where upstream flows are not attenuated, flooding at the 1:200 year level would impact Mission and proceed along the rail lines south of Fort Calgary. This flooding could compromise Downtown if not addressed.

With flows attenuated upstream of The City, the 1:200 year river level would overtop between West Eau Claire Park and the Reconciliation Bridge. This has been illustrated within Figure 7-4 in **Appendix A**. The attenuated flow scenario was considered for the refined conceptual designs, reducing the required length of flood protection required at the Downtown site.

8 Complementary Barriers - Refined Conceptual Designs

8.1 BOWNESS

The Bowness site is located on the right bank of the Bow River, and extends between Bow Village Crescent NW and River Valley School. Flood protection at this location would be designed to protect to the 1:20 year river level, with 0.5 m of freeboard. Most of the flood protection at this site would consist of an earthen dyke constructed in private property, through the backyards of riverfront homes. The design figures and cost estimate breakdowns for this site are included in **Appendix J**.

A major consideration for the design of this site was to include access for maintenance as the flood protection is proposed to traverse the backyards of private residences. AE recommends that land for the flood protection be protected with an easement or right-of-way to prevent unintended alterations to the flood protection. AE also recommends including a minimum of two access routes for each section of flood protection for maintenance and repair. This would allow for access from both sides in the event of a dyke breach, and would reduce the amount of reversing required by maintenance vehicles accessing the dyke.

To reduce the amount of private property acquisition required and to make the proposed land acquisition more amenable to residents, AE aligned the flood protection as close to the river as possible considering the parameters identified in previous sections. AE also proposed dykes instead of flood walls wherever possible to minimize construction costs. The alignment was designed to avoid all houses and garages. However, four small outbuildings conflict with the proposed design and would need to be removed or relocated.

At River Valley School, AE proposed installing a flood wall along the alignment of the existing school fencing to minimize impacts to the school fields. The required height of the flood wall in this area is between 0.4 – 0.8 m, so fencing will need to be installed on top of the proposed flood wall for safety purposes.

Due to the cost associated with obtaining a right of way through riverfront properties, the proposed land acquisition width is limited to what is required for the 20 year return period design. Expanding the dykes to a higher level of protection in the future would require the purchase of additional land, or the expansion of flood protection using retained dykes. The City could elect to reduce the crest width of the dykes. This would reduce land acquisition costs, but would limit maintenance access on the dykes.

The capital cost estimate for this flood protection barrier is $24.6 Million and includes an assumed cost for land acquisition.

AE did examine an alternative flood protection alignment along Bow Crescent NW. A flood protection barrier along this alignment would not protect homes along the river from river flooding. The barrier along this alignment would consist of a concrete flood wall along the centre of the road. Where the proposed flood wall would cross streets, it would limit vehicle access to those streets as they could not cross the barrier.

Alternatively, a semi-permanent barrier could be used to permit left turns from vehicles. There would be a semi-permanent barrier required across the westbound lane of Bow Crescent NW west of Bowness Road NW as the barrier would tie into high ground north of the road. This alignment would pose several constructability challenges. It would restrict emergency vehicle access along Bow Crescent NW due to the narrowed road width and require elimination of street parking in proximity to the barrier. This alignment would also require relocation of a sanitary trunk and leave little room within the road to realign it. This option was not deemed to be desirable because of the noted challenges and because it would not protect homes immediately adjacent to the river eliminating much of the benefit of the flood protection.

8.2 SUNNYSIDE

The Sunnyside site is located on the left bank of the Bow River, and extends between the Peace Bridge and the existing flood protection constructed as part of the bank restoration work completed east of Centre Street N. Flood protection at this site is proposed to protect to the 1:20 year river level, with 0.5 m of freeboard. Flood protection at this site would require the construction of earthen dykes and flood walls along the existing public pathway system south of Memorial Drive NW. The design figures and cost estimate breakdowns for this site are included in **Appendix J**.

There is an old existing berm constructed along the proposed alignment for this site. AE completed a condition assessment of this berm and noted that it does not meet proposed dyke design criteria, but that it also has not failed to date and the composition of the berm is unknown. For the proposed flood protection in this area, AE assumed that the berm is suitable to serve as the base for a new dyke. AE recommends geotechnical assessment of the berm to confirm its suitability prior to proceeding with preliminary design. Within the cost estimate, AE included an allowance for potential modifications to the existing berm. If the berm is found to be completely unsuitable as a base for the proposed dyke, the cost of flood protection at this site would significantly increase.

There is a pedestrian bridge that connects between Prince’s Island Park and Sunnyside, which is located between 3 Street NW and the Calgary Curling Club. At this bridge, there is a stone block retaining wall that runs parallel to the pathway system south of Memorial Drive. AE proposed to replace this existing retaining wall with a flood wall, which would minimize alterations to the pathway system in the area. Installing flood wall footings in this area will be difficult as the site is constrained. AE recommends that the flood wall footings be constructed to suit a wall elevation for a higher return period. This should simplify the work required to implement future expansion of the flood wall if it is ever required.

Groundwater protection for the site entails a seepage trench system running along the length of the site, and connecting to the stormwater pump stations proposed for the community. Initial groundwater modelling determined that the seepage trench would need to extend from west of 10A Street NW to east of the pedestrian bridge. However, the groundwater modelling was conducted assuming a typical soil composition for the Bow River upstream of the Elbow River. AE recommends that The City conduct additional groundwater modelling for Sunnyside, based on site-specific geotechnical data, before advancing design of groundwater flood protection for the site.

The capital cost estimate for the overland flood protection barrier at this site is $8.2 Million which includes an allowance for modifications to the existing berm to accommodate the proposed barrier.

The capital cost estimate for groundwater flood protection at this site is $4.7 Million.

8.3 DOWNTOWN

The Downtown site is located on the right bank of the Bow River between the proposed West Eau Claire Park flood protection and Reconciliation Bridge. Flood protection at this site was designed to protect to the 1:200 year river level, with 0.5 m of freeboard. Flood protection at this site is proposed to include a mix of flood walls, dykes, and retained dykes constructed along the public pathway system adjacent to the river. At the Centre Street Bridge, the design connects with flood protection The City is implementing across the bridge. The design figures and cost estimate breakdowns for this site are included in **Appendix J**.

AE determined the downstream extents of this site by modelling the Bow and Elbow Rivers with the reduced flood flows expected as a result of proposed upstream mitigation on the Elbow River. AE noted that with upstream attenuation, downstream flood extents at the site do not extend beyond Reconciliation Bridge.

The public pathway system in this area contains some of the most well used pathways in the city. AE proposed flood protection solutions at this site that would not require reducing the width or number of pathways in this area. To maintain access to the river and pathway system from Downtown, AE proposed multiple self-raising barriers across the proposed flood protection. In Eau Claire, there is a large plaza area which is often used for events. AE proposed installing the footings for a stop-log system across this area, which would avoid impacting the plaza area outside of flood events.

A major consideration for the design of this site was to avoid private property completely, due to the high cost and low availability of land in this area. AE also avoided impacting the RiverWalk pathway system, due to the expensive surface treatments used in the construction of the pathways. During a site visit, AE observed an oil-grit separator and two large underground electrical vaults adjacent to the river. AE designed the flood protection for this site to avoid these structures.

The capital cost estimate for this overland flood protection barrier $14.9 Million for the area west of the Centre Street Bridge and $10.7 Million for the area east of the Centre Street Bridge.

8.4 FISH HATCHERY

The Fish Hatchery site is located on the right bank of the Bow River in Pearce Estates Park, and extends from the CP Rail line adjacent to the Bow Habitat Station and 17 Avenue SE. Flood protection at this site was designed to protect to the 1:75 year river level, with 0.5 m of freeboard. Proposed flood protection at this site includes an earthen dyke constructed in the park, with a public pathway along its crest for portions of the design. The flood protection will be incorporated in the upcoming Bend in the Bow project, which involves improvements to Pearce Estate Park. The design figures and cost estimate breakdowns for this site are included in **Appendix J**.

AE designed the flood protection alignment to follow the current alignment proposed in the Bend in the Bow project. As the proposed design incorporates public pathways, AE incorporated City of Calgary pathway specifications for pathway widths, bend radii, and maximum grades into the flood protection design. At three locations, pathways would intersect the proposed dyke and need to be regraded to connect to the elevated pathway on the dyke crest.

At the upstream end of the design, the proposed dyke connects to the existing CP Rail embankment, which is higher than the proposed dyke crest. The CP Rail embankment is constructed with gravel and is likely highly permeable. Improvements to the embankment will likely be required at this tie-in for the proposed dyke. The cost estimate includes an allowance for the work required at the CP Rail embankment. The actual costs for this work should be verified in preliminary design through consultation with CP Rail.

The capital cost estimate for this overland flood protection barrier is $4.1 Million and includes an allowance for treatment of the CP Rail embankment and costs for the flood protection work. This estimate does not include costs for surface restoration as that is expected to be included in the Bend in the Bow project.

8.5 SUMMARY OF LOCAL FLOOD PROTECTION REQUIREMENTS

The following table summarizes the recommended local flood protection measures at the complementary barrier sites:

Table 8-1
Recommended Local Flood Protection Measures at Complementary Barrier Sites

Site	Overland Flood Protection Length (m)				Groundwater Flood Protection Seepage Trench Length (m)	Capital Cost Estimate
	Earth Fill Dyke	Flood Wall	Semi-Permanent Barrier	Total		
Bowness	2810	206	0	3016	N/A	$24.6 Million
Sunnyside	458	195	0	653	1800	Overland: $8.2 Million Groundwater: $4.7 Million
Downtown West	137	431	58	626	N/A	$14.9 Million
Downtown East	444	288	44	776	N/A	$10.7 Million
Fish Hatchery	564	0	0	564	N/A	$4.1 Million

9 Recommendations

9.1 RECOMMENDED LOCAL FLOOD PROTECTION MEASURES

The following table summarizes the recommended local flood protection measures:

Table 9-1
Recommended Local Flood Protection Measures

Site	Proposed Level of Service	Overland Flood Protection Length (m)	Groundwater Flood Protection Seepage Trench Length (m)	Capital Cost Estimate
Bowness	1:20 year	3016	N/A	$24.6 Million
Sunnyside	1:20 year	653	1800	Overland: $8.2 Million Groundwater: $4.7 Million
Downtown West	1:200 year	626	N/A	$14.9 Million
Downtown East	1:200 year	776	N/A	$10.7 Million
Fish Hatchery	1:75 year	564	N/A	$4.1 Million

9.2 FUTURE WORK TO SUPPORT LOCAL FLOOD PROTECTION IMPLEMENTATION

9.2.1 Geotechnical Field Investigation of the Sunnyside Berm

AE recommends that The City undertake geotechnical investigation of the Sunnyside Berm prior to implementing improved flood protection in the area. The results of this investigation should inform the design, and whether or not the existing berm can be constructed upon.

9.2.2 Update Groundwater Modelling and Inundation Mapping

The groundwater modelling and inundation mapping conducted as part of this Study was based upon a simplified approach and was broadly conducted across the entire City. Typical cross sections were determined and used to represent entire reaches of the Bow and Elbow Rivers. As such, this analysis did not include site specific stratigraphy and channel geometry. Variation within the predicted hydraulic conductivity or the presence of confined aquifers or paleo-channels could significantly impact the anticipated inundation extents. Furthermore, the analysis does not include groundwater movement contributing from upland areas.

The groundwater modelling and inundation mapping identified the potential for groundwater flooding in the community of Sunnyside. Therefore, AE recommends development of a three-dimensional groundwater model for Sunnyside. The three-dimensional model would allow understanding of spatial variability of parameters such as hydraulic conductivity, lithology and storativity. The results of the model would yield a more accurate representation of groundwater conditions and a better estimation of storage and pumping requirements. These results could then be used to confirm whether groundwater protection should be incorporated into the flood protection requirements. To develop this three-dimensional model, AE recommends that a geotechnical field investigation be conducted to provide appropriate input into the model.

9.2.3 Requirements for Preliminary Design of Complementary Barriers

AE recommends that during preliminary design of the proposed flood protection, further analysis of items such as utility conflicts, local geotechnical conditions, landscaping requirements and the feasibility of land acquisition be conducted to better understand the impacts on the proposed solutions.

Preliminary design should also include stakeholder and public engagement. Stakeholders to be engaged include the Government of Alberta, TransAlta, Canadian Pacific (CP) Rail and various City departments.

9.2.4 Climate Change Assessment

Research indicates that the climate is changing and incurring more extreme conditions. In various areas, the severity of high intensity rainfall and the duration of drought events have increased. Much of the evidence and research leads to predictions that this trend will continue.

The Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) prepared a professional practice guideline which mandates that engineers consider climate change within future designs. There are established workflows and analyses to determine the impacts of climate change on a project. At this time, neither the Alberta government nor the Association of Professional Engineers and Geoscientists of Alberta (APEGA) regulate design for climate change or provide guidelines for consideration of climate change impacts.

Nevertheless, it would be beneficial to review the adaptive capacity of existing or proposed flood protection infrastructure to changes in flows and water levels. Understanding the potential future conditions enables development of a design that is able to add adaptive capacity, if justified, based on estimated increased flood severity, frequency or risk to property or the public. This can therefore increase the resiliency and function of the proposed infrastructure. One such measure that was incorporated into the conceptual design was that the complementary barriers were designed with the ability to be raised in the future. Additionally, the use of upstream attenuation can provide the climate change resilience for both flood and drought conditions.

If The City chooses to undertake a future climate change study, AE recommends the following items form part of the study:

- Prepare a hydrology report
- Update the hydraulic models
- Determine the equivalent return periods for a climate change scenario
- Re-evaluate the TBL analysis
- Conduct a sensitivity analysis for changes to the predicted, future climate conditions
- Quantify the adaptive capacity of the system and proposed solutions.

Certification Page

This report presents our findings regarding the City of Calgary - City of Calgary Permanent Flood Barrier Protection Assessment.

Respectfully submitted,

ANDREW RUSHWORTH

2018-04-27

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APEGA Permit to Practice P 3979

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Appendix A – Figures

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Appendix B – Background Data

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Appendix C – Spill Line Figures

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Appendix D – Existing Flood Barrier Inventory

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Appendix E – Groundwater Inundation Mapping

Refer to Appendix E

Appendix F – Groundwater Modelling Results

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Appendix G – TBL Analysis Write Ups

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Appendix H – TBL Analysis Graphs & Tables

Jump to River Flow Rates by Return Periods

Jump to River Reaches by Site

Jump to Graphs - Attenuates

Jump to Graph Tables - Attenuates

Jump to Component Tables

Appendix I – TBL Benefit Cost Summaries

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Appendix J – Refined Designs

Refer to Appendix J

Associated Engineering

GLOBAL PERSPECTIVE.
LOCAL FOCUS.

Stantec Consulting Ltd.
200 - 325 25th Street SE, Calgary AB T2A 7H8

October 15, 2015
File: 110773407

Attention: Mr. Frank Frigo, Senior Planning Engineer
The City of Calgary
Water Resources
Infrastructure Planning
Water Centre #428
4th Floor, 625 – 25th Avenue SE

Dear Mr. Frigo,

Reference: Glenmore Reservoir Fish Creek Flood Diversion – Feasibility Assessment

Stantec Consulting Ltd. is pleased to provide the City of Calgary with the feasibility assessment of three possible diversion routes to discharge flood flows from the Glenmore Reservoir to Fish Creek within the City of Calgary (Figure 1).

1. BACKGROUND

The Elbow River originates in the eastern slopes of the Rocky Mountains and travels through the foothills ultimately discharging to Glenmore Reservoir situated on the western edge of the City of Calgary. The Glenmore Reservoir was built in 1932 as a storage reservoir for the primary source of the City's drinking water.

The Fish Creek watershed also originates in the eastern slopes of the Rocky Mountains and runs parallel to the Elbow River watershed passing through the City of Calgary approximately 5 km south of Glenmore Reservoir before discharging into the Bow River (Figure 1). The creek and valley within the City of Calgary comprises Fish Creek Provincial Park.

While not intended to be a flood mitigation structure under its Water Act license, the Glenmore Reservoir has historically been used as a flood protection measure to reduce downstream flood flows when warranted and under emergency conditions. In 2005 and 2013, major floods caused the reservoir to exceed its capacity and allow uncontrolled release of flood flows downstream.

The City of Calgary and the provincial government have completed numerous studies to assess the feasibility of alternative protection measures to mitigate flooding caused by the Elbow River, resulting in damages to communities and public infrastructure that are downstream of the reservoir. This preliminary hydraulic assessment of a diversion channel to release Elbow River flood flows south from the Glenmore Reservoir to Fish Creek is one of these alternatives.

1.1. RELATED PROJECTS

The following projects have been previously considered to mitigate Elbow River flows downstream of Glenmore Reservoir. SR1 was commissioned by Alberta Environment and Sustainable Resource Development (ESRD, now Alberta Environment and Parks) and is currently undergoing detailed design. This Glenmore diversion study was commissioned by the City of Calgary and is being further studied with respect to hydrology, environmental impacts and high level conceptual engineering design.

1.1.1. Springbank Road Off-Stream Reservoir (SR1)

The provincial government has proposed the construction of a diversion off-stream reservoir (SR1) upstream of the City of Calgary along the Elbow River. AMEC Environment and Infrastructure completed the conceptual design of SR1, which is summarized in a May 2014 report commissioned by the Southern Alberta Flood Recovery Task Force (Appendix G). The proposed flood storage reservoir is intended to divert a maximum of 300 m^3/s of Elbow River flows and store a maximum of 57,000 dam^3. This was determined to be adequate to store the 100-year event and to reduce the peak inflow to the Glenmore reservoir from 930 m^3/s to 630 m^3/s. This reduced inflow would be expected to be stored within Glenmore Reservoir while releasing a maximum downstream flow of 170 m^3/s to the low lying communities within the City.

The proposed design condition for SR1 of the 100-year event is 310 m^3/s less than the flows that were experienced during the 2013 event.

For the purposes of the current preliminary design assessment Stantec has assumed that SR1 will be constructed as per the conceptual design (AMEC, 2014).

1.1.2. Glenmore Reservoir Diversion – Feasibility Study

Hatch Mott MacDonald prepared a report for The City of Calgary to determine the feasibility of three tunnel diversion alignment options from the Glenmore Reservoir. These three options were along 58th Avenue South to the Bow River, along Heritage Drive to the Bow River and to Fish Creek. The report states that the Fish Creek option was “deleted from further review because of potential impacts to Fish Creek” (Hatch, 2014) on the pre-feasibility level. This current Fish Creek Diversion report is a due diligence study initiated by the City of Calgary to further look at this deleted option.

The report recommended an 8.0 m diameter tunnel along the Heritage Drive alignment to the Bow River with a flow capacity of 500 m^3/s. This tunnel would be capable of accommodating the 100-year flood event.

For the purposes of this feasibility assessment of the Glenmore Reservoir to Fish Creek diversion channel, Stantec has assumed that the tunnel described in the Hatch report will not be constructed.

2. STUDY BASIS

Stantec's preliminary hydraulic assessment is based on:

- Digital database information including LiDAR data, GIS layers, roadway geometry and aerial photo images;
- A site visit to each of the three possible diversion routes by James Bigelow, E.I.T. and Catalina Tandara on October 31st, 2014;
- Available past studies including:
    - "Southern Alberta Flood Recovery Task Force, Volume 4 – Flood Mitigation Measures – Appendix G – Springbank Off-Stream Storage Project" by AMEC Environment and Infrastructure in May 2014;
    - "Basin-Wide Hydrology Assessment and 2013 Flood Documentation" by Golder Associated Ltd. in September 2014;
    - "Fish Creek Drainage Study – Final Report" by AGRA Earth and Environmental Limited in July 2000;
- Glenmore Reservoir Bathymetric Data surveyed by Klohn Crippen Berger in 2013 provided by the City of Calgary;
- Discussions with the City of Calgary on November 14, 2014; and
- Water Survey of Canada hydrometric data from the following stations:
    - 05BK001 – Fish Creek near Priddis (1908-2013)
    - 05BJ010 – Elbow River at Sarcee Bridge (1979-2012)

3. HYDROLOGY

Following the 2013 flood events, Golder Associates Ltd. prepared a basin-wide hydrologic assessment for the major watercourses through the City of Calgary that included flood frequency estimates for the Elbow River upstream of Glenmore Reservoir and Fish Creek at the mouth of the Bow River (Golder, 2014). Table 1 provides the relevant flood frequency estimates described in Golder's assessment:

Table 1 – Flood Frequency Estimates

Return Period (yr)	Maximum Instantaneous Flow (m^3/s)	
	Elbow River above Glenmore Dam	Fish Creek at Bow River
2	84.6	39
5	194	85.7
10	307	134
20	454	198
50	708	317
100	954	444

3.1. RECENT FLOOD EVENTS AND IMPACTS

Two of the largest floods on record for both the Fish Creek and Elbow River watersheds occurred in 2005 and 2013. The following section describes both of these events and the resulting damage.

3.1.1. 2005 EVENT

On June 19, 2005 the Glenmore reservoir exceeded its capacity and excess floodwater spilled over the spillway. A peak flow of 301m^3/s was recorded below the Glenmore Dam (WSC, 2015) causing evacuations and infrastructure damage to the downstream communities.

Fish Creek also experienced significant flooding as a peak flow of 482 m^3/s was recorded upstream of the City of Calgary at Priddis (WSC, 2015). This flood event destroyed seven bridges and 40% of the pathways within Fish Creek Provincial Park and cost an estimated $7.5 million (Kaufmann, 2013).

Photo 1: Looking west at bank erosion and pathway washout just downstream of the LRT Bridge over Fish Creek following the 2005 flood event (Stantec, 2006)

3.1.2. 2013 Event

The 2013 Flood Event resulted in Elbow River peak flows of 1240 m³/s upstream of Glenmore Reservoir (Golder, 2014). Prior to the flood, reservoir operators lowered the reservoir to the minimum operating level of 1071.85 m; thus, storing 10,461 dam³ and reducing the peak flow released down the Elbow River by 40% to 700 m³/s downstream of Glenmore. Despite this significant reduction in the peak flood discharge, flood damage through the residential communities and the downtown area from the Elbow River was extensive.

The 2013 event on Fish Creek peaked at 218 m³/s at Priddis (WSC, 2015); approximating a 25-year event (Golder 2014). The event caused bank and pathway erosion and damage to pedestrian bridges. The effects of the 2013 event on Fish Creek were less than the 2005 event. Photo 2 illustrates some of the bank and infrastructure damage incurred during the 2013 event.

Reference: Glenmore Reservoir Fish Creek Flood Diversion – Feasibility Assessment

Photo 2: Looking northwest at bank erosion and pathway washout near Bebo Grove along Fish Creek (Stantec, 2013).

3.2. PRELIMINARY DESIGN HYDROLOGY

While the 100-year event is considered the design standard for Alberta, its common practice to use the largest event on record when there exists an event greater than the 100-year event. The design event for the Elbow River watershed was selected as the 2013 event. While the 2013 event created a unique hydrograph shape, the preparation of a new design flood hydrograph for another event of this magnitude was not part of the scope of this report. For simplicity, Stantec used the Glenmore reservoir inflow hydrograph from 2013 for the preliminary routing calculations.

Similarly, in Fish Creek, the 2005 event (482 m^3/s) was slightly more than the current estimate of the 100-year event (444 m^3/s); therefore the 2005 event for Fish Creek was selected as the design event.

The Elbow River and Fish Creek watersheds are in close proximity to each other and both have been affected by the same storm events in the past. For the purposes of the preliminary design hydrology, the peak flow in Fish Creek is assumed to pass the proposed diversion outlet (from the

Glenmore Reservoir) while the diversion is flowing at peak discharge. This assumption of coincident peaks is considered conservative.

4. DESIGN DIVERSION DISCHARGE

An effective flood diversion and protection plan for the Glenmore Reservoir – Fish Creek Diversion would require close cooperation between all dam operations on the Elbow River. These include the existing Glenmore Reservoir and the proposed Springbank Reservoir (SR1).

Using the design hydrology previously discussed, storage routing calculations have been completed on a volumetric basis to optimize a design diversion discharge from Glenmore Reservoir to Fish Creek.

Assumptions

The storage routing calculations have been based on the following assumptions:

- The SR1 reservoir will be built to the specifications described in the conceptual design report (AMEC, 2014). These specifications include:
    - Elbow River flows are diverted once the river reaches 200 m³/s; and
    - Maximum diversion rate is 300 m³/s until the reservoir reaches a maximum volume of 57,000 dam³.
- The desired maximum discharge rate of the Elbow River downstream of Glenmore Reservoir is equal to 170 m³/s. This value is accepted by the City of Calgary as the maximum flow within the river without the need for sandbagging or other temporary flood protection measures.
- Sufficient flood forecasting will allow for the water level in the Glenmore Reservoir to be drawn down to an elevation of 1071.85 m (-3.5 m) thus providing a storage capacity of 10,461 dam³ (Klohn, 2013). This storage capacity assumes no stop-logs are installed at the Reservoir and any future upgrades to the reservoir have not been constructed.

Results

The preliminary routing calculations indicate the following results:

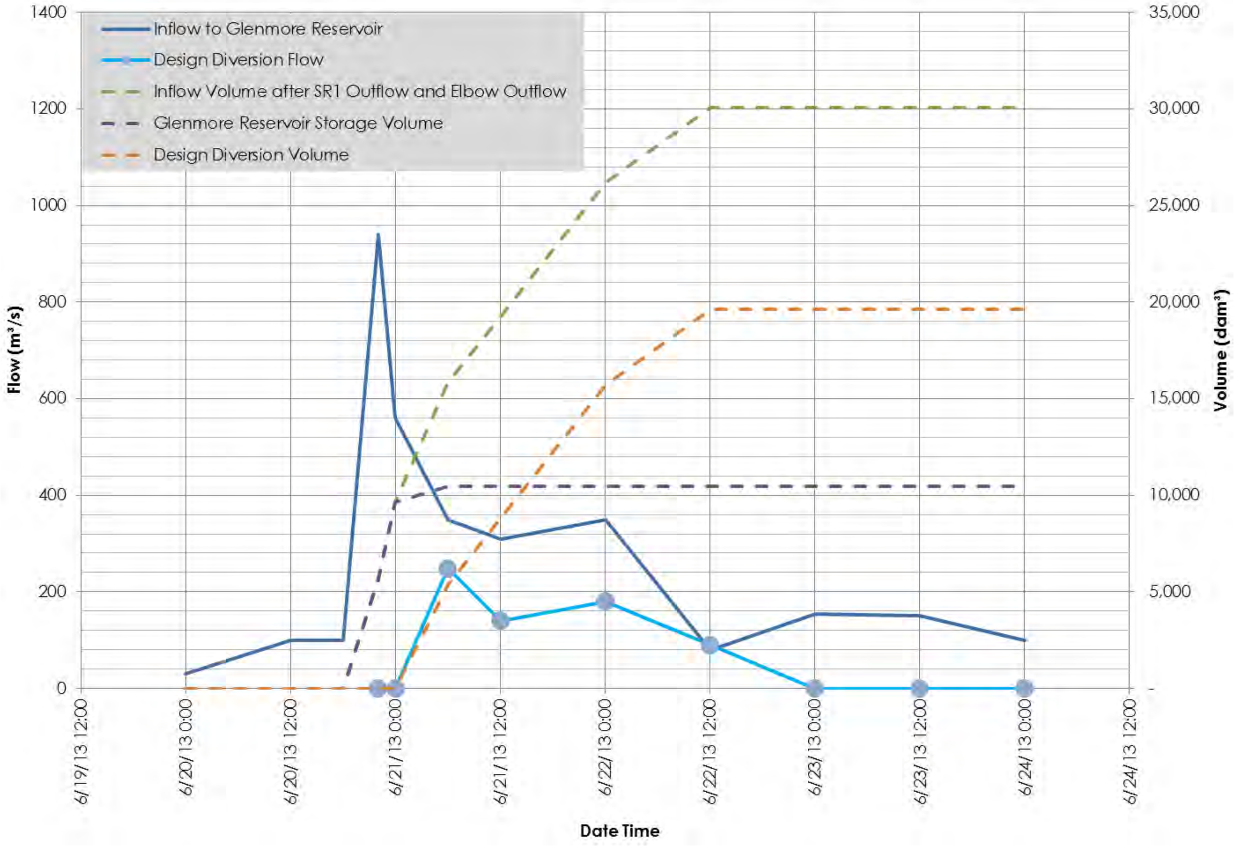
- SR1 reduces the peak flow rate into the reservoir from 1240 m³/s to 940 m³/s and continues providing a reduction of 300 m³/s for 53 hours until the maximum volume is reached. Based on the 2013 flood hydrograph, the inflows fall below 200 m³/s after 53 hours.

- Glenmore Reservoir fills up to maximum capacity within the first 12 hours of the peak reaching the reservoir.

- The resulting required diversion peak flow to Fish Creek so as to maintain Elbow River outflow at 170 m³/s is 250 m³/s, and a required diversion volume of 19,600 dam³.

The following Chart 1 provides a graphical representation of the storage routing results.

Chart 1 - Storage Routing Results



This Fish Creek flow is 50% of the 500 m^3/s diversion flow originally suggested by the City of Calgary and was the scope of our assessment. In this report, the analysis focuses on the flow of **250 m^3/s**, however the results will speak to the feasibility of the higher 500 m^3/s flow.

Preliminary routing calculations indicate a peak discharge that must be diverted from Glenmore Reservoir is equal to 250 m^3/s and a volume of 19,600 dam^3.

5. HYDRAULIC ANALYSES

The Glenmore Reservoir and Fish Creek are separated by 4.4 km to 5.7 km of primarily residential areas. Three major roadways running north-south from the reservoir to the edge of the Fish Creek valley have been selected by the City of Calgary as the possible diversion routes. These diversion routes are illustrated on Figure 2 and are as follows:

1. 37th Street SW;
2. 24th Street SW; and,
3. 14th Street SW.

Both open-channel and closed conduit options were analyzed to determine conveyance capacity for the design flows. Figures 3, 4 and 5 provide additional details for each of the alignments and channel profiles. Both options employ gravity based drainage. Stantec considered the possibility of using pumps to increase the head thus decreasing the required depth of cut. Preliminary estimates suggest the required horsepower to pump this flow is in the order of 630,000 HP. The quantity size and electrical power draw of pumps required to convey a flow of this magnitude rendered this possibility unfeasible.

5.1. OPEN CHANNEL DESIGN

A typical open channel design was used in this feasibility assessment. There is an opportunity for optimizing the shape of this channel to provide minor reductions to footprint in preliminary engineering, should the option be feasible.

The open channel design option would simplify the complicated hydraulic effects at the inlet and outlet compared to a closed conduit and eliminate the need for pressurized flow conditions.

The open channel arrangement includes the following design features:

- Discharge will be conveyed by gravity only. Positive drainage can be attained for each of the three alignments; however, this requires the maximum depth of cut to range from 40 m to 61 m.

- The side slopes of the channel will be 3H:1V to allow for landscaping and geotechnical stability. This could be optimized in the preliminary design.

- The bottom width will be 10 m to allow for constructability as it enables crews and equipment to work from the bottom and pass each other if required.

- The wetted area of the channel up to the design depth will be lined with 6" articulated concrete matting to provide erosion control up to a design peak channel velocity of 4.0 m/s

Table 2 provides specific design data for each of the open channel alignment options.

Table 2 – Open Channel Diversion Design Data

Diversion Alignment	**37th Street**	**24th Street**	**14th Street**
Design Flow (m^3/s)	250 (500)		
Elevation Change (m)	7	16	20
Standard Cross Section	**Standard Trapezoid**		
Bottom Width (m)	10		
Side Slopes	3H:1V		
Depth of Flow (m)	4.4 (6.0)	3.3 (4.6)	3.0 (4.2)
Flow Velocity (m/s)	2.5 (2.9)	3.8 (4.6)	4.0 (5.3)
Maximum Depth of Cut (m)	61	41	40
Maximum Width of Cut (m)	370	250	190
Estimated Volume of Cut (million m^3)	34.0	21.9	9.59

The conveyance sizing for an open channel diversion channel would require a 190 m to 370 m wide right of way along the proposed alignments and a 40 to 61 m deep excavation.

5.2. CLOSED CONDUIT DESIGN

A closed conduit bored into the bedrock has also been considered for the diversion channel design. This conduit would be very similar to the conduit that was considered to divert flood flows from Glenmore Reservoir east to the Bow River.

The closed conduit design option includes the following design features:

- A maximum tunnel flow velocity of 10 m/s to avoid cavitation and hydraulic erosion of the conduit. This assumption was also used in the feasibility assessment for the diversion conduit from Glenmore Reservoir to the Bow River (Hatch, 2014).
- The conduits have been designed based on a full flow capacity of 250 m³/s
- The conduit lining is assumed to be concrete.

Table 3 provides design details for the closed conduit diversion channel for each of the alignment options.

Table 3 – Closed Conduit Diversion Design Data

Diversion Alignment	37th Street	24th Street	14th Street
Design Flow (m³/s)	250 (500)		
Elevation Loss (m)	7	16	20
Closed Conduit Type	**Circular Pipe**		
Maximum Depth of Pipe (m)	61	41	40
Flow Velocity (m/s)	4.2 (4.9)	6.4 (7.9)	7.8 (8.9)
Min. Diameter (m)	9 (11.5)	7 (9.5)	6.5 (8.5)

The conveyance sizing for a closed conduit would require a 6.5 m to 9 m diameter pipe installed 40 to 61 m below existing ground along the proposed alignments.

5.3. INLET DESIGN

The inlet must be designed to create adequate head to pass the design peak flow of 250 m³/s. The following inlet design options have been considered.

- Plunge intake – A plunge intake consists of weir flow over a structure into a vertical shaft connecting to the diversion channel or conduit. The low gradient of the channel in order to obtain positive drainage, safety issues and construction difficulties render this option unfeasible.
- Horizontal Intake – A horizontal intake would consist of a broad-crested weir followed by bellmouth entrance structure along the banks of the reservoir. A gate at the entrance of the diversion channel or conduit would be closed during normal conditions and control the flow during flood conditions.

The inlet location along the 37th Street alignment is within a depositional area where the Elbow River empties into the reservoir. This deposition and shallow water depths would pose challenges in the design of the inlet structure. The 24th Street and 14th Street alignments are in deeper areas of the reservoir and are further from the depositional area. Therefore this is not expected to be an issue at these alignments.

5.4. OUTLET DESIGN

Left uncontrolled, both types of diversion channels would result in local scour, erosion and channel degradation at the outlet. An energy dissipation structure such as a stilling basin complete with baffles or an expansion channel/chamber would be required. The selection of the outlet design would be dependent on the channel configuration, alignment and specific outlet location.

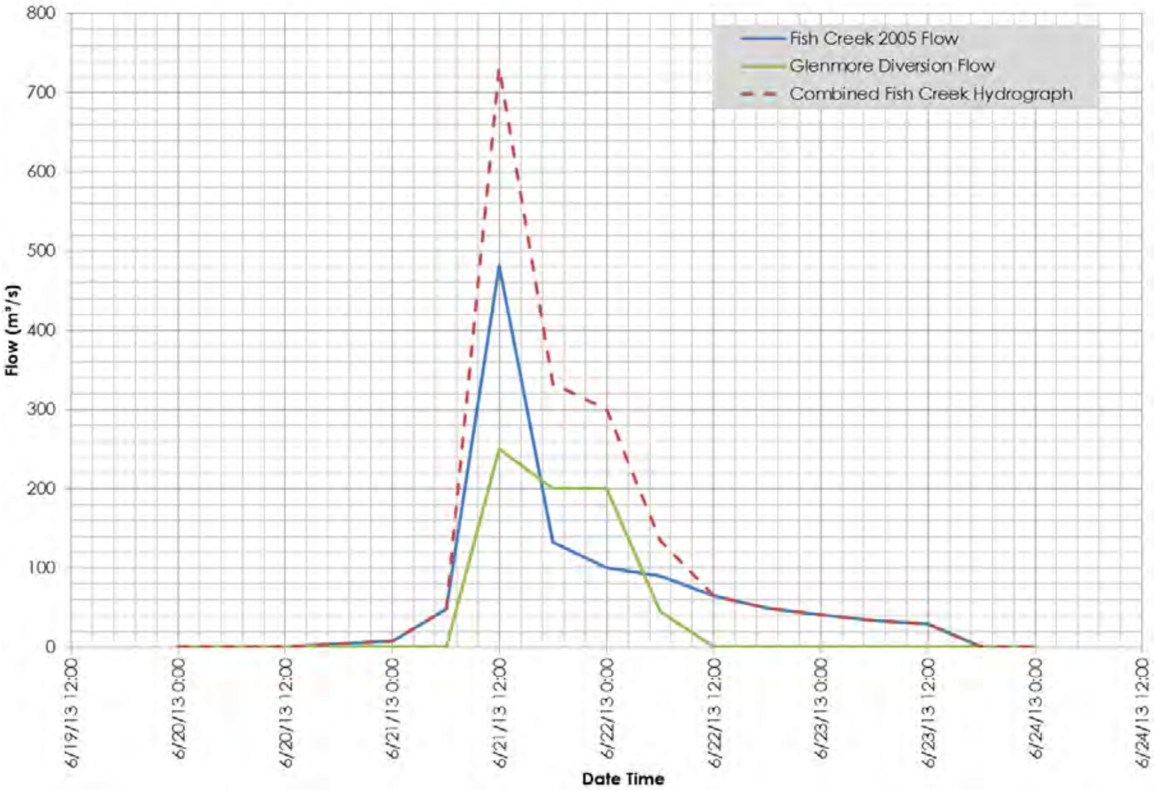
6. CONVEYANCE CAPACITY OF FISH CREEK TO RECEIVE DIVERSION FLOW

The conveyance capacity of Fish Creek to receive the additional flow was determined by:

- analyzing the impacts of past floods in Fish Creek; and,
- developing a hydraulic model to quantify the impacts of the additional flood flow to the watercourse and riparian areas (Section 8 of this document).

The additional flood flow released into Fish Creek as per the design scenario described previously is 250 m^3/s. This flow would increase the flow through Fish Creek by approximately 50% (from 482 m^3/s to 732 m^3/s) in the routing scenario described in Section 4. Chart 2 provides an illustration of the flows through Fish Creek assuming no storage structure is implemented. The 2005 and 2013 natural peak flows in Fish Creek area are also shown on Chart 2 for reference.

Chart 2 – Fish Creek Hydrology



Under the most optimistic scenario (where Fish Creek flows upstream of the Park are near zero), releasing the diverted flow directly into Fish Creek would result in higher flows than the 2013 event. The conservative design scenario would result in flows 150% greater than those observed in 2005.

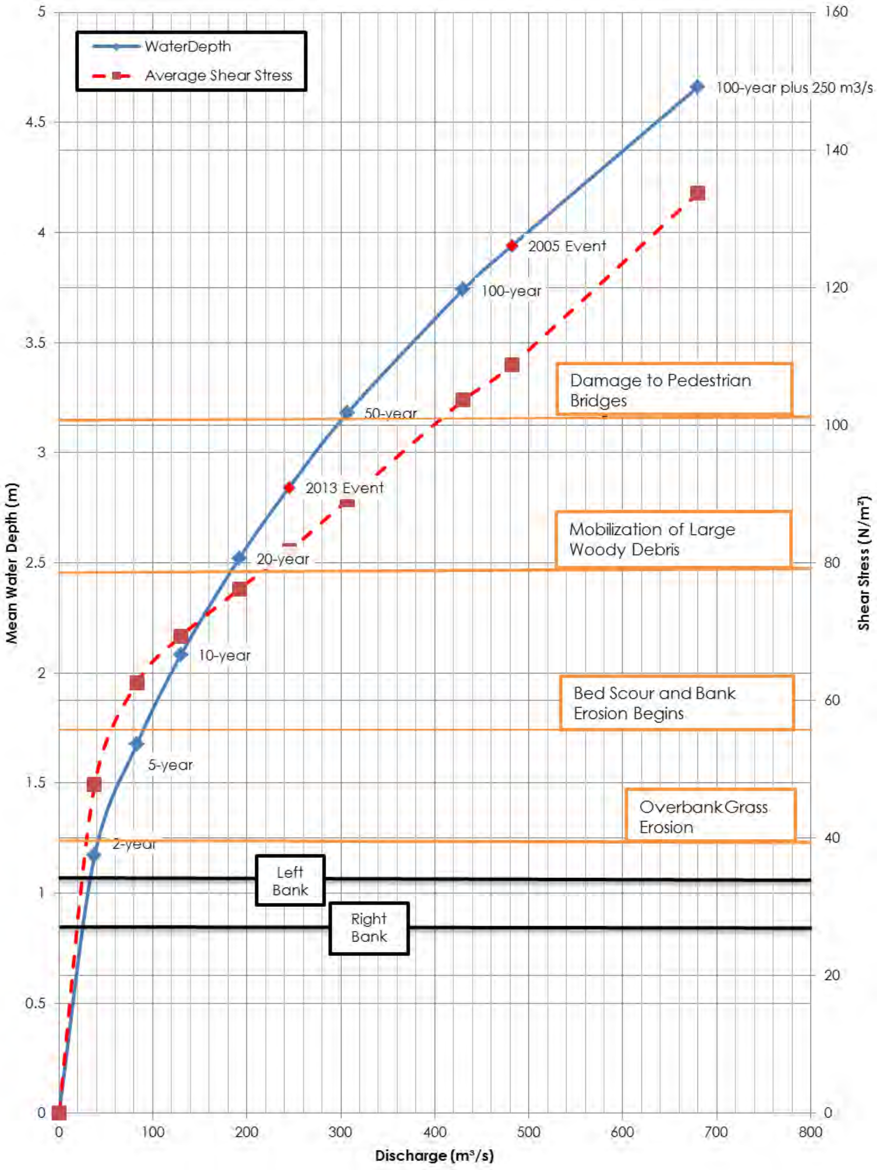
7. HYDRAULIC AND GEOMORPHIC IMPACTS WITHIN FISH CREEK

A preliminary hydraulic model was developed using HEC-RAS to provide a better understanding of Fish Creek conveyance within the provincial park and to estimate the effects of the increased flows due to the possible diversion channel.

This high-level HEC-RAS model of Fish Creek was intended to provide approximate average water depths and overbank shear stresses within the floodplain. The model was based on available LiDAR data only and was not calibrated due to the limited scope of this exercise. A digital copy of the hydraulic model files is provided with this document.

Chart 3 provides an estimate of the average water depths (m) and average shear stress (N/m²) of Fish Creek between the 37th Street Bridge and the LRT Bridge. The model also provided estimates of flood inundation extents under such a scenario. These flood extents are illustrated on Figure 7.

Chart 3 – Fish Creek Hydraulic and Shear Stress Results



As illustrated in Chart 3, the negative effects on infrastructure and the natural areas of the park could be extreme during the design routing scenario.

Analysis of aerial imagery indicates that Fish Creek is an extremely active channel and has experienced extensive channel migration through this reach. The increased flow has the potential to cause geomorphic effects and channel migration resulting in damage to infrastructure and riparian areas. High and low risk paths of potential channel migration within the valley have been identified on Figure 8. Flood levels at key hydraulic locations have been identified on Figure 9.

The hydraulic and geomorphic impacts on Fish Creek from the increased flow would include riparian erosion, bed and bank scour, channel migration and damage to existing infrastructure.

8. STORAGE OPTIONS

An uncontrolled release of the entire design diversion discharge into the Fish Creek Channel would be akin to adding an event equal to the 25-year return period to the Fish Creek channel. This is in addition to any existing flows in the creek at the time of diversion. During an event where the diversion channel is activated, these existing flows, as discussed previously, can be expected to be high due to the proximity and similarity of the Fish Creek and Elbow River watersheds.

A dam within the Fish Creek valley or diversion channel could be designed to provide storage to control or attenuate the diversion discharge to eliminate or reduce the impacts to the downstream reaches of Fish Creek. The mitigation effects of a dam are only noticed after sufficient inundation occurs. During the initial flow diversions, there is still the potential for scour and erosion of the banks.

Preliminary design data for various storage options that were identified are provided in Table 4 and Figure 6.

Table 4 - Storage Options Design Data

	Crest El. (m)	Dam Height (m)	Maximum Volume (dam³)	Distance of Fish Creek Flooding Upstream of Dam (km)	Fish Creek Flooded Area (km²)
Dam 1 – Canyon Meadows Driving Range	1085	25	3900	N/A	0.2
Dam 2 – Votiers Flats	1066	22	16,000	2.8	1.14
Dam 3 – Bridge 7	1070.5	23	15,200	3.6	1.06
Dam 4- LRT Bridge	1056	19	15,200	2.7	0.97
37th Street Open Channel	1100	30	8,200	N/A	N/A
24th Street Open Channel	1085	28	7,500	N/A	N/A
14th Street Open Channel	1068	18	2,000	N/A	N/A

N/A = Dam is not across the Fish Creek Channel therefore there is no distance or area of Fish Creek Flooding as a result of the dam.

Additional details for each of the options are provided below:

1. Dam 1 – Canyon Meadows Driving Range

   - This storage area would involve the construction of a dam spanning the southern end of the Canyon Meadows Golf Course Driving Range. This dam would only be effective in conjunction with the 14th Street SW alignment.

   - Due to the limited storage capacity of this area, Dam 1 would only reduce the diversion peak flow by 95 m³/s thereby still releasing a peak flow of 155 m³/s into Fish Creek.

2. Dam 2 – Votiers Flats

   - This storage area would span across the entire Fish Creek valley in the vicinity of Votiers Flats. This location was selected to maximize an existing rise in the topography along the left valley wall. This dam would be effective in conjunction with all three of the diversion channel alignments.

   - The dam could be designed to contain the equivalent of the entire diverted volume.

3. Dam 3 - Bridge 7

   - This storage area would span across the entire Fish Creek valley in the vicinity of Bridge 7. This location features an extreme narrowing of the natural valley thus reducing the required construction footprint. This dam would be effective in conjunction with only the 37th Street and 24th Street diversion channel alignments.

   - The dam could be designed to contain the equivalent of the entire diverted volume.

4. Dam 4 – LRT Bridge

   - This storage area would span across the entire Fish Creek valley in the vicinity of the LRT Bridge. This location was selected to use the existing embankments of the LRT Bridge and would involve replacing the bridge with a flow control structure. This dam would be effective in conjunction with all three of the diversion channel alignments.

   - The dam could be designed to contain the equivalent of the entire diverted volume.

5. Open-Cut Diversion Channel

   - This storage option would make use of the deep cut required to build the open cut diversion channel by placing a control structure near the downstream end of the channel. Flows would back up within the channel and be released into Fish Creek following the peak event.

   - The maximum stored water level in the diversion channel is limited by the elevation of the Glenmore Reservoir at the upstream end of the channel.

   - This storage option would not be effective with the closed conduit channel option.

9. REGULATORY REQUIREMENTS AND ISSUES

The regulatory requirements and issues that would apply to the diversion include:

- The *Water Act* would apply to any kind of construction along the banks of the Glenmore Reservoir, diversion channel release (controlled or uncontrolled) and storage structure within Fish Creek Park.

- Authorization under the *Fisheries Act* would be required as the diversion channel release and/or storage structure would result in serious harm to fish habitat.

- Fish Creek Park is a provincial park therefore negotiations with the Provincial Government and applications under the *Public Lands Act* would be required.

- The watercourse is not included in the list of scheduled watercourses under the *Navigation Protection Act*. Vessels can navigate the Fish Creek channel therefore the public right of navigation must be maintained.

10. IDENTIFICATION OF IMPACTS

The following section provides a desktop preliminary identification of the regulatory, environmental and social impacts of the conceptual design. These impacts include:

10.1 ENVIRONMENTAL IMPACTS

- Effects of changes in flood flows, sediment load and water quality within Fish Creek with any additional release into the creek.

- Effects on fish and fish habitat. The following species have been identified within Fish Creek from 37th Street SW to the LRT Bridge: Rainbow Trout, Brook Stickleback, White Sucker, Pearl Dace, Longnose Sucker and Trout-Perch (ESRD, 2015).

- Effects on riparian vegetation and soil erosion within the Fish Creek floodplain resulting from the uncontrolled release of flood flows and/or construction of a storage reservoir.

- Effects on wildlife within the Key Wildlife and Biodiversity zone in the Fish Creek watershed (ESRD, 2015) resulting from the release of flood flows and proximity to urban communities, construction of any works within Fish Creek Provincial Park.

    - The Fish Creek Provincial Park consists of a Sensitive Raptor Range (Prairie Falcon, Golden Eagle and Bald Eagle), and Sharp-Tailed Grouse habitat area (ESRD, 2015).

10.2 SOCIAL IMPACTS

- Effects to existing residential and commercial areas with the construction of the open channel alignments.

- Social impacts due to the purchase and relocation of 20 properties, 860 properties and 380 properties for 37th Street, 24th Street and 14th Street alignments respectively

- Effects to the Tsuu T'ina First Nations traditional territory with the construction of any works along the 37th Street SW alignment. It is likely that this conflict makes this alignment not feasible for the channel option.

- Effects on aesthetic concerns along an open channel alignment and any works within Fish Creek Provincial Park.

- Effects on citizens and park users within the vicinity of Fish Creek Provincial Park resulting from erosion and damage due additional flows and/or the construction of a storage structure.

- Effects on traffic patterns within the City's southwest quadrant.

11. POSSIBLE SYNERGIES WITH OTHER PROJECTS

There are two projects currently in design phases that could be combined with this project:

- Springbank Reservoir (SR1)
    - Coordination between the storage capacity of the proposed Springbank Reservoir and design diversion flow could optimize the efficiency of both flood mitigation measures.
- Glenmore Reservoir Upgrades
    - Synergy with possible upgrades to the storage capacity of Glenmore Reservoir could also be implemented to optimize the efficiency of both flood mitigation measures.

12. OPINION OF PROBABLE COST

Stantec has developed an opinion of probable cost for an open channel diversion and closed conduit diversion for each of the alignments. Additionally, an opinion of probable cost for each of the storage structure options has also been completed. These opinions of probable costs are provided in Table 5.

Reference: Glenmore Reservoir Fish Creek Flood Diversion – Feasibility Assessment

Table 5: Opinion of Probable Costs (millions)

Design Option		Total Construction Costs	Land Acquisition / Right of Way	Engineering/ Environmental	Contingency	Total Estimated Cost (million $)
Open Channel Diversion	**37th Street**	310.9	9.8	62.2	95.7	479
	24th Street	197.7	419.3	39.5	164.1	821
	14th Street	98.4	182.8	19.7	75.2	376
Closed Conduit	**37th Street**	334.4	0.1	66.9	100.3	502
	24th Street	299.7	0.1	59.9	89.9	450
	14th Street	293.4	0.1	58.7	88.0	440
Storage Structures	**Dam 1**	16.3	?	2.0	3.5	25*
	Dam 2	22.2	?	2.9	4.9	34*
	Dam 3	14.7	?	1.8	3.2	23*
	Dam 4	15.1	?	1.8	3.3	23*

Notes:

1. All costs in millions of CAD dollars.
2. Assumptions and unit rates are consistent with the cost estimates for SR1 (AMEC, 2014) and the Glenmore Diversion Tunnel (Hatch, 2014).
3. Land acquisition for the storage structures is not known at this time and will be subject to negotiations with the provincial government.
4. Residential Land Acquisition is based on a 2014 annual average residential property price in Calgary of $487,500 per residence (CREB, 2015) and an estimated 20 properties, 860 properties and 380 properties for 37th Street, 24th Street and 14th Street alignments respectively.
5. Engineering/Environmental is assumed to be 20% of Total Construction Costs
6. Contingency is assumed to be 25% of Total Construction Costs

13. RECOMMENDATIONS

Based on the preliminary routing and hydraulic calculations, a channel or tunnel from Glenmore Reservoir to Fish Creek could be successful in diverting flood flows and controlling the discharge in the Elbow River downstream of Glenmore Reservoir.

The financial costs as well as social, environmental and geomorphic impacts associated with diverting flood flows into Fish Creek render this concept unfeasible. Stantec recommends not moving forward with this Glenmore Reservoir diversion to Fish Creek flood mitigation option.

Regards,

STANTEC CONSULTING LTD.

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October 15, 2015

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PERMIT TO PRACTICE
STANTEC CONSULTING LTD.

Signature

Date Oct 15/15

PERMIT NUMBER: P 0258
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

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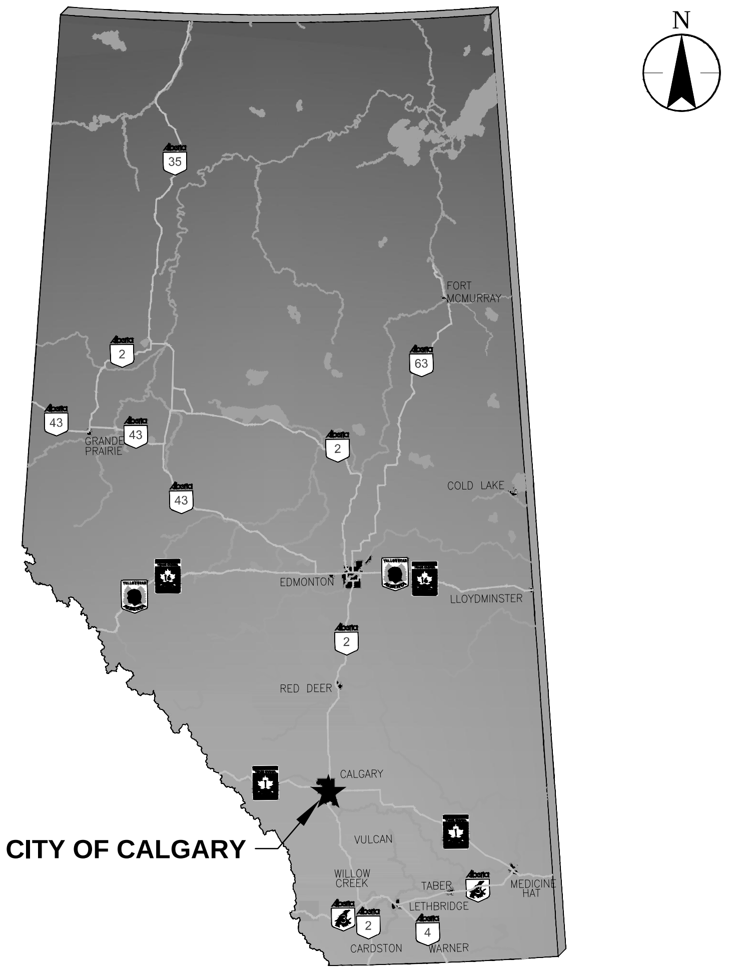
1 LOCATION PLAN
1:40000



KEY PLAN
N.T.S.

DRAWING LIST

DRAWING No	DESCRIPTION
FIGURE 1.0	LOCATION PLAN
FIGURE 2.0	SITE PLAN
FIGURE 3.0	37th STREET FLOOD DIVERSION ALIGNMENT OPTION
FIGURE 4.0	24th STREET FLOOD DIVERSION ALIGNMENT OPTION
FIGURE 5.0	14th STREET FLOOD DIVERSION ALIGNMENT OPTION
FIGURE 6.0	FISH CREEK VALLEY STORAGE OPTIONS
FIGURE 7.0	FISH CREEK FLOOD EXTENTS
FIGURE 8.0	POSSIBLE GEOMORPHOLOGICAL EFFECTS OF DESIGN DIVERSION ON FISH CREEK
FIGURE 9.0	FISH CREEK KEY HYDRAULIC SECTIONS

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October, 2015
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Legend

- - - ASSESSMENT AREA LIMITS
— · · — CALGARY CITY LIMITS

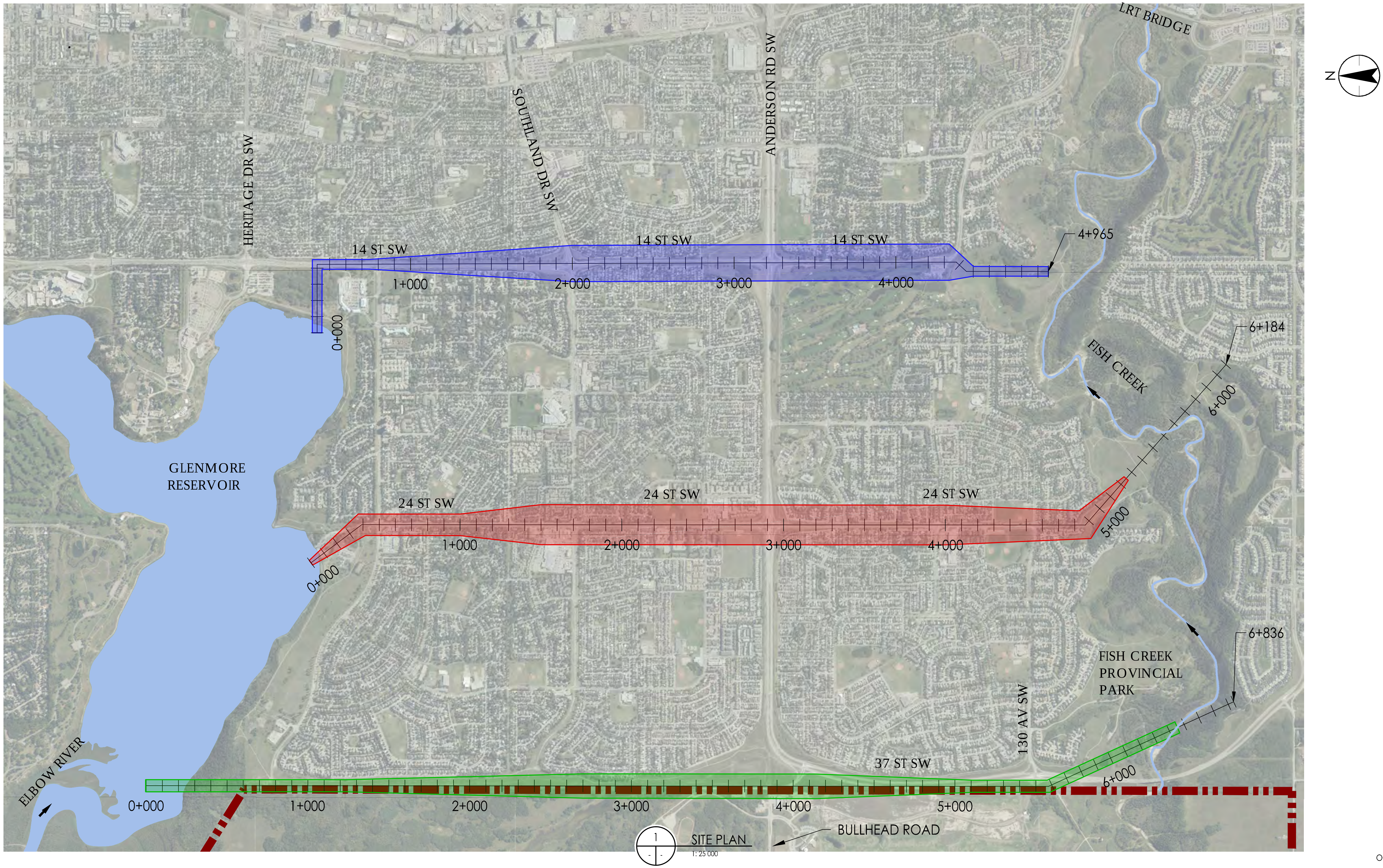
Notes

Scale: NO SCALE

Client/Project
THE CITY OF CALGARY
GLENMORE RESERVOIR TO FISH CREEK FLOOD
DIVERSION FEASIBILITY ASSESMENT

Figure No.
1.0

Title
Location Plan



1 SITE PLAN
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Legend

▬ ▪ ▬ CALGARY CITY LIMITS

🟩 🟥 🟦 OPEN CHANNEL CUT EXTENTS

➞ FLOW ARROW

Notes

Scale: 1:25 000 0 250 750 1250m

Client/Project

THE CITY OF CALGARY

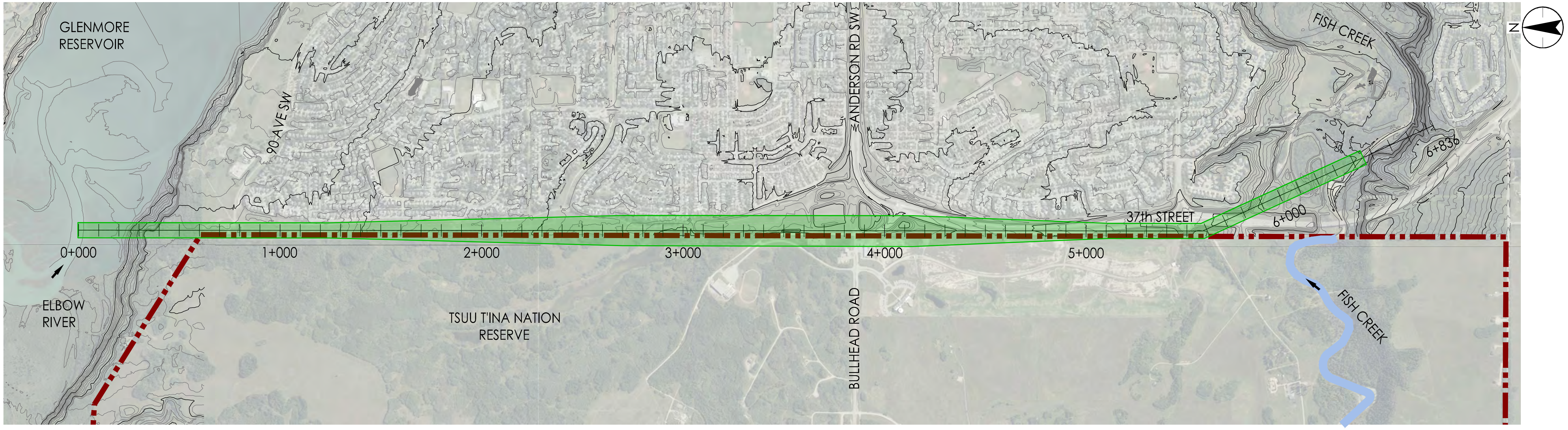
GLENMORE RESERVOIR TO FISH CREEK FLOOD
DIVERSION FEASIBILITY ASSESMENT

Figure No.

2.0

Title

SITE PLAN OF ASSESED ALIGNMENTS



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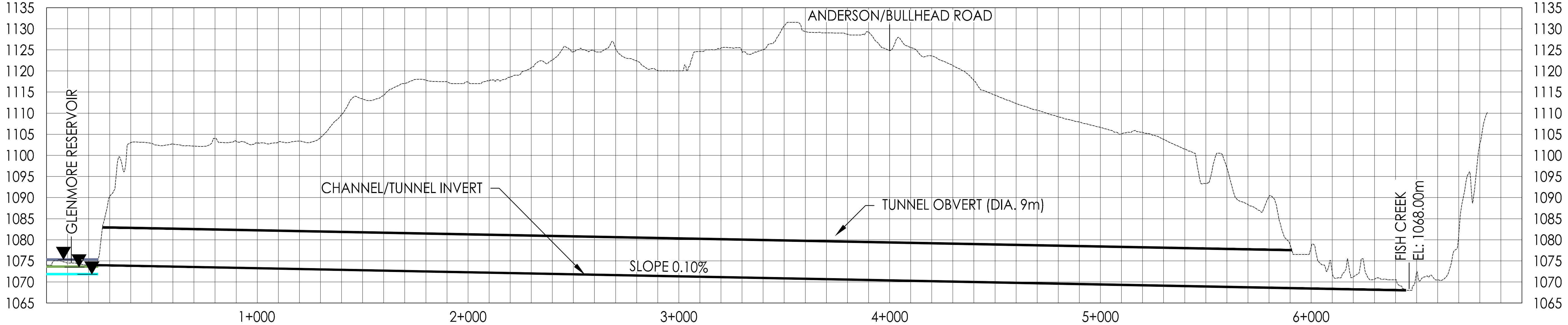

2 PROFILE VIEW
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Legend

- - - - EXISTING GROUND
▬ · ▬ CALGARY CITY LIMITS
▬ GLENMORE DAM CREST 1075.33m
▬ GLENMORE SPRING OPERATING LEVEL 1073.65m
▬ GLENMORE MIN. OPERATING LEVEL 1071.85m
🟩 CHANNEL CUT EXTENTS

Notes

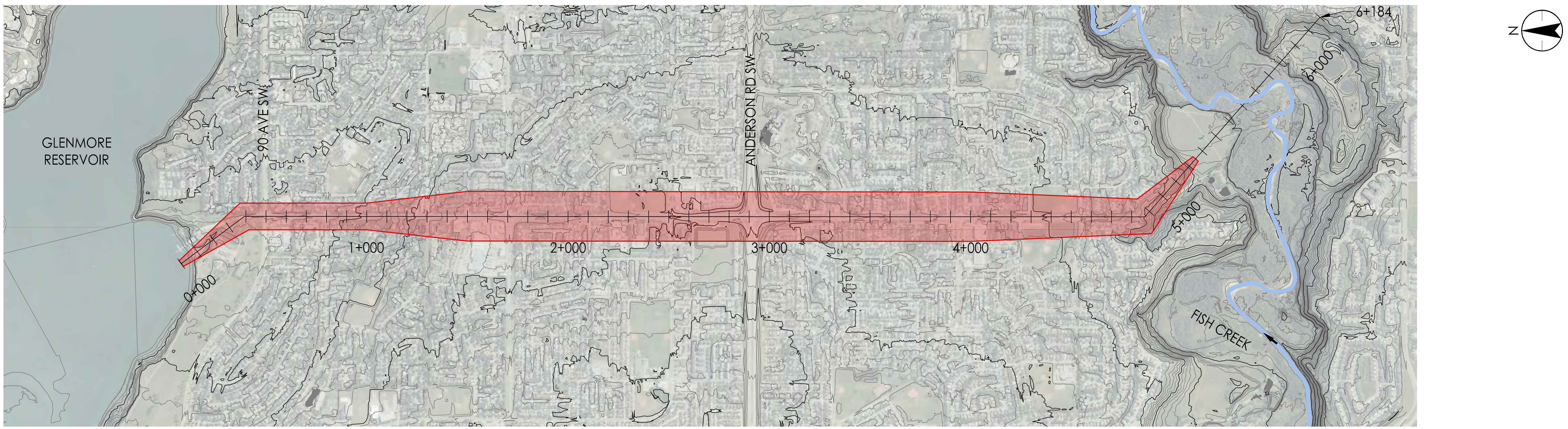
1.0 CONTOUR INTERVALS ON SITE PLAN ARE 10m MAJOR AND 2m MINOR

Scale: 1:20 000 0 200 600 1000m

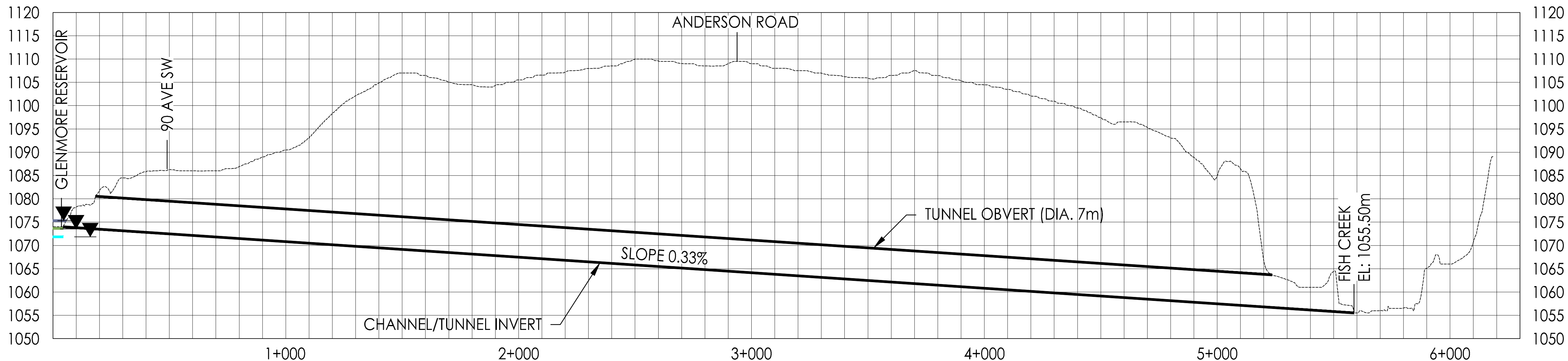
Client/Project
THE CITY OF CALGARY
GLENMORE RESERVOIR TO FISH CREEK FLOOD DIVERSION FEASIBILITY ASSESMENT

Figure No.
3.0

Title
37th STREET FLOOD DIVERSION ALIGNMENT OPTION



1 - | - PLAN VIEW
1:20000



2 - | - PROFILE VIEW
H 1:20000 V 1:1000

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ORIGINAL SHEET - ANSI B

October, 2015
110773407

Stantec

Legend

- - - - - EXISTING GROUND
━━ GLENMORE DAM CREST 1075.33m
━━ GLENMORE SPRING OPERATING LEVEL 1073.65m
━━ GLENMORE MIN. OPERATING LEVEL 1071.85m
🟥 CHANNEL CUT EXTENTS

Notes

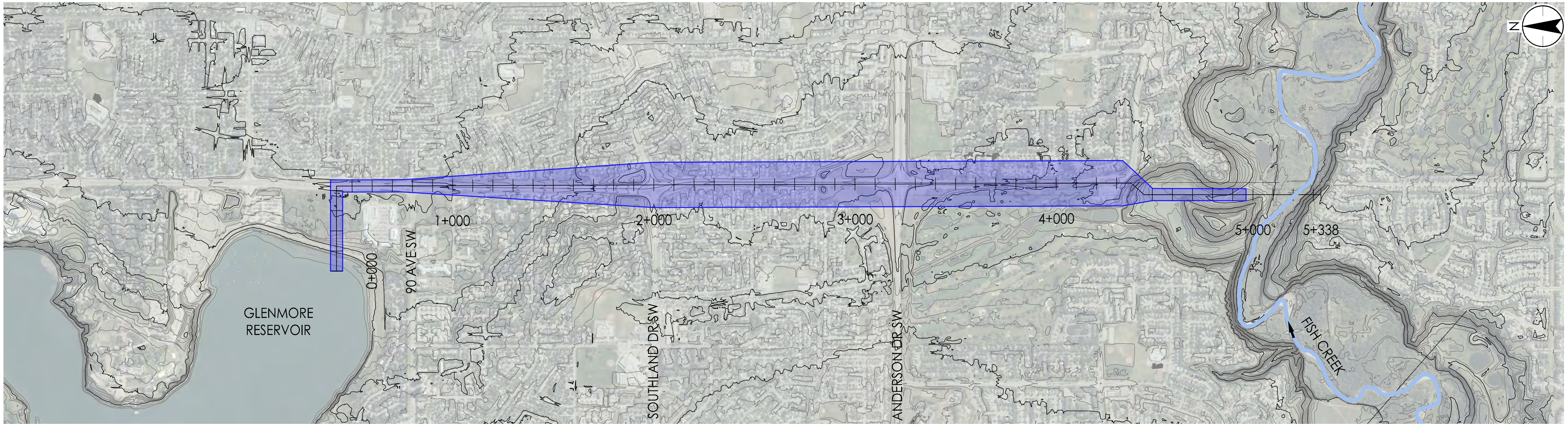
1.0 CONTOUR INTERVALS ON SITE PLAN ARE 10m MAJOR AND 2m MINOR

Scale: 1:20 000 0 200 600 1000m

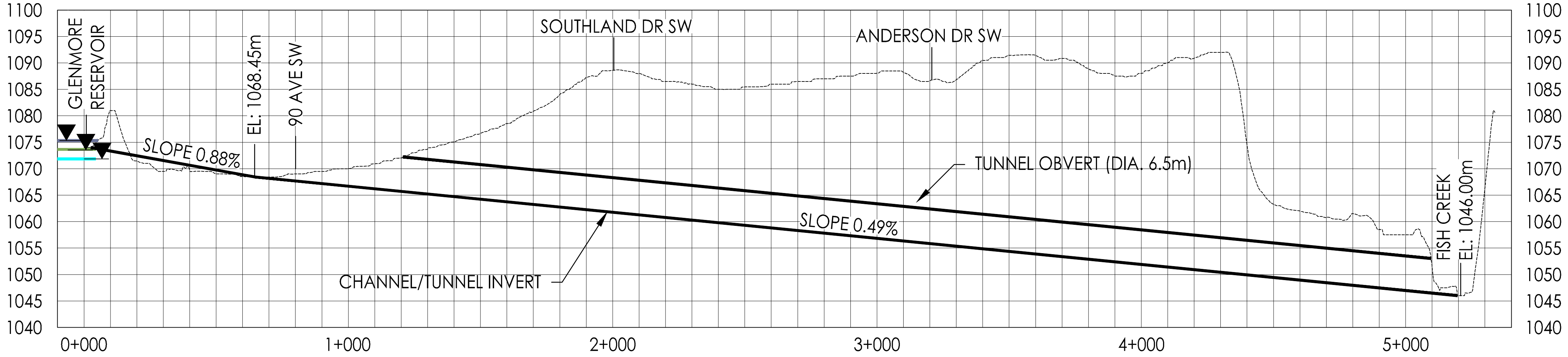
Client/Project
THE CITY OF CALGARY
GLENMORE RESERVOIR TO FISH CREEK FLOOD DIVERSION FEASIBILITY ASSESMENT

Figure No.
4.0

Title
24th STREET FLOOD DIVERSION ALIGNMENT OPTION



1 PLAN VIEW
1:20000



2 PROFILE VIEW
H 1:20000 V 1:1000

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ORIGINAL SHEET - ANSI B

October, 2015
110773407

Stantec

Legend

- ┄┄┄ EXISTING GROUND
- ━━ GLENMORE DAM CREST 1075.33m
- ━━ GLENMORE SPRING OPERATING LEVEL 1073.65m
- ━━ GLENMORE MIN. OPERATING LEVEL 1071.85m
- ▢ CHANNEL CUT EXTENTS

Notes

1.0 CONTOUR INTERVALS ON SITE PLAN ARE 10m MAJOR AND 2m MINOR

Scale: 1:20 000 0 200 600 1000m

Client/Project

THE CITY OF CALGARY

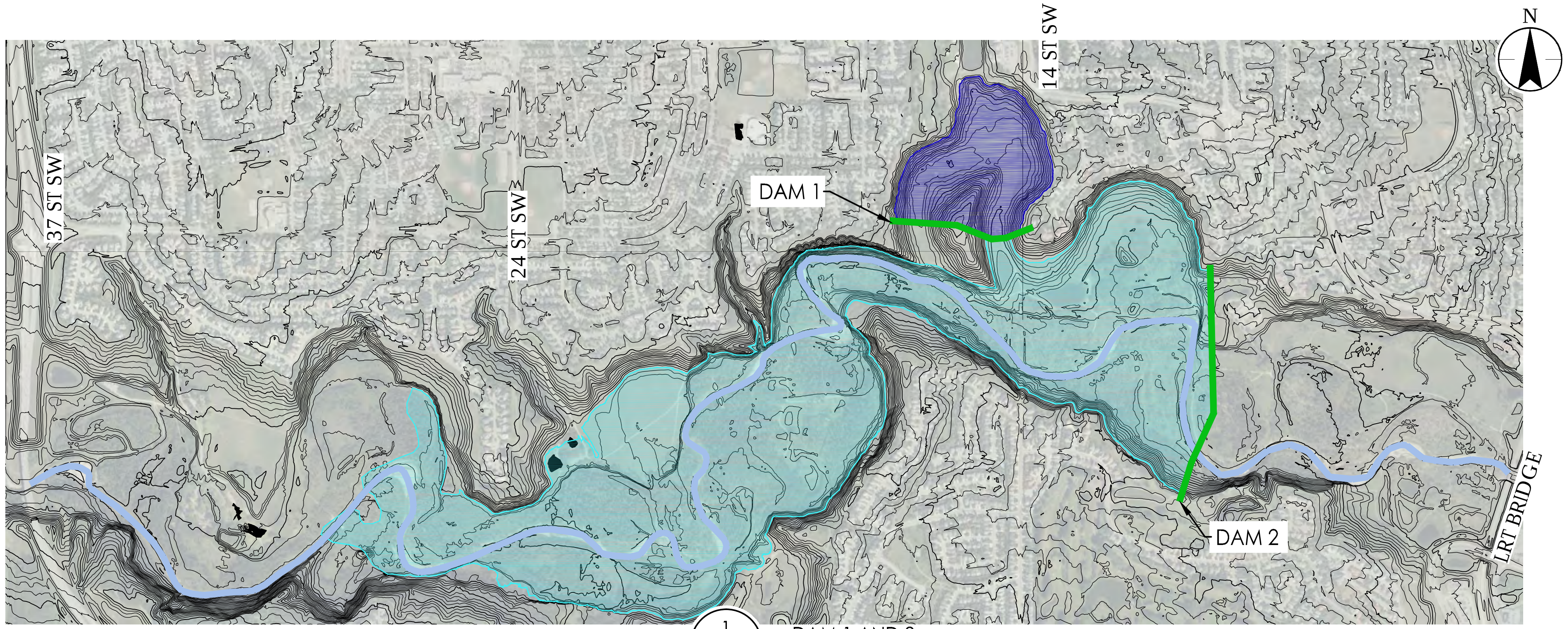
GLENMORE RESERVOIR TO FISH CREEK FLOOD DIVERSION FEASIBILITY ASSESMENT

Figure No.

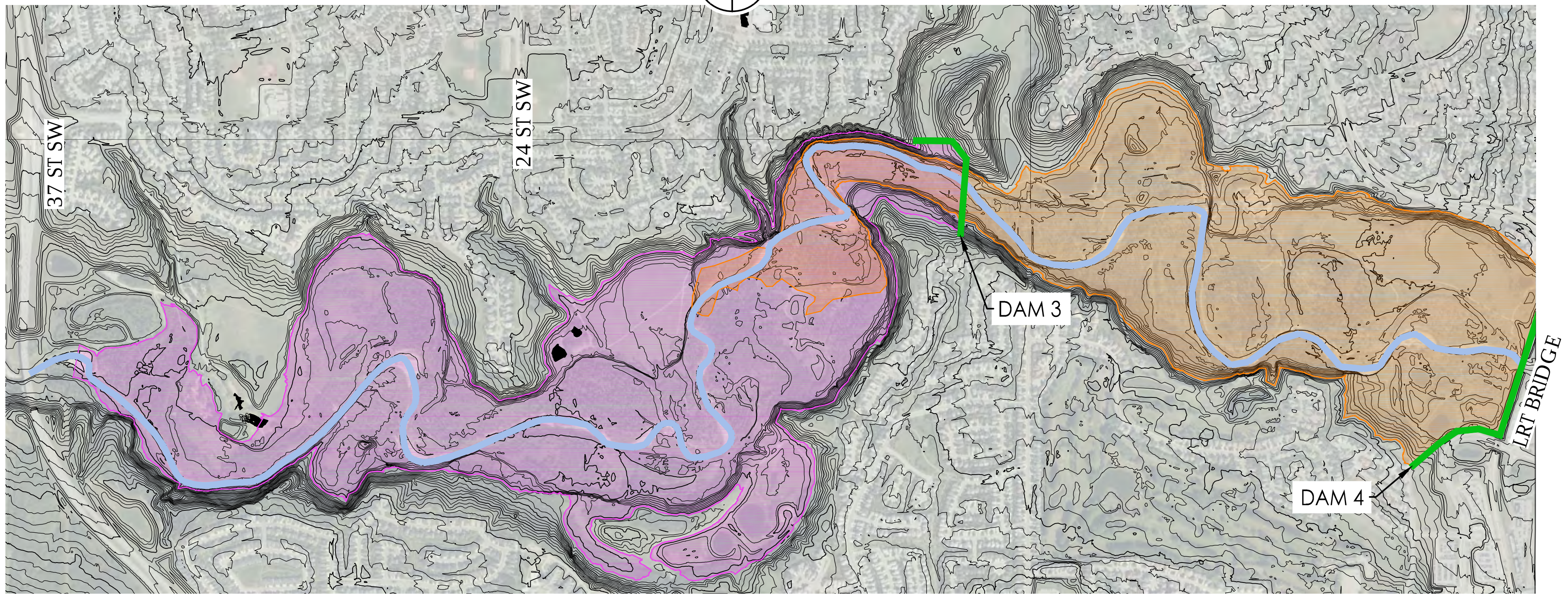
5.0

Title

14th STREET FLOOD DIVERSION
ALIGNMENT OPTION



1 DAM 1 AND 2
1: 20 000



2 DAM 3 AND 4
1:20 000

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ORIGINAL SHEET - ANSI B

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Legend

🟦 DAM 1 FLOODED AREA
🟦 DAM 2 FLOODED AREA
🟪 DAM 3 FLOODED AREA
🟧 DAM 4 FLOODED AREA
🟩 DAM EMBANKMENT ALIGNMENT

Notes

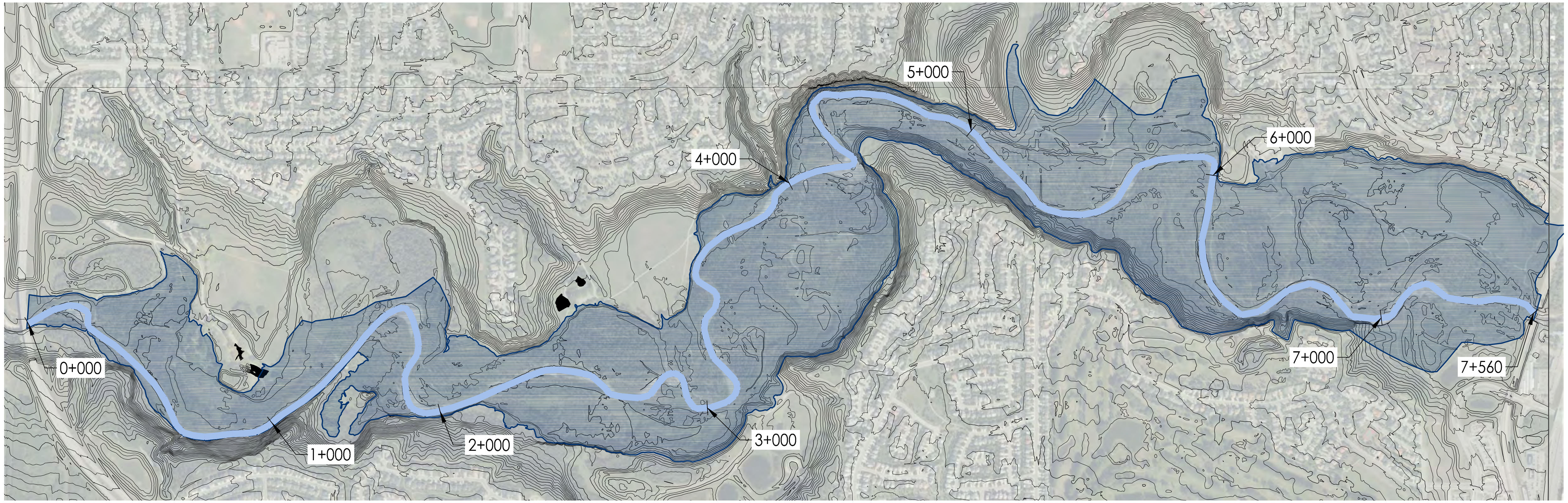
1.0 CONTOUR INTERVALS ON SITE PLAN ARE 10m MAJOR AND 2m MINOR
2.0 SHADED AREAS DENOTE MAX. RESERVOIR LEVELS

Scale: 1:20 000 0 200 600 1000m

Client/Project
THE CITY OF CALGARY
GLENMORE RESERVOIR TO FISH CREEK FLOOD DIVERSION FEASIBILITY ASSESMENT

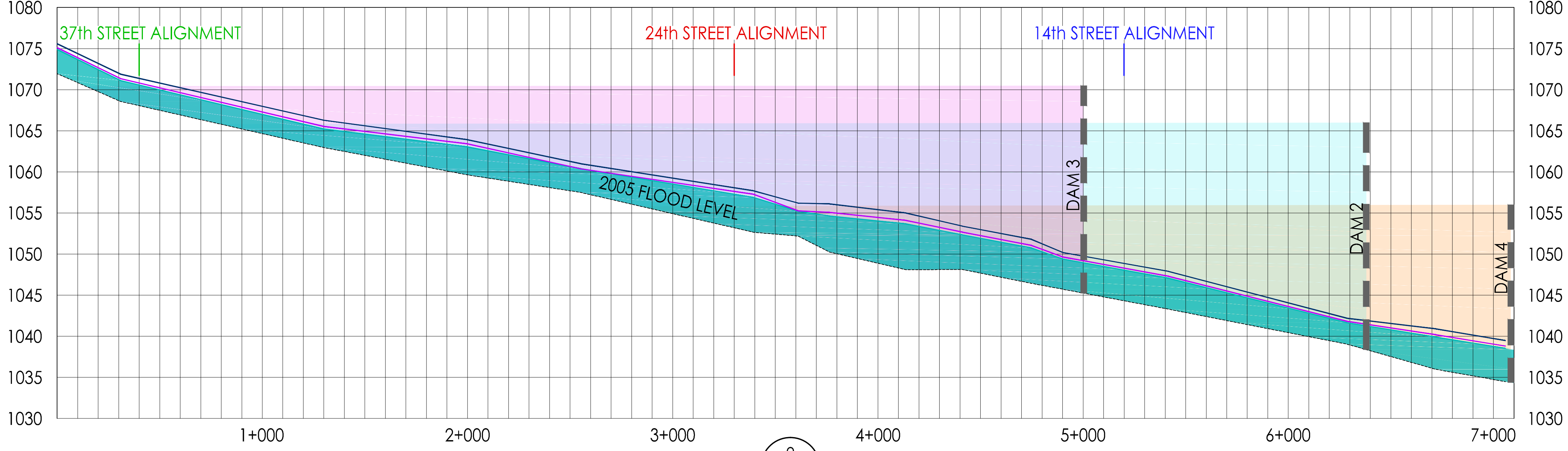
Figure No.
6.0

Title
FISH CREEK VALLEY STORAGE OPTIONS



1 FISH CREEK FLOOD EXTENTS OF DIVERTED FLOW (250m3) PLUS 100-YR EVENT WITHOUT RESERVOIRS

1: 15 000



2 FISH CREEK PROFILE

H 1 : 25 000 V 1 : 625

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ORIGINAL SHEET - ANSI B

October, 2015
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Stantec

Legend

EXISTING GROUND
100yr + 250m³/s FLOOD WATER LEVEL
100yr FLOOD WATER LEVEL
2005 FLOOD WATER LEVEL
DAM LOCATION
DAM RESERVOIR PROFILE
MAIN CHANNEL FISH CREEK

Notes

1.0 DAM 1 IS NOT SHOWN AS IT IS OFF THE FISH CREEK CHANNEL

Scale: NO SCALE

Client/Project

THE CITY OF CALGARY
GLENMORE RESERVOIR TO FISH CREEK FLOOD
DIVERSION FEASIBILITY ASSESMENT

Figure No.

7.0

Title

FISH CREEK FLOOD EXTENTS

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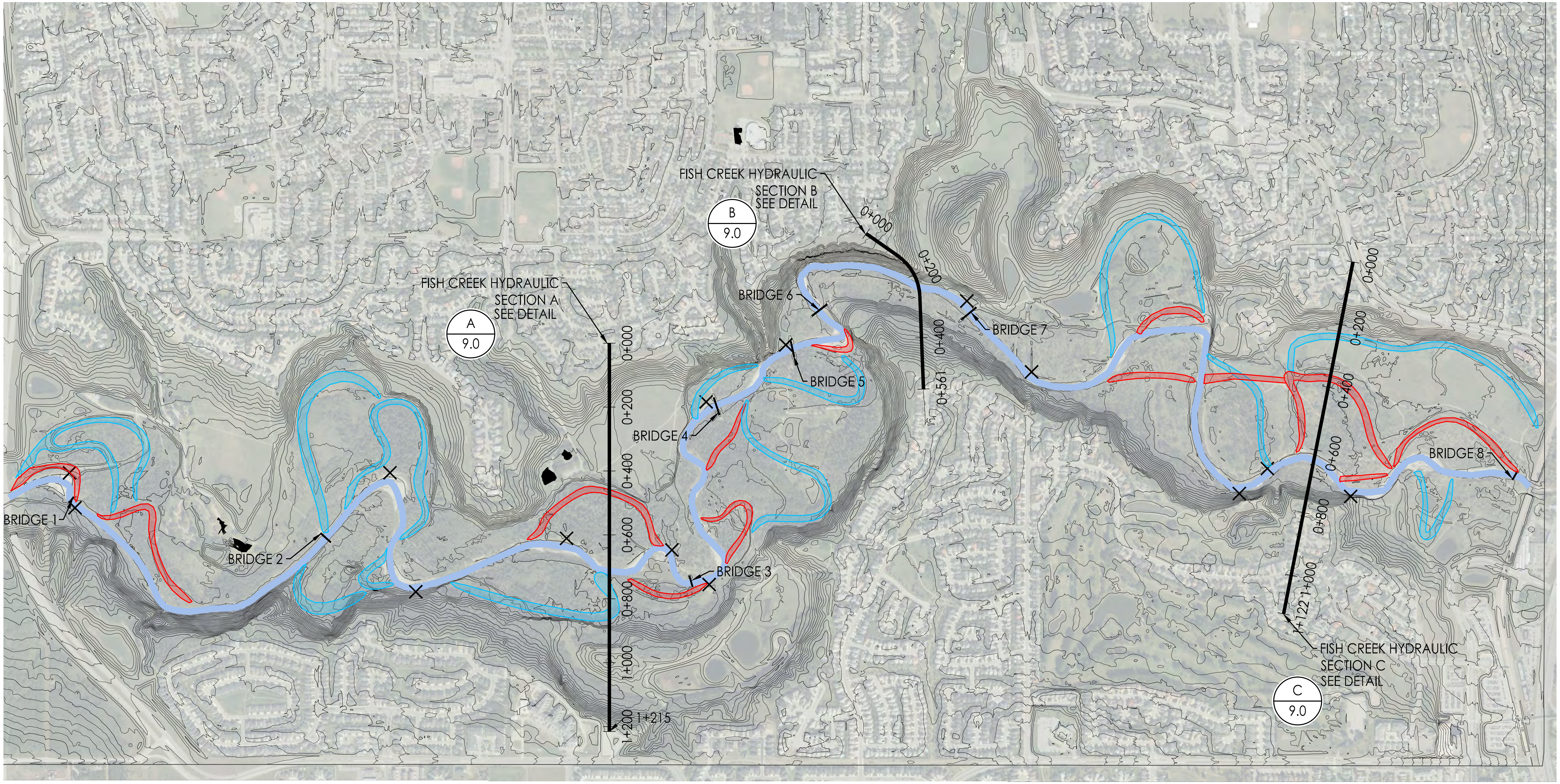

1
–
–

GEOMORPHOLOGICAL EFFECTS PLAN VIEW
1 : 12 500

ORIGINAL SHEET - ANSI B

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110773407

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Legend

🟥 SUB-CHANNEL (HIGH RISK OF ACTIVATION)
🟦 SUB-CHANNEL (LOW OR MODERATE RISK OF ACTIVATION)
✕ EROSION CONCERN SITE

Notes

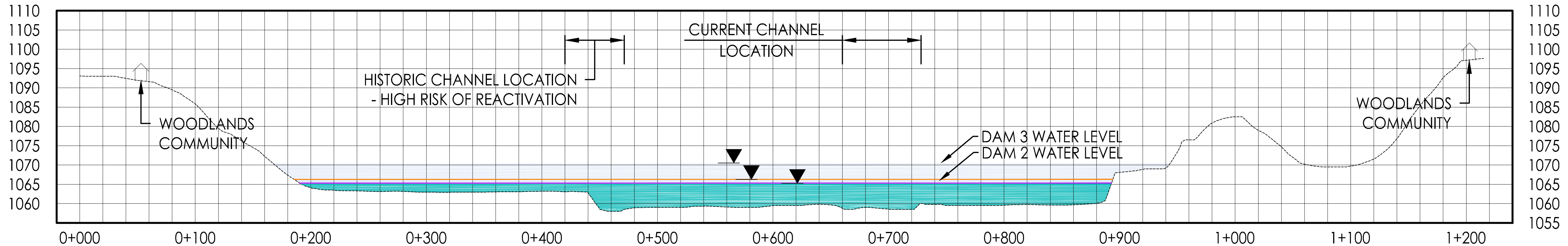
1.0 CONTOUR INTERVALS ON SITE PLAN ARE 10m MAJOR AND 2m MINOR

Scale: 1:12 500 0 125 375 625m

Client/Project
THE CITY OF CALGARY
GLENMORE RESERVOIR TO FISH CREEK FLOOD DIVERSION FEASIBILITY ASSESMENT

Figure No.
8.0

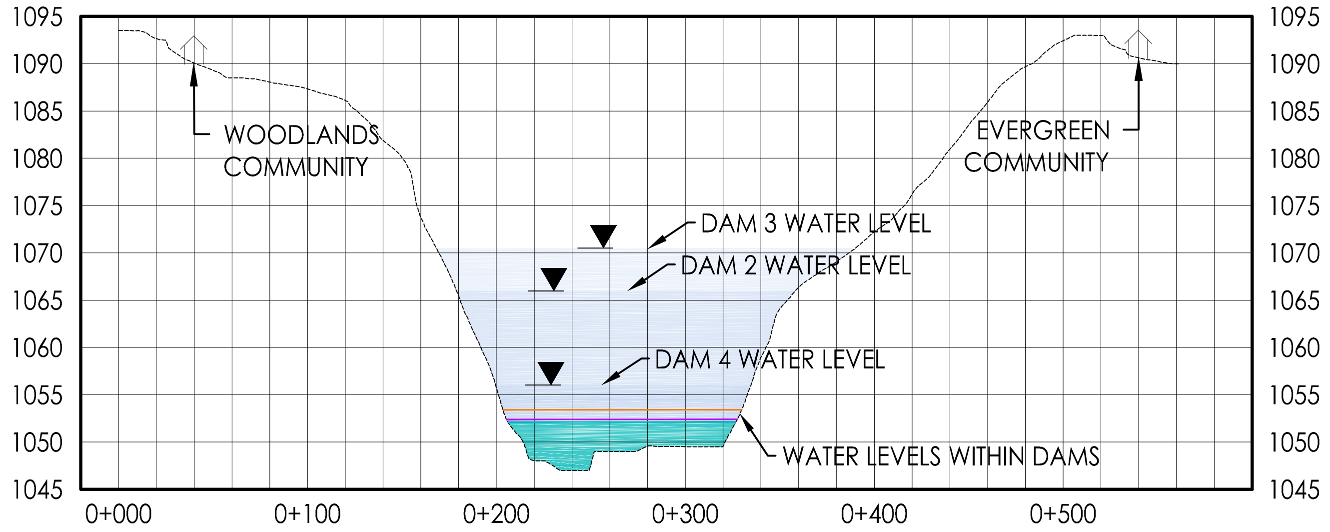
Title
POSSIBLE GEOMORPHOLOGICAL EFFECTS OF DESIGN DIVERSION ON FISH CREEK



A

SECTION A

H 1:4000 V 1:1200



B

SECTION B

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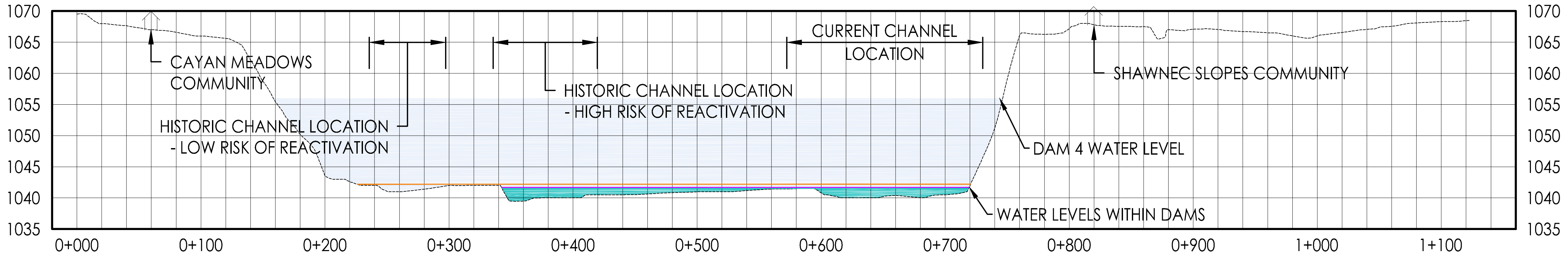

C

SECTION C

H 1:4000 V 1:1200

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ORIGINAL SHEET - ANSI B

October, 2015
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Stantec

Legend

- — 100yr + 250m³/s FLOOD WATER LEVEL
- — 100yr FLOOD WATER LEVEL
- — 2005 FLOOD WATER LEVEL
- ▭ WATER LEVELS FROM DAMS

Notes

Scale: NO SCALE

Client/Project

THE CITY OF CALGARY

GLENMORE RESERVOIR TO FISH CREEK FLOOD
DIVERSION FEASIBILITY ASSESMENT

Figure No.

9.0

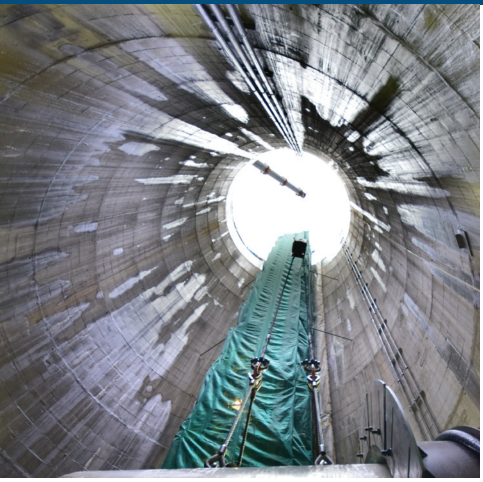
Title

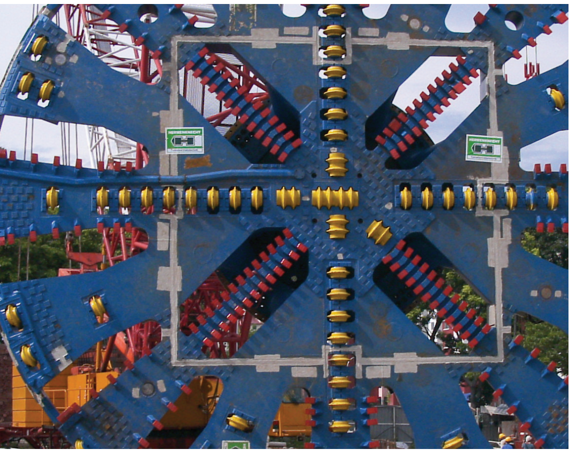
FISH CREEK KEY HYDRAULIC SECTIONS

THE CITY OF
CALGARY

FINAL REPORT

CITY OF CALGARY
GLENMORE RESERVOIR DIVERSION
FEASIBILITY STUDY





Hatch Mott
MacDonald

THURBER ENGINEERING LTD.

>> PREPARED FOR:
The City of Calgary, Water Resources
PO Box 2100, Stn M #438
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Canada

JULY 18, 2014

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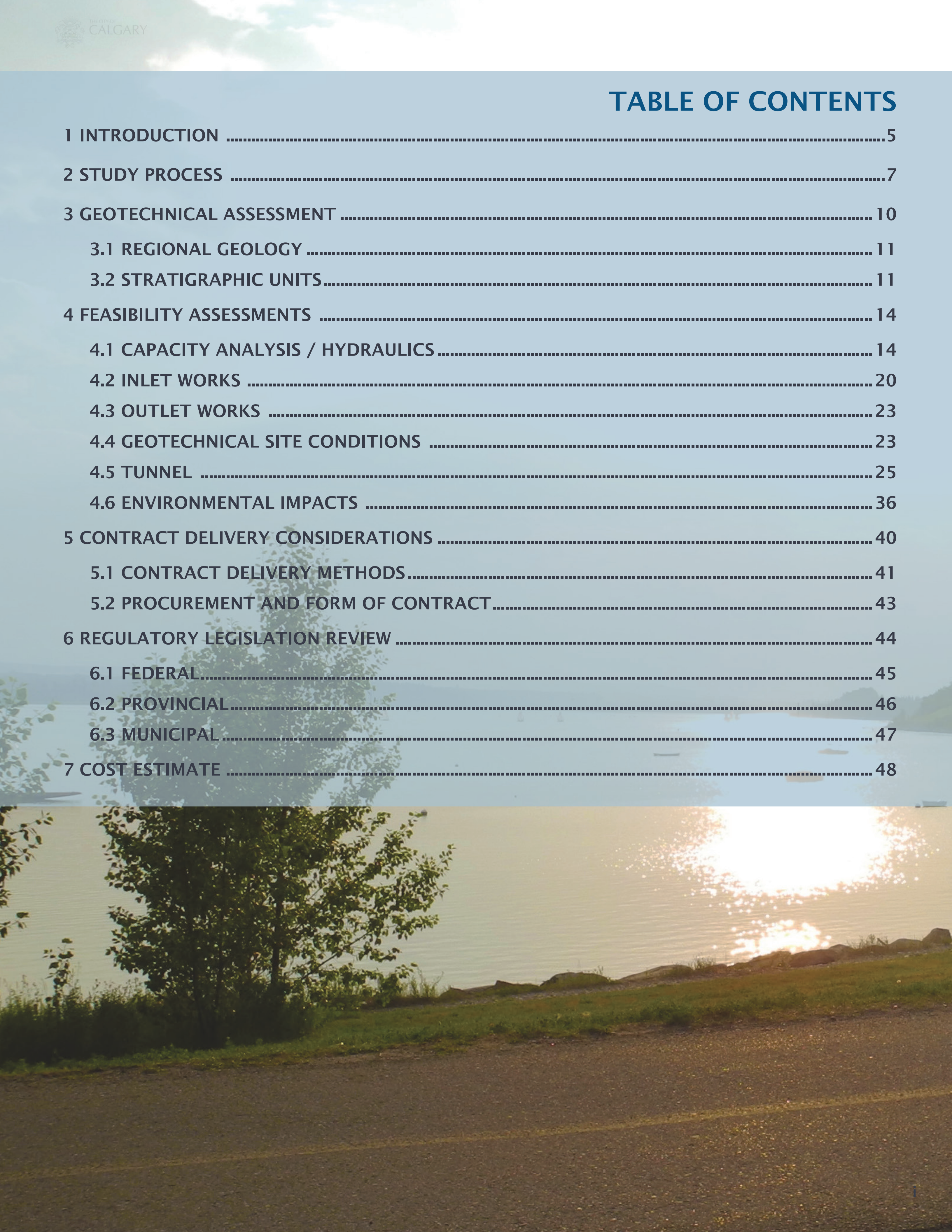


TABLE OF CONTENTS

1

INTRODUCTION

The great flood of 2013 was a devastating event for southern Alberta and the city of Calgary. The flood event had the largest economic impact of any extreme weather event in Canada to date. As part of their response to protect communities from future flood damage, the Province of Alberta commissioned a study (the Flood Mitigation Report, October 2013) through the Flood Mitigation Advisory Panel to provide engineering assessments and practical solutions on possible flood mitigation measures.

1 INTRODUCTION

The preliminary feasibility assessment for the diversion considered three tunnel diversion alignment options from the Glenmore Reservoir: 1) along 58th Avenue South to the Bow River; 2) along Heritage Drive to the Bow River; and 3) to Fish Creek. The third option was subsequently deleted from further review because of potential impacts to Fish Creek. The Flood Mitigation Report advanced the review of these options to the pre-feasibility level.

The City of Calgary retained Hatch Mott MacDonald (HMM) in March 2014 to prepare a more detailed feasibility study to provide recommendations for the preferred tunnel alignment; develop more accurate cost estimates for the diversion; confirm the cost-benefit for a tunnel diversion; and provide recommendations for a suitable delivery model for the Glenmore Reservoir Diversion. This report documents the results of this detailed feasibility study.

2

STUDY PROCESS

During the early stages of the study process, it was important to address the question of tunnel alignment and location. The project scope of work required the assessment of two alternative tunnel alignments: 58th Avenue South to Bow River; and Heritage Drive to Bow River, as shown in **Figure 2-1**.

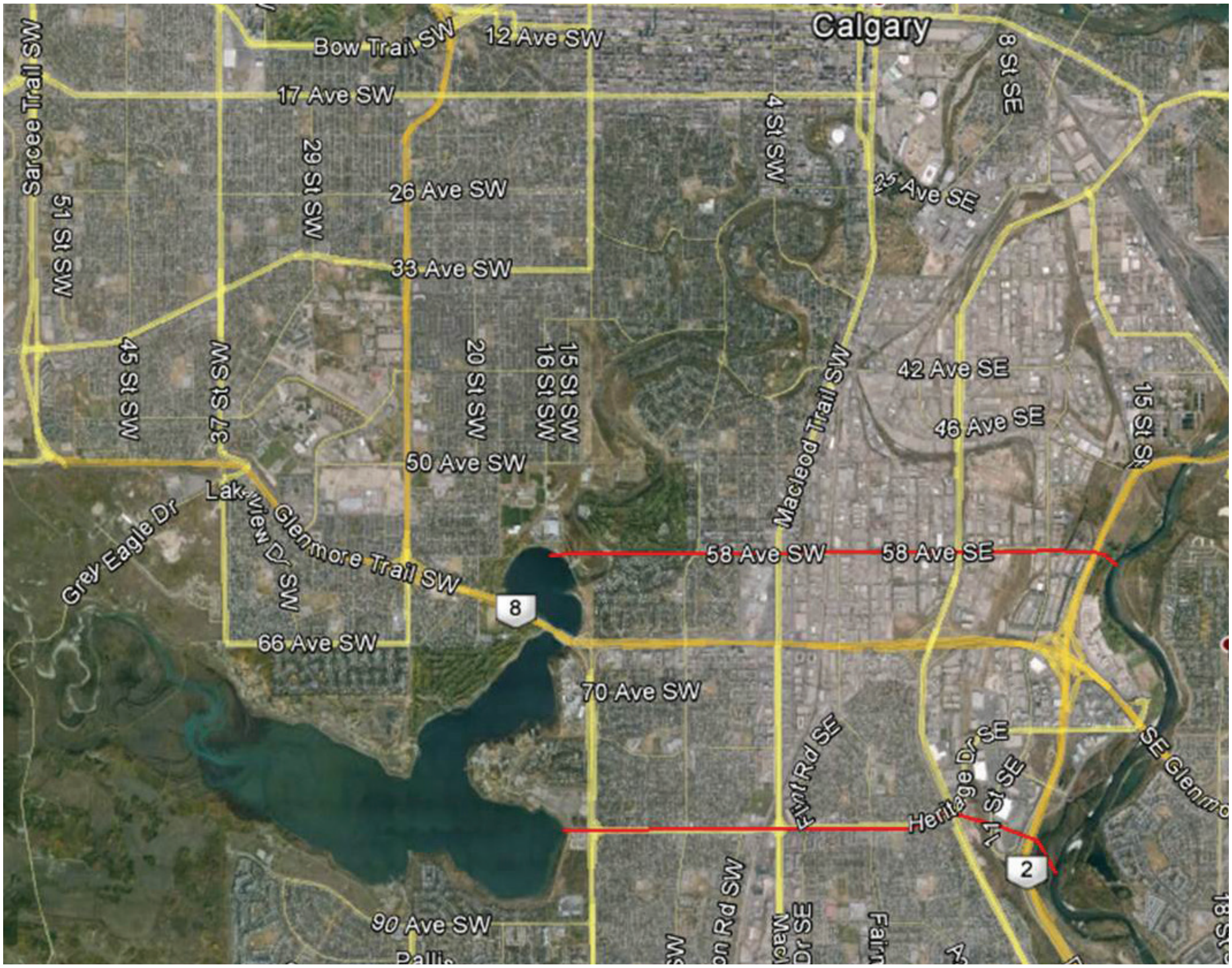


Figure 2-1 Alignment Options Aerial

The 58th Avenue alignment requires that the inlet works be located near the downstream end of the Glenmore Reservoir – a relatively complicated and congested area. Existing utility routes will make it difficult to utilize the area located along and immediately in behind the east dike line of the Reservoir. Although it may be possible to avoid the east dike line, and construct some form of vertical intake in the Reservoir, this may be difficult logistically to construct and tie into an excavated tunnel. It is likely that the best option for the inlet works of the 58th Avenue alignment is to physically locate the intake structure downstream of the existing dam. An intake could be built into/under the high banks in the river at this location. By building a small check structure in the river downstream of the dam, it would be possible to stage up water levels and divert the flow into some form of vertical drop inlet. It should be noted, however, that if the inlet is located downstream of the dam, the head available to drive water through the conveyance system will be almost 20 m smaller. Therefore, the maximum velocity that can be attained in the tunnel would also be considerably smaller, and initial estimates suggest the overall cross-sectional area of the tunnel would need to be approximately 25% larger to compensate for the lost head.

A deep tunnel on the 58th Avenue alignment would pass through similar rock conditions as the Heritage Drive alignment, but the 4.9 km-long tunnel would be approximately 700 m longer than the Heritage Drive option. At the tunnel exit, there is a considerable area available within which to locate the outlet structure, which is advantageous. However, since the outlet is located further upstream on the Bow River, overall flood damage reduction potential may be slightly less for this alignment.

For the Heritage Drive route, the inlet works can be located near or within the parking areas just south of the main access road into Heritage Park. A considerable area is available, making construction easier to execute at this location. Since it is relatively easy to connect into the Glenmore reservoir, a larger head can be utilized to drive flow through the tunnel allowing a smaller tunnel cross section to be used. The Heritage Drive tunnel is approximately 4.2 km in length. The available area within which to locate the outlet structure and launching trench at the east end of the tunnel alignment is smaller than for the 58th Avenue option, owing to the very close proximity of Deerfoot Trail to the Bow River. However, the orientation of the tunnel exit and the Bow River is quite favourable in terms of re-entry of flows into the Bow River.

Table 2-1 provides a comparative assessment of the two tunnel alignments.

TABLE 2-1 COMPARATIVE REVIEW OF ALTERNATIVE ALIGNMENTS

KEY PARAMETER	58TH AVENUE SOUTH	HERITAGE DRIVE	FAVOURED
Inlet works	Relatively congested site – limited availability due to existing utilities, etc.	Relatively easy access and considerable space downstream of east dyke.	Heritage Drive – most flexible
Tunnel length	Best option is to construct an intake downstream of the Glenmore Dam	Approximately 4.2 km	Heritage Drive – shorter tunnel
Tunnel diameter	Approximately 4.9 km	Highest driving head – lowest tunnel diameter	Heritage Drive – smallest diameter
Flood Damage Reduction Potential	Outlet located further upstream – cannot protect as many properties on the Bow River	Outlet located further downstream – can lower flood levels at a greater number of properties on the Bow River	Heritage Drive – greatest damage reduction potential
Outlet	Relatively large open area for outlet area and tunnel launch	Smaller area available for outlet, but well aligned with Bow River	58th Avenue – most flexible

Based on the above, the Heritage Drive route is considered to be the preferred tunnel alignment. This feasibility study, therefore, focuses on this alternative.

This assessment consisted of a review of published and unpublished geological and geotechnical data from the Calgary region. Borehole data were also reviewed, including a This assessment consisted of a review of published and unpublished geological and geotechnical data from the Calgary region. Borehole data were also reviewed, including a geotechnical assessment of five boreholes completed along the 58th Avenue alignment in the fall of 2013 as part of a preliminary study conducted for the Province of Alberta. No additional field investigations were conducted at this stage.

This information was used to develop preliminary stratigraphic sections along the two proposed alignments. Brief descriptions of the major stratigraphic units were also prepared and are summarized in the following sections.

It should be noted that a number of limitations exist with respect to the geotechnical data that has been collected at this stage. First, the majority of the test holes available for this assessment were relatively shallow and did not penetrate significantly into bedrock. Further, many of the boreholes assessed were drilled using percussion methods such as the Becker hammer. These drilling methods destroy the natural fabric of the native soils, limit identification of their geological origin, and introduce uncertainty in the identification of material depths. As such, the following information should be considered preliminary only.

3

GEOTECHNICAL ASSESSMENT

A preliminary geotechnical assessment was performed along the proposed Heritage Drive and 58th Avenue alignments by Thurber Engineering Ltd. The complete report and figures are provided in **Appendix B**.

3 GEOTECHNICAL ASSESSMENT

3.1 REGIONAL GEOLOGY

The city of Calgary is located at and around the confluence of the Bow and Elbow Rivers near the western edge of the Canadian plains and approximately 90 kilometres east of the Front Ranges of the Rocky Mountains.

The primary bedrock unit of interest in this area is the Tertiary Paskapoo Formation, a highly variable sedimentary unit approximately 600 m thick. Surficial sediments overlying the bedrock were deposited during various glacial advances and retreats during the Pleistocene glaciation, with additions from both pre-glacial and post-glacial river deposition. Glacial soils on the west side of the city were deposited by ice originating in the Rocky Mountains, whereas those on the east side were transported by the Keewatin ice sheet which came from the northeast. The zone of coalescence of western and eastern ice contains a string of glacial erratics (i.e. large ice-transported boulders), originating in the mountains then deposited along the junction where the western and eastern ice masses collided and flowed southward together (Osborn, 2006).

After the ice retreated from the area, rivers such as the Bow and Elbow cut down to their present levels, creating steep slopes adjacent to the modern floodplains. Alluvium was then deposited in these areas, and constitutes the majority of the sediments on the eastern edge of the study area, close to the Bow River.

3.2 STRATIGRAPHIC UNITS

The stratigraphy along the two proposed tunnel alignments is presented in **Appendix B**. Based on the geotechnical information from the borehole logs, the following geological units have been identified:

3.2.1 SURFICIAL DEPOSITS

Undifferentiated Deposits: This unit is composed of a variety of soils, ranging from fill of variable thickness, organic soils, clays, silts and sands of lacustrine origin, and occasional gravel layers. Colluvium derived from various units is found at the Bow River escarpment on the eastern edge of the alignments. The fill typically consists of reworked native soils, and may contain construction debris.

Alluvial Sand and Gravel: This unit consists predominantly of gravels, sandy gravels, and gravelly sands as well as cobbles, occasional boulders and occasional silt/clay layers. The gravel is generally well graded with well-rounded particles, and contains fine to coarse grained sand. The gravel beds are frequently cemented and interlocked, and steep excavation faces will stand-up for some time when above the water table. These deposits are considered to be dense to very dense and very pervious, with hydraulic conductivities in the range 0.02 cm/s to 2 cm/s.

Pre-glacial Sand and Gravel: This unit lies between bedrock and the overlying till along both alignments. Whitaker and Christiansen (1971) note that such deposits include a wide range of sediments laid down as fluvial, lacustrine and colluvial deposits prior to and during glaciation. They report thicknesses in excess of 30 m in Saskatchewan, whereas in Calgary, a thickness of 7.3 m was measured in a borehole in the study area (Moran, 1986). It should be noted that evidence of the existence of these pre-glacial soils along the two tunnel alignments comes from Moran's mapping, and from interpretation of three test holes where a layer of gravels was encountered below the till/lacustrine deposits. As such, these boundaries should be considered preliminary and will require further investigation if they are of significance to the project.

Glacial Till and Lacustrine Soils: A considerable number of till units overlie the bedrock and/or the pre-glacial gravels, and have been given different names by authors based primarily on subtle differences in gravel composition, fabric, grain size, clay mineralogy and plasticity. The tills are irregularly interbedded with poorly to moderately stratified sands and gravels of variable thicknesses, as well as glaciolacustrine sediments formed during glacier advances and retreats. Geotechnically, the local tills are generally classified as low to medium plastic clay tills using the Modified Unified Soil Classification (generally adopted in the Prairies by geotechnical consultants). They do, however present relatively high silt contents and are classified as stiff to very stiff on the basis of estimated undrained shear strengths (Osborn and Rajewicz, 1998).

3.2.2 Bedrock

The Paskapoo bedrock consists predominantly of flat lying to gently dipping sandstones, siltstones, and mudstones (locally called claystones and/or clay shales). No major faulting or folding has been reported; however, the bedrock is known to contain jointed, more permeable zones. There is often a weathered horizon near its surface, generally extending 1 m to 2 m below surface, but sometimes penetrating to 4 to 6 m (**Figure 3-1**).

In general, the bedrock is typically classified as a weak or soft rock, with unconfined compressive strengths (UCS) generally ranging widely. UCS values as low as 0.2 MPa in the mudstones and greater than 160 MPa in the siltstones/sandstones have been measured.

From the preliminary geotechnical investigation along 58th Avenue, the mudstones were typically classified as extremely weak to weak (0.25 MPa to 25 MPa) and the sandstones as moderately strong (25 MPa to 50 MPa) with occasional weak zones (Stantec, 2013).

Common layer thicknesses for the Paskapoo bedrock have been obtained from a review of field investigations for shallow tunnelling projects around the Calgary area. Common layer thicknesses are 0.3 to 0.4 m for sandstone, 0.2 to 0.3 m for siltstone and 0.1 to 0.2 m for mudstone (Crockford, 2012). Layer thicknesses up to 7 m were encountered in the deep borings along 58th Avenue (Stantec, 2013). The relative abundance of these units can be highly variable in the Calgary region, as shown in **Figure 3 2**.

Rock Quality Designation (RQD) is generally above 60%, except for the upper 1 to 3 m below the top of the bedrock where it can be lower. CERCHAR abrasivity indices (CAI) up to about 2.0 have been measured in a limited number of tunnel projects.

X-ray diffraction tests in the claystones have shown absence of highly active smectite and predominance of less active illite and kaolinite clay minerals. Based on the results of index testing, the mudstone beds are sometimes classified as high plastic, and having

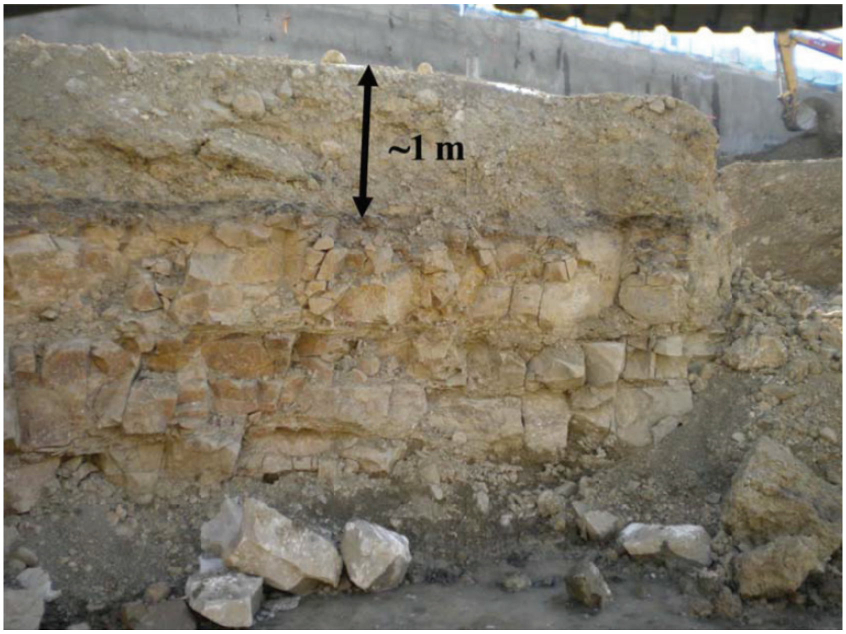


FIGURE 3-1 – Excavation site in Calgary showing weatherd zone on top of bedrock (Crockford, 2012) a moderate to high swelling potential. Some of the mudstones have also been found to slake, i.e. lose strength and disintegrate on contact with water.

With respect to stress conditions, a coefficient of earth pressure at rest (Ko) of 1.6 is typically recommended based on anecdotal evidence related to back-analysis of excavations in the city's downtown core. Lardner et al. (2008) suggest that large lateral in-situ stresses were encountered during the recently completed Bow Project (Ko = 2.0).

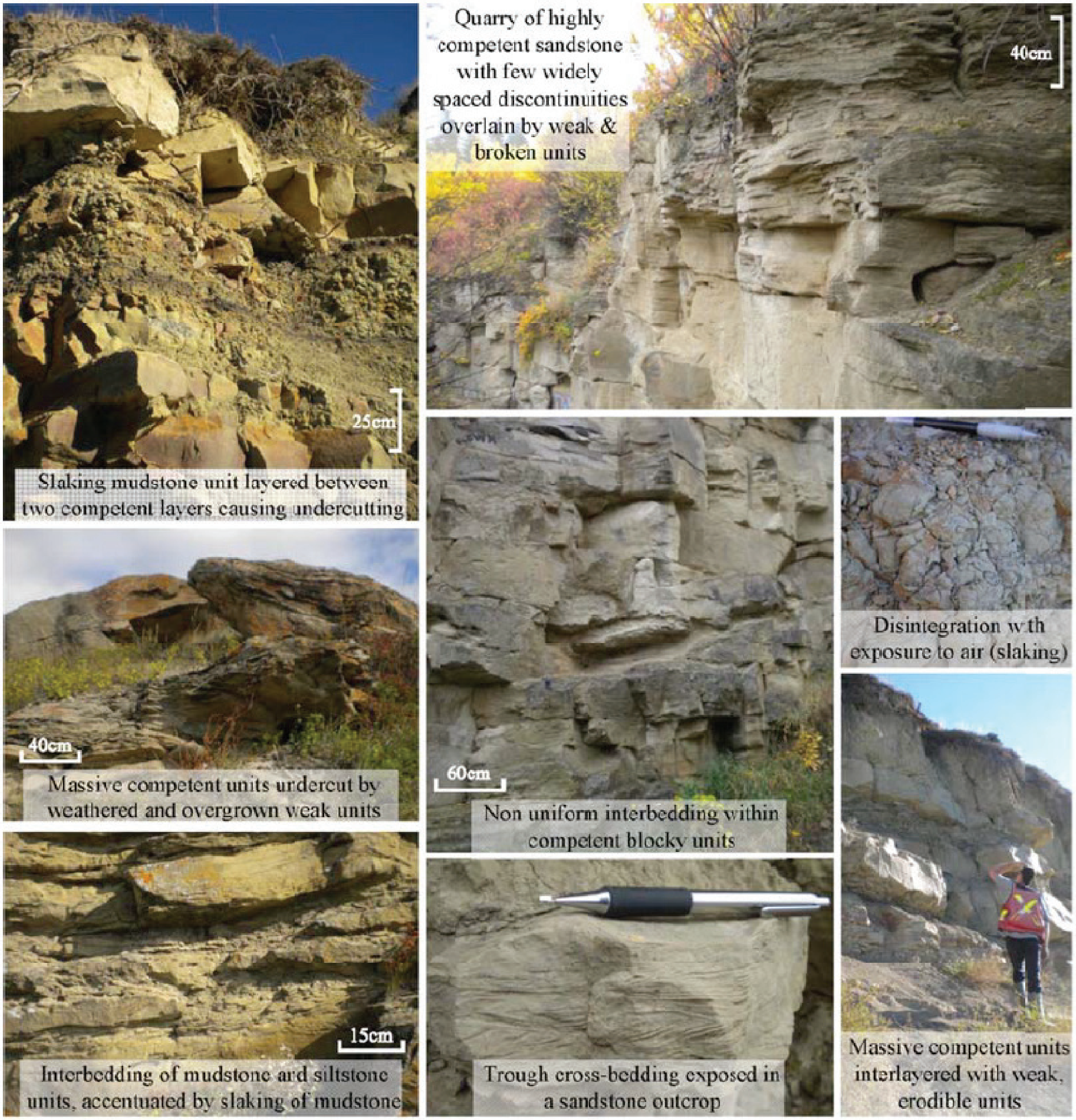


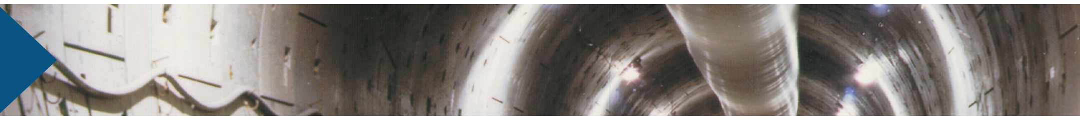
Figure 3-2 – Outcrop photographs from the Calgary region showing geological variability in the Paskapoo Formation (Crockford, 2012)

4

FEASIBILITY ASSESSMENTS

4.1 CAPACITY ANALYSIS / HYDRAULICS

One of the key hydraulic challenges associated with this project is the development of a tunnel system that is able to convey the diversion flows safely and efficiently from the Glenmore Reservoir through to the Bow River. The successful system must provide an efficient means to divert water into the tunnel, transmit these diverted flows along a 4 to 5 km distance (while managing the possible effects of surges and transients, cavitation, and excessive air entrainment), and releasing these flows back into the Bow River with minimum disruption to the existing aquatic regime.



Control on flow through the system can be achieved by one or a combination of structures at the tunnel inlet and/or outlet. Given that this is fundamental to the design process, it required that an early decision be made on the type of control to adopt for the tunnel system. Two possible options were considered:

1. **Inlet Control:** For an inlet controlled system, flow through the tunnel would be regulated near the upstream end of the tunnel using some form of regulating gate. Energy would be primarily dissipated along the tunnel length, and velocities at the outlet would be managed with a simple diffuser.
2. **Outlet Control:** For an outlet controlled system, flow through the tunnel would be regulated near the downstream end of the tunnel, again using some form of regulating gate. Flows released from the outlet structure would be released into a stilling basin, designed to safely manage super-cavitating flows.

There are various advantages and disadvantages associated with the two types of control. From a hydraulic perspective, outlet control is preferred since it provides excellent control over velocities in the tunnel system, easy maintenance for any mechanical equipment and gates, and an efficient way to dissipate energy in an open water environment. However, a major disadvantage of this control scheme is that fact that under a static load case, the entire tunnel is pressurized to a hydraulic grade line equivalent to the reservoir elevation along the entire tunnel length. As a result, there would be a very high internal pressure in the outlet area where the rock cover is at its lowest.

The high internal tunnel pressures will have two important impacts on the tunnel design:

1. A much more extensive tunnel lining would be needed to ensure the internal pressures could be safely managed, particularly in the tunnel outlet area. The lining would therefore require additional design effort and the thicker lining would significantly increase the support cost.
2. The tunnel would also need to be deeper at the outlet (necessitating a 65 m deep outlet shaft) in order to provide suitable rock pressure to prevent hydrojacking in the rock should leakage occur. This would require launching of the tunnel boring machine (TBM) from a shaft as opposed to a less costly (and shorter construction duration) launch box at the outlet.

These two points are considered to be of sufficient importance to preclude further consideration of the outlet control option. Therefore, the design concept presented in this study report is based on an inlet control arrangement.

Other hydraulic design considerations associated with the tunnel design include:

- **Pressurized flow:** In order to avoid damaging transient flow conditions, it is recommended that the flow regime for the tunnel system be either a pressurized conduit or an open channel over its full length. This would avoid the complexities of accommodating transitory flow regimes in the tunnel where the flow may switch from open channel flow to full conduit flow. Such occurrences in other facilities have sometimes led to catastrophic failure as a result of the hydraulic transients that can form. It would not be possible to maintain an open water flow regime throughout the tunnel given the depth of the downstream reach required to prevent hydrojacking of the overlying land/rock. Therefore, it is recommended that the system operate as a pressurized flow conduit.

- **Flood Frequency Analysis:** Flood frequency estimates for the Bow and Elbow Rivers were required to: i) select a design capacity for the tunnel, and; ii) allow flood damages to be evaluated over a probabilistically derived range of flood flows. Flood estimates on these two rivers were selected based on information provided in the report entitled: "Hydrology Study, Bow and Elbow River Updated Hydraulic Model Project" (Golder, 2010).
- **Tunnel Design Capacity:** Past studies have indicated that the Elbow River is capable of passing a 1:10 year flood (approximately 200 m^3/s) without incurring significant flood damage along the river. Therefore the operating strategy anticipated for the tunnel is that for up to a ten-year flood event, flows would continue to be released through the Glenmore Dam into the Elbow River. For flows in excess of the ten-year event, the tunnel would begin to divert excess water directly into the Bow River. With this in mind, two tunnel diversion capacities were considered:

   1. A tunnel flow capacity of 500 m3/s, which would allow a 100-year flood event (equivalent to the 2013 flood event) to be safely managed. This tunnel capacity would also safely pass all more frequent smaller than 100-year floods. The peak outflow for this event is 700 m3/s; 200 m3/s will flow to the Elbow River, and 500 m3/s will flow through the tunnel.
   2. A larger capacity tunnel sufficient to safely pass the 200-year flood event. The peak outflow for this event expected outflow is approximately 900 m3/s; 200 m3/s will flow to the Elbow River, and 700 m^3/s will flow through the tunnel. This larger tunnel capacity would also safely pass all more frequent smaller than 200-year floods.

For reference, the 2013 flood hydrograph, which is considered to be a 100-year flood event, is shown in **Figure 4-1** and **Figure 4-2** for the Bow and Elbow Rivers, respectively. The shapes of these hydrographs provide good insight into the temporal characteristics of these types of design flood events. As shown, the peak outflow for this event was relatively steady and persisted for a period of over 12 hours. This is a long enough time period to result in a quasi-steady-state flow condition in the tunnel and on the downstream river reach, therefore calculations for the tunnel capacity and damage assessment for this feasibility study were all completed based on steady-state flow assumptions.

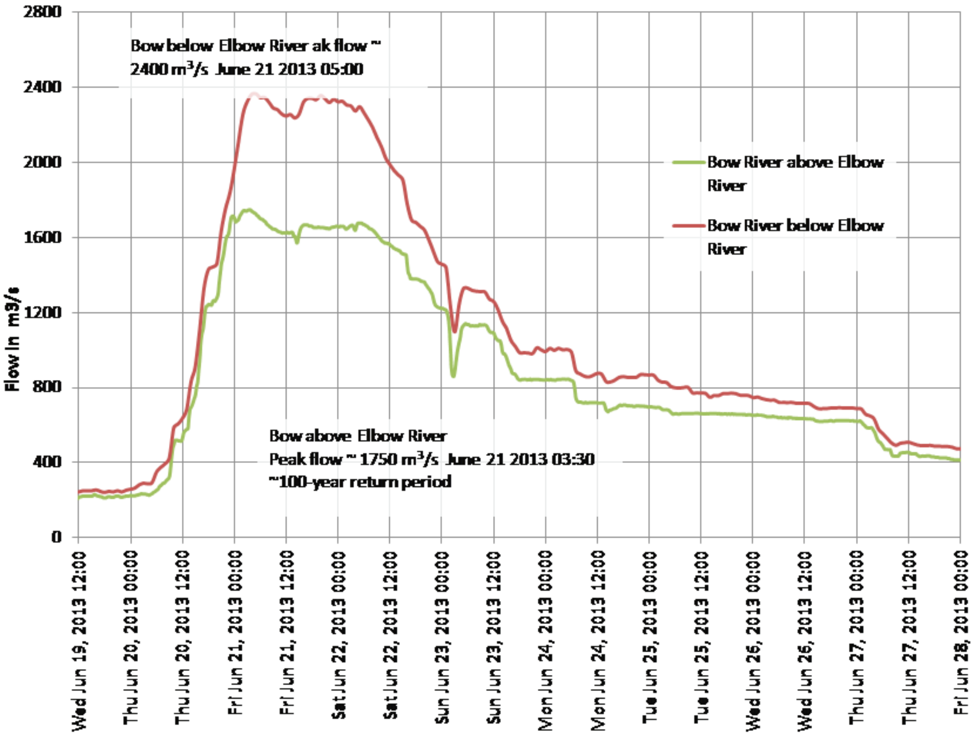


FIGURE 4-1 BOW RIVER FLOWS 2013 FLOOD EVENT

Note: *The presented data has yet to be verified by external sources and must therefore be treated as preliminary in nature and subject to change. Due to the preliminary nature of the data, this information cannot be relied upon and is not being warranted or confirmed by The City of Calgary.*

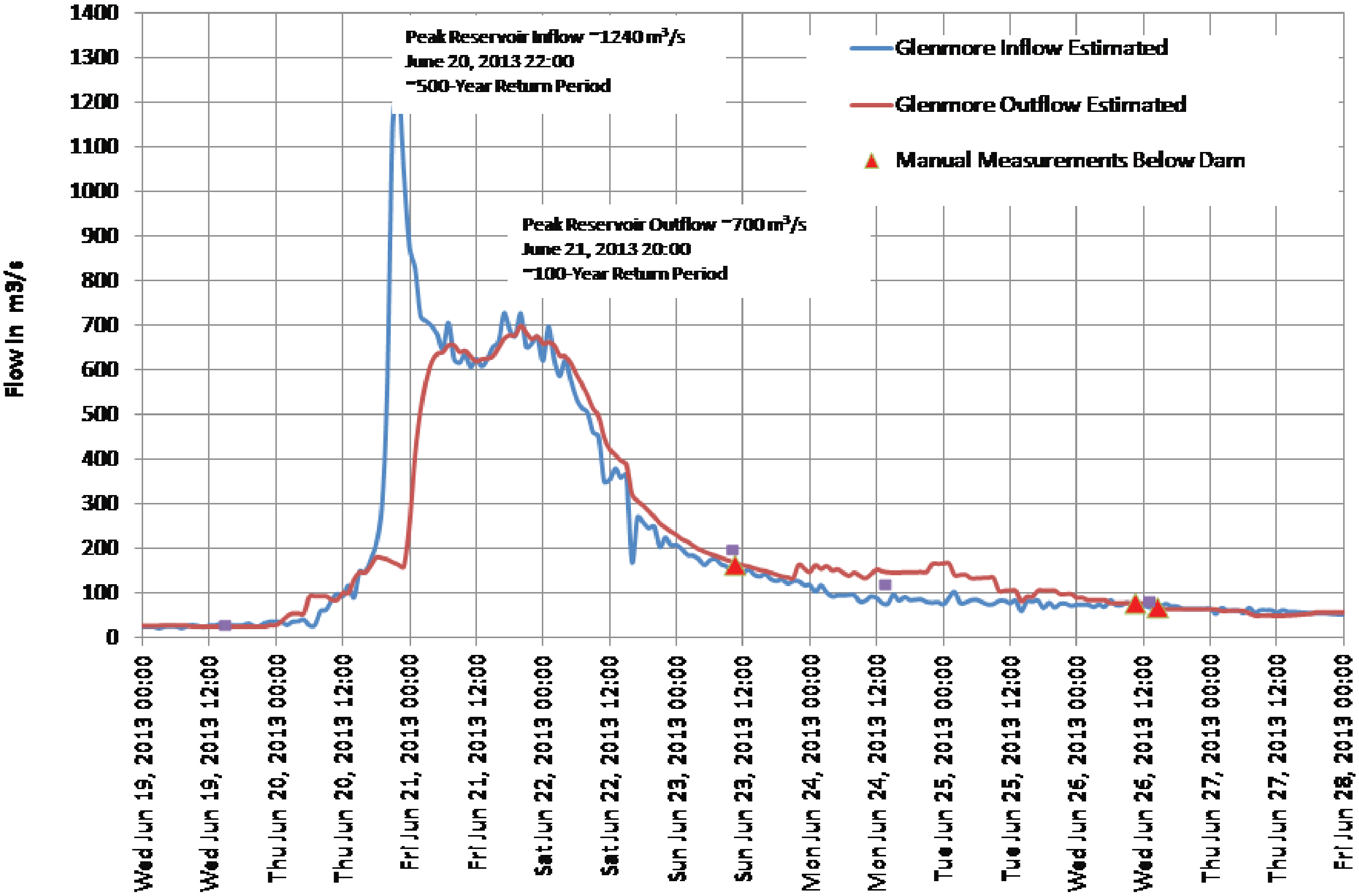


FIGURE 4-2 ELBOW RIVER FLOWS 2013 FLOOD EVENT

- **Tunnel Velocity and Size:** Given the expected nature and roughness of the concrete lining, it is recommended that the maximum average tunnel velocity be restricted to 10 m/s or less when operating at the design condition. This will help to maintain a cavitation index that is at or greater than two throughout the tunnel. It should be noted that locally higher velocities may be acceptable in upstream reaches of the tunnel. The required tunnel size is sensitive to this maximum allowable velocity, and it is desirable to have as small a tunnel as possible. For a design flow of 500 m^3/s, this results in a 8.0 m inner diameter tunnel and for a 700 m3/s design flow this results in an 9.5 m inner diameter tunnel. **Figure 4-3** illustrates the relationship between tunnel design capacity and tunnel diameter.

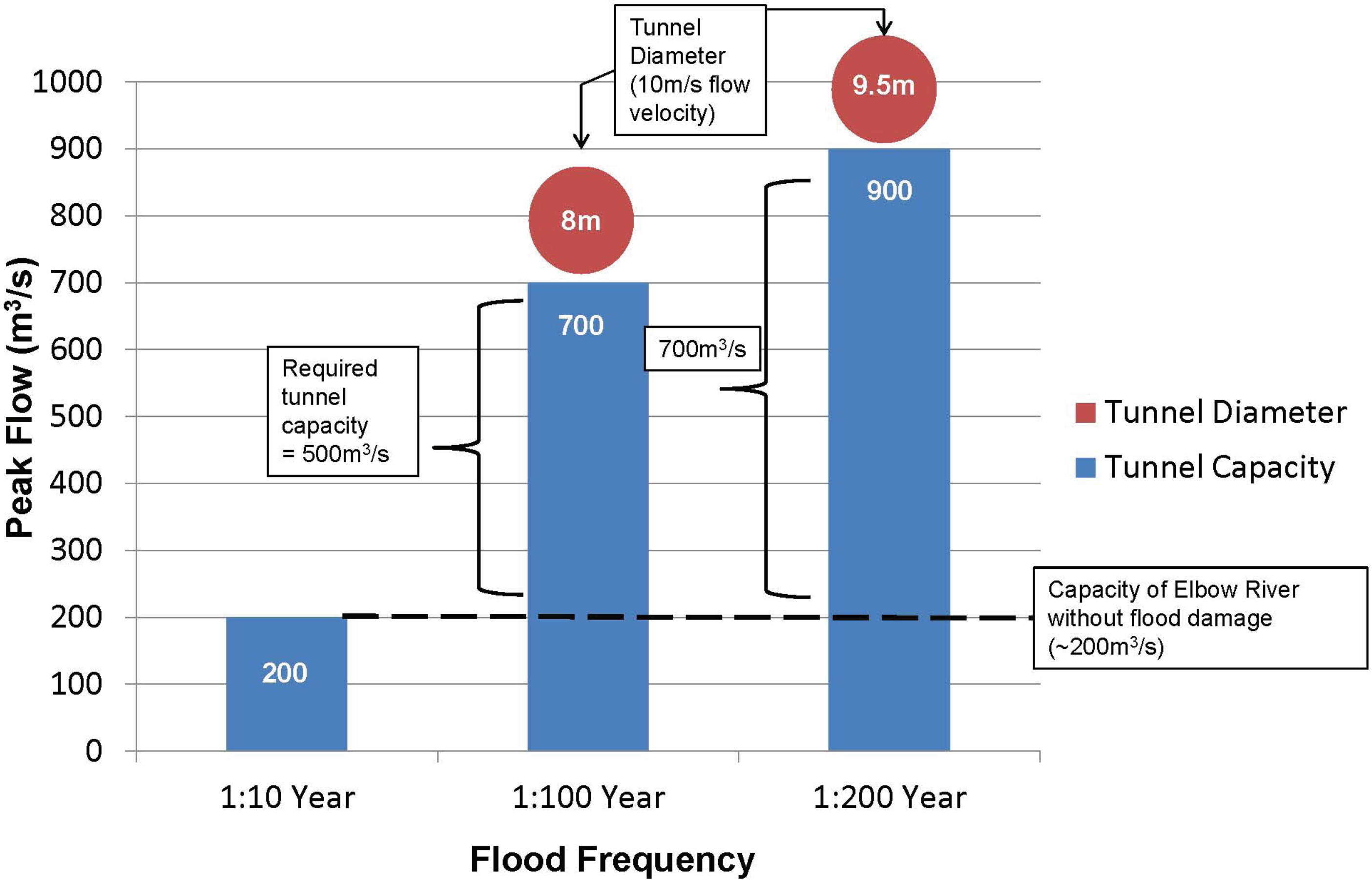


Figure 4-3 Tunnel Capacity and Size

- **Tailwater Conditions:** In the City's 2012 flood mapping study report, entitled "Hydraulic Modelling and Inundation Mapping" (Golder, 2012), information is provided on an updated HEC-RAS model that was set up to simulate water levels along the Bow and Elbow Rivers under various levels of flood. This model and the information provided in the study report was used to prepare tailwater rating curves for the Heritage Drive and 58th Avenue alternative outlet locations, shown in **Figure 4-4**. It should be noted that the development and assessment of the tunnel outlet structure concepts is based on a conservatively low ten-year flood occurring on both the Bow River and Nose Creek in combination with a 100-year flood on the Elbow River.

The hydraulics of the Glenmore Reservoir Diversion tunnel are governed by the differential head between the Glenmore Reservoir and Bow River, and the head losses that occur throughout the tunnel. For the capacity assessment, the Glenmore Reservoir intake water level is assumed to be at the spillway crest elevation of 1075.3 m. This results in a total head loss of 56 m at the Heritage Drive location, and 50.1 m at the 58th Avenue location. Losses through the trashracks, intake transition, intake gate slots, along the concrete lined tunnel, through each bend, through the regulating gate downstream of the inlet and at the outlet were taken into consideration for energy dissipation. All losses resulting from bends, contractions, and expansions were accounted for and were estimated based on standard empirical relationships provided in a design guideline compiled by Miller entitled Internal Flow Systems (Miller, 1978). Friction losses for the tunnel were based on an estimated hydraulic roughness of 2 to 3 mm. This roughness was selected based on existing literature on concrete linings and the installation tolerances for precast concrete tunnel lining segments provided in **Appendix D**. A spreadsheet model was setup to simulate the overall energy and hydraulic grade lines expected along the tunnel when operating at design capacity.

Using this model, a concept for the tunnel and gate configuration was developed. The concept includes the following key components, in order from upstream to downstream:

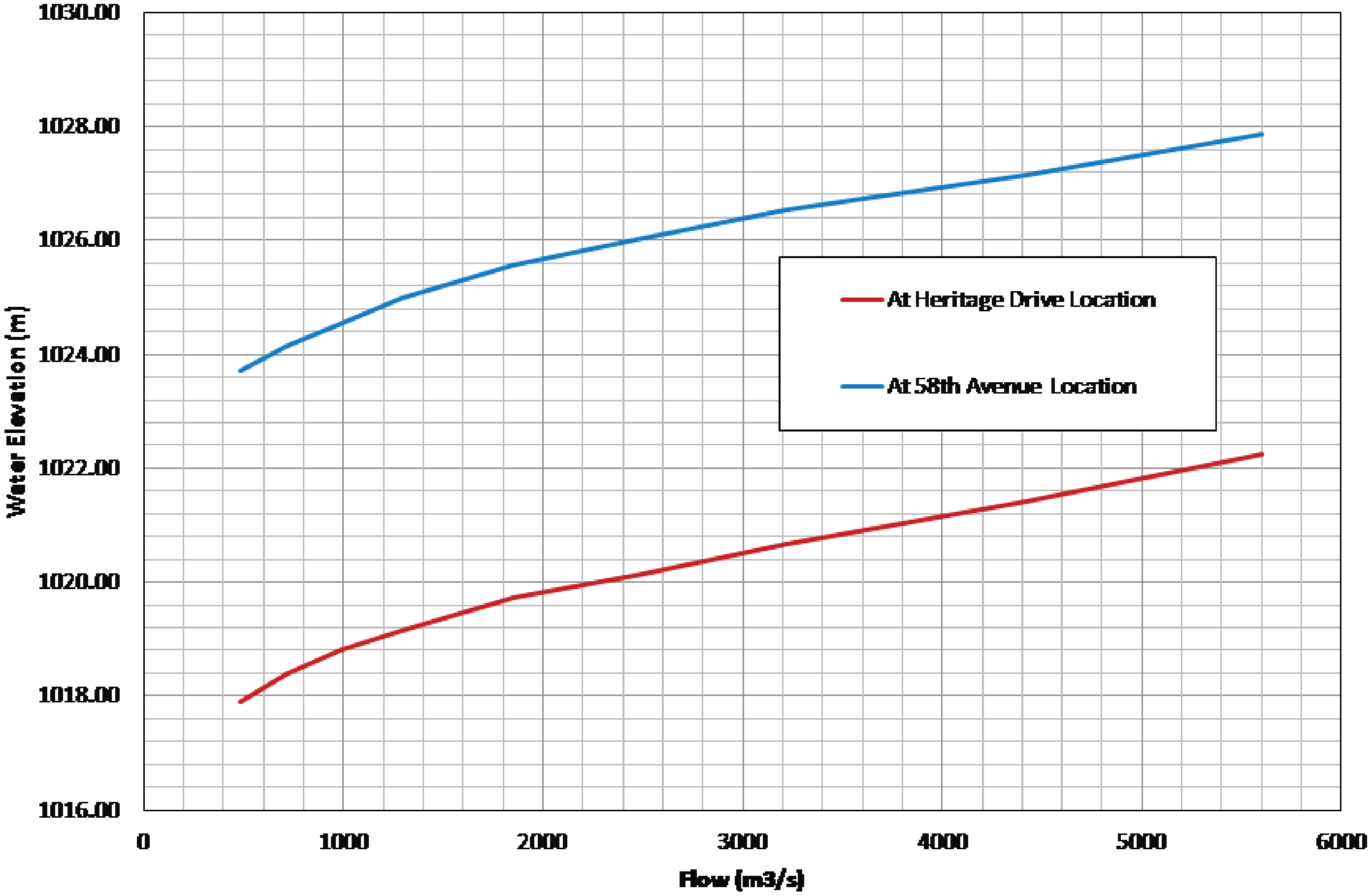
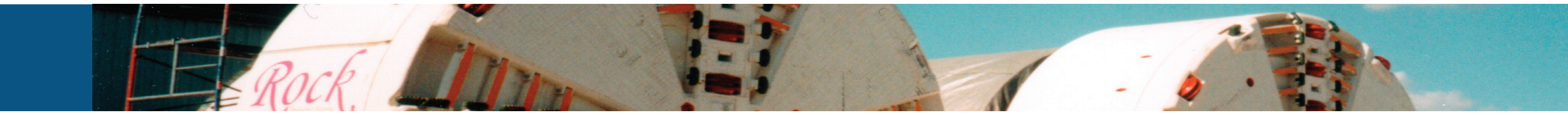


Figure 4-4 Tailwater Rating Curves

- Water from the Glenmore Reservoir flows through a relatively short, dredged channel to enter into a horizontal intake that will be constructed along the same alignment as the existing dyke at the Heritage Drive location.
- The intake itself will consist of three separate water passage bays. Each bay will be equipped with a trash rack and a guard gate that can be closed if need be to isolate the system.
- Downstream of the guard gate, the flow will enter a short, transition section of the intake that will intersect with the upstream access shaft used in the deployment of the TBM. Flow will make a 90 degree bend, to enter the upstream access shaft.
- At the bottom of the access shaft, flow will again turn 90 degrees, and then transition down to a square cross section shape. A bonneted slide gate or slide valve will be located here and will be used to control flow rates in the tunnel.
- The flow from the valve/gate will transition into the downstream tunnel and flow a distance of 4.2 to 4.9 km before reaching the outlet area. The section of tunnel immediately downstream of the slide gate will be lined in steel to provide cavitation protection. Headloss through the tunnel can be effectively managed by adjusting the size of the opening at the regulating gate, and/or possibly adding in small orifice rings along the tunnel periphery.
- At the end of the tunnel, the flow will be released directly into a simple diffuser consisting of a basin with diverging sidewalls that will help to gradually slow down the flow velocity before releasing it into the river.
- Each of these system components was simulated within the hydraulic spreadsheet model, and estimates of hydraulic capacity were made for the tunnel when operating under various gate openings. Of particular interest, the tunnel system was shown to be quite capable of passing each design flow. The final hydraulic grade line plots for both design flows are shown in **Figure 4-5** for the Heritage Drive alignment.



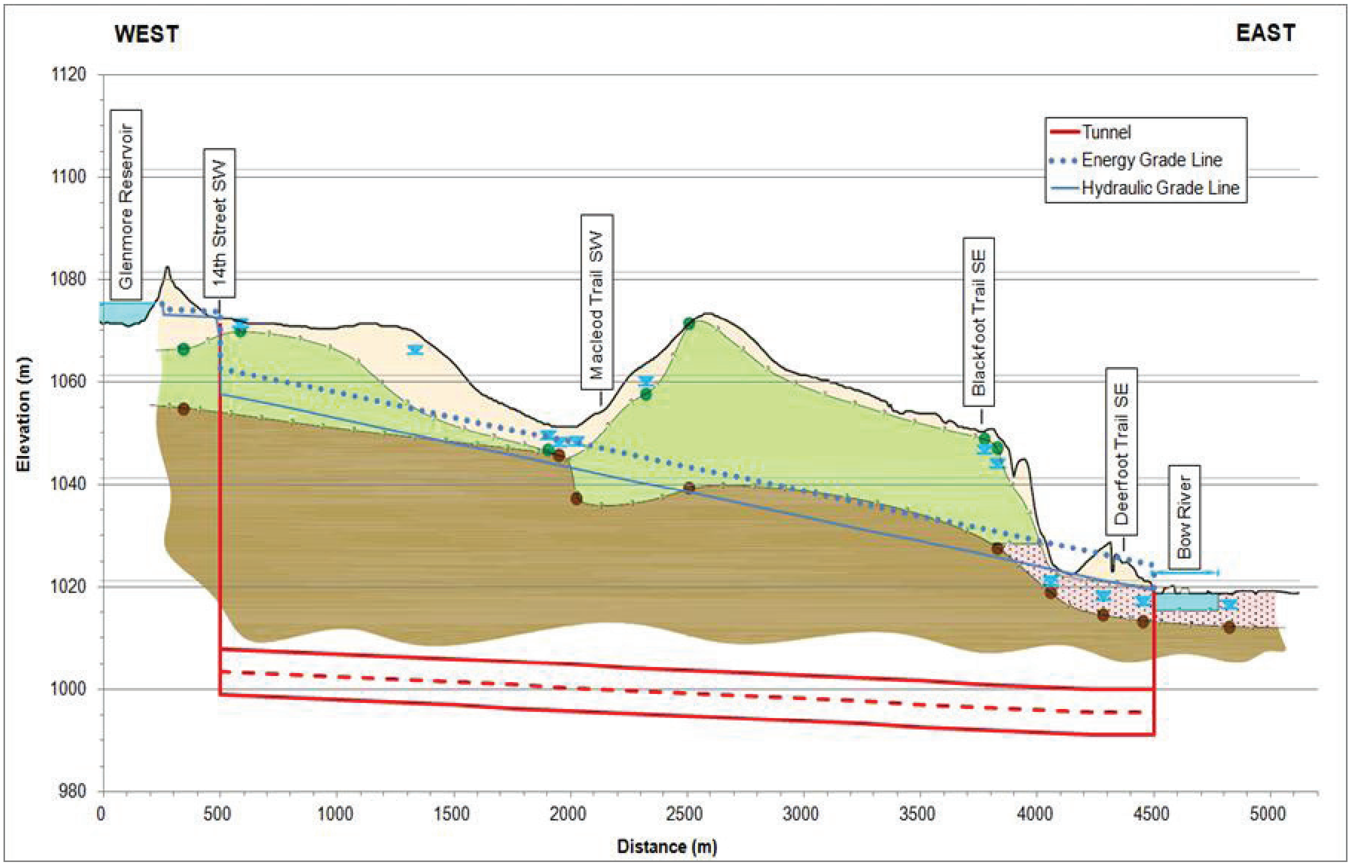


Figure 4-5 Hydraulic Grade Line Plot: Heritage Drive (500 m3/s)

4.2 INLET WORKS

The inlet works represent the entry point for the diversion, and must be designed to safely and efficiently convey water into the tunnel system. The intake configuration for the tunnel can serve the dual purpose of providing access to remove the TBM following excavation of the tunnel as hydraulics demands that it will be of the approximate size needed to remove the TBM, and the incremental cost of upsizing slightly for this purpose outweighs the alternative of burying the TBM. This access shaft will become an effective drop shaft for the inlet. In addition, it is recommended that the intake system include a trashrack, a guard gate, and a separate regulating gate. The trashrack would be relatively coarse in nature, and would serve to prevent large debris from entering the tunnel. The function of the guard gate will be to provide an emergency shutoff for tunnel flows in the event that the regulating gate fails. A separate regulating gate would be constructed to provide flow control capability under smaller flood events.

Various concepts, generally categorized into vertical and horizontal arrangements, were assessed for the inlet works including:

- **Plunge Intake:** A plunge intake (see **Figure 4-6**) normally consists of some form of free overflow structure, set immediately over a vertical drop shaft. Flow passes over the overflow structure, enters the drop shaft radially, and falls vertically into the drop shaft. The Morning Glory design is a typical example, and can be equipped with a ring gate(s) to assist in regulating flow. A separate guard gate can be provided at the base of the drop shaft to provide emergency shutoff capability. The crest elevation for this type of intake is relatively high, which can be advantageous in terms of its ability to minimize the transport of potentially abrasive sediment (that may be present near the bottom of the reservoir) through the tunnel. Conversely, disadvantages potentially inherent in this free-standing inlet design are its

Figure 4-6 Plunge Intake

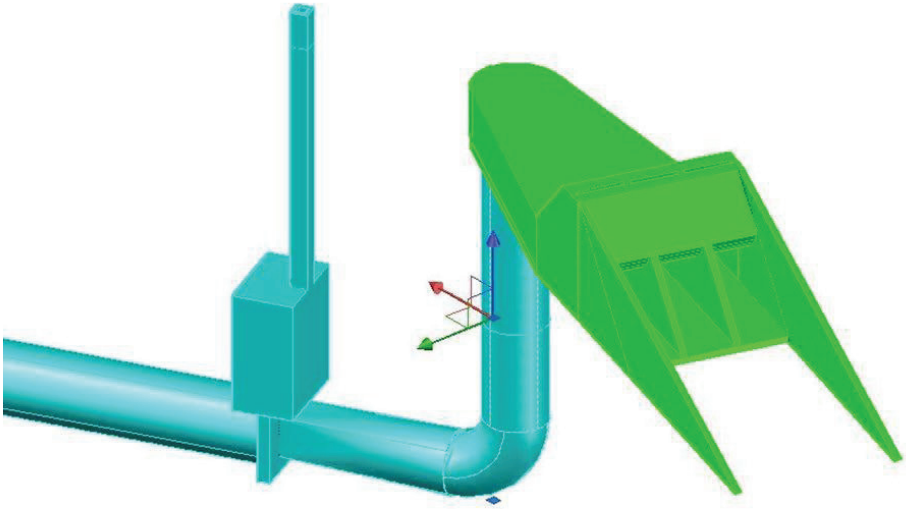


Figure 4-7 Isometric View of Tunnel and Inlet

susceptibility to unbalanced ice forces that develop on the reservoir each winter, safety and navigation issues for recreational users of the reservoir and difficulties with construction of such an intake in the reservoir.

- **Vortex Flow Inlet and Drop-Shaft Structure:** The vortex flow intake is a form of vertical intake, and is designed to cause flow to wind down a drop shaft in a helical path rather to plunge vertically downward. This is accomplished by directing the flow so that it enters the shaft tangentially, and thereby remains in close contact with the drop shaft wall as it spirals down the shaft. This also allows a central air core to form, providing an efficient escape route for any entrained air. Regulation of flow into the intake would likely be accomplished with a gated control structure that could be constructed upstream of the drop shaft inlet.

- **Horizontal Intake:** A horizontal intake consists of a bellmouth entrance constructed along the banks of a dyke or reservoir. The intake delivers water directly into a downstream penstock, tunnel, or channel, eliminating any possible air entrainment caused by a plunging jet in the drop shaft. Velocities in the shaft and tunnel can then be carefully controlled with the use of a deep regulating gate. The horizontal intake design is considered to be particularly advantageous at the Heritage Drive location, given that it can be relatively easily incorporated into the existing reservoir dyke, and would provide better submergence performance (helping to avoid air entraining vortices which can reduce efficiency). This intake is described in more detail in the paragraphs below.

Although all three intake types are considered to be viable for this project, the vortex flow inlet and horizontal intake are judged to be the most appropriate. The preferred intake configuration advanced for this pre-feasibility design is a horizontal intake, complete with a deep regulating gate to provide maximum control on tunnel discharges and velocities. It unfortunately also represents the most challenging option with respect to gate maintenance activities. The inlet works associated with this concept are shown in plan view in Figure 334731-SK-02 in **Appendix A**, and in a profile view in Figure 334731-SK-03 in **Appendix A** for the tunnel capacity of 500 m^3/s. **Figure 4-7** and **Figure 4-8** provide three-dimensional isometric views of the inlet structures, both with and without the surrounding land topography.

The inlet works consist of the following components:

- **Approach Channel:** The intake and its approach channel will be located along a section of the east dyke at the Heritage Drive location. To facilitate construction of the intake and channel, a cofferdam will initially be constructed out from the existing dyke, along a shallow shelf of the reservoir bathymetry. This cofferdam will tie back into the existing dyke both north and south of the intake. The existing dyke will be removed within the confines of this cofferdam, and the excavation will proceed. The approach channel will be partially excavated in the dry and partially dredged. Beginning at the inlet structure, the channel will rise at a slope of 4H:1V from approximately elevation 1062 m to eventually daylight within the reservoir.

- **Intake Structure:** The intake structure for the 500 m^3/s capacity tunnel case, shown in **Figure 4-6** , will consist of three separate water passages, each approximately 6.0 m wide, and 7.0 m high. The 700 m^3/s case will also consist of three separate 7.5 m wide by 7m high water passages. Each bay will be equipped with a guard gate that can be closed if needed to isolate the system. A sloped coarse trashrack will be provided at the entrance to the intake structure to prevent large debris from entering the tunnel. Based on criteria provided by the USBR, the maximum allowable velocity at this trash rack has been set to 2.5 m/s. Submergence has been provided at each water passage to meet criteria proposed by Gulliver in the 1995 USACE publication on intake design. These criteria were also checked against earlier criteria proposed by Gordon, and the two matched well.

- **Tunnel to Regulating Gate/Valve:** Downstream of the guard gate, the flow will enter a short, transition structure which will direct the flow into the upstream access shaft used for the retrieval of the TBM. At this point, the flow will make a 90 degree bend, to enter the upstream access shaft, which is a full 10.5 m in diameter. At the bottom of the access shaft, flow will again turn 90 degrees, and then transition down to a square cross sectional shape that is 5.7 m wide by 5.7 m high (for the 500 m^3/s tunnel design) and 6.5 m wide by 6.5 m high (for the 700 m^3/s tunnel design).

- **Regulating Gate:** The regulating gate will be located within the square section of the tunnel lining and will consist of a bonneted slide gate or valve. As shown in **Figure 4-8**, a gate maintenance area will be provided consiting of a chamber excavated within the rock. A man access shaft will be provided to the chamber to allow direct access from the surface. An air vacuum valve will be provided immediately downstream of the gate, but the gate seat will be set at an elevation that will ensure that the tunnel will flow full under all possible conditions (gated and fully open) and that cavitation indices meet suggested minimum values. Given the high velocities expected downstream of the gate, it is proposed that the tunnel be lined with steel for a minimum distance of 6 to 10 times the diameter of the tunnel. Under small gate openings, this short reach of the tunnel will be where energy is dissipated and the flow expands to fill the full tunnel area. In terms of transitions, since head loss is not a concern, the transition from the 5.7 m square opening to the 8 m internal diameter round tunnel will be abrupt, and the tunnel section will effectively act as a small expansion chamber. This will accomplish two things: i) it will help to maximize energy losses, much like an orifice ring or expansion chamber would do; and ii) should cavitation bubbles form (possible under small openings), the bubbles will form at some distance

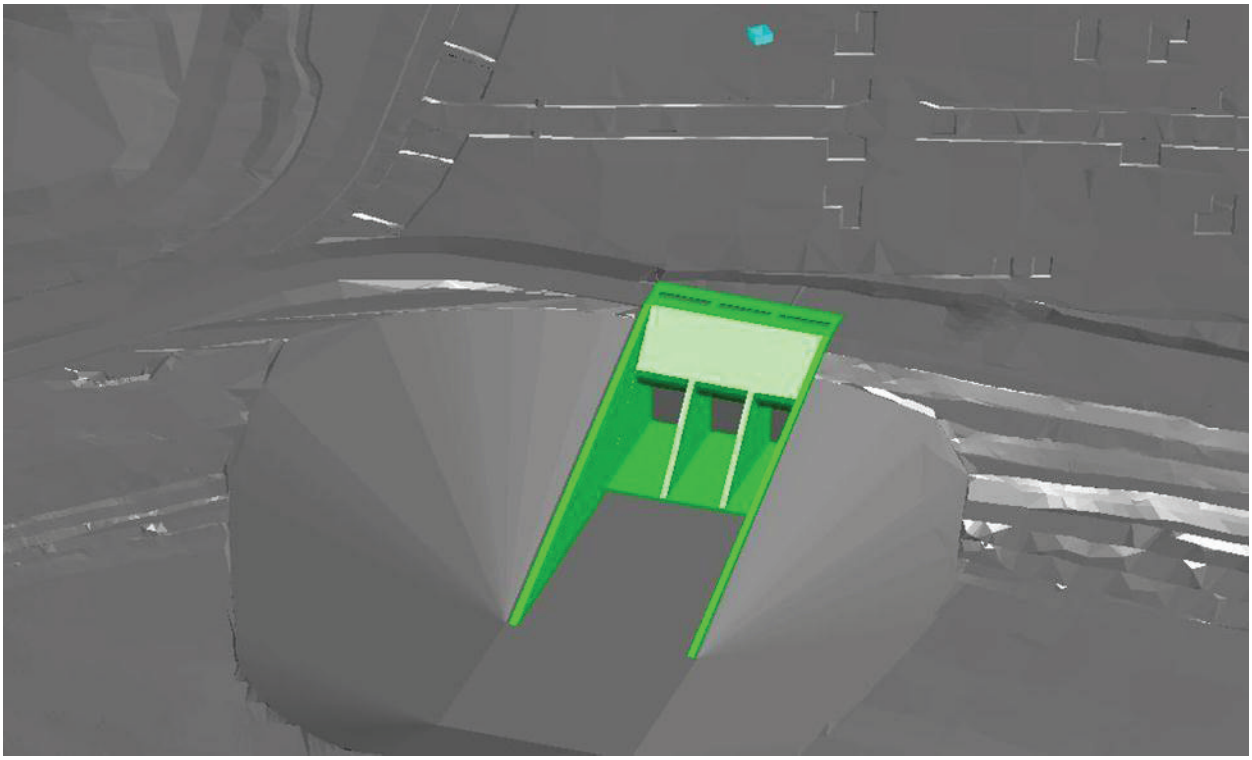


FIGURE 4-8 ISOMETRIC VIEW OF APPROACH CHANNEL AND INLET

above the walls of the tunnel, and will likely just collapse harmlessly away from the walls of the tunnel (akin to a supercavitating block design). The steel liner will provide added protection against possible pitting and any pressure fluctuations generated by the turbulent flow. The flow will then gradually slow and expand to fill the entire tunnel cross section. Initial tests with the FLOW3D model confirm that this strategy of energy dissipation under small gate openings will work effectively. Transient pressures within the tunnel system would be controlled by setting restrictions on the opening and closing times of the slide gate.

4.3 OUTLET WORKS

Before flow can be discharged into the Bow River, care must be taken so that the energy, turbulence, and velocity of the tunnel discharges are sufficiently reduced to minimize any impacts they may have on the downstream flow regime. Downstream impacts may include possible erosion of the river substrate, and a possible reduction in water quality due to increases in total dissolved gas content and/or suspended sediment load. The Bow River is a key resource, providing important habitat to fish species such as Brown Trout and Mountain Whitefish.

Depending on the degree of energy dissipation expected within the tunnel, and whether the tunnel flows are regulated at an upstream or downstream location, the dissipater may take the form of a gradually expanding chute or diffuser, a series of rapid expansion chambers, or a more conventional baffled stilling basin design. For outlet-controlled options considered in this study, the preferred energy dissipation mechanism consists of a stilling basin, modified to better manage the super cavitating flow releases expected. This type of stilling basin requires a relatively deep setting to provide the necessary tailwater for jump formation, and this can significantly increase the excavation and concrete quantities associated with the outlet.

For the recommended inlet-controlled option it is possible to use a much simpler diffuser structure. The purpose of the diffuser is, through a very controlled expansion, to lower the tunnel outlet velocities from the design 10 m/s down to 2.5 m/s prior to releasing these flows into the Bow River. As shown in Figure 334731-SK-04 in **Appendix A**, the orientation of the diffuser has been selected so as to provide a streamlined re-entry into the Bow River. The expansion has been designed to ensure it is of sufficient length and width to dissipate the incoming energy and provide a well distributed outflow at the exit of the chute. Flows exiting the expansion chamber will then be released into a short open channel chute, properly armoured to resist expected flow velocities in the river for the various design events.

The excavation required to mobilize or launch the tunnel boring equipment at the tunnel outlet will also form the excavation for the construction of the diffuser. The final diffuser design is shown in plan view and in profile view in 334731-SK-04 and 334731-SK-05 in **Appendix A**, respectively. **Figure 4-9** provides a three-dimensional isometric view of the outlet structure.

4.4 GEOTECHNICAL SITE CONDITIONS

A preliminary assessment of the geotechnical conditions along the preferred tunnel alignment (Heritage Drive) based on the information collected thus far follows.

4.4.1 SURFICIAL SEDIMENTS

As shown in the Heritage Drive Geological Section in Appendix B, the overburden varies from 5 to 30 m along the proposed alignment and predominantly consists of undifferentiated soils and glacial till and glaciolacustrine soils, ranging in thickness from 0 to 20 m thick to the west of the Bow River area. In the vicinity of the Bow River, the overburden is significantly thinner (5 to 10 m) and consists primarily of pre-glacial and alluvial sands and gravels. It is also noted that the water table is expected to be within 5 m of the ground surface, and typically less in the vicinity of the Glenmore Reservoir and the Bow River.

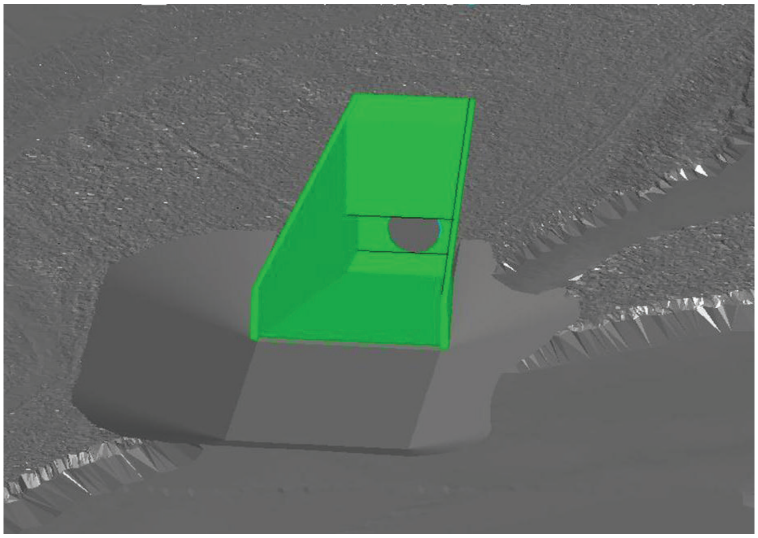


FIGURE 4-9 ISOMETRIC VIEW OF OUTLET DIFFUSER STRUCTURE AND RIVER

4.4.1.1 Previous Excavation Experience

Deep excavations have been routinely constructed in Bow River gravels in downtown Calgary. Historically, the most common method of supporting deep excavations in the downtown area has been the use of soldier H-piles and timber lagging. Problems have occurred with excavations well below the water table when silt horizons tend to flow through the lagging boards, creating significant loss of ground and surface settlements. As well, in at least one instance, during construction of a deep shaft penetrating a pervious sand horizon underneath the clay till, significant "boiling" was observed forcing the contractor to adjust the construction method. More recently, deep temporary shoring projects have incorporated tangent or secant pile walls below the water table.

In the Bow River floodplain, secant pile walls penetrating into bedrock have been used with success for shafts within the gravel horizon, where high water inflows are present. Shotcrete and welded wire mesh have been used to protect exposed bedrock within these shafts.

4.4.1.2 Geotechnical Considerations

Based on these experiences and the geotechnical descriptions of the soil units, significant inflow issues in Bow River gravels are anticipated for excavations that are below the water table. When excavating through this unit, a construction method will be required that provides a relatively impermeable barrier, such as secant pile walls.

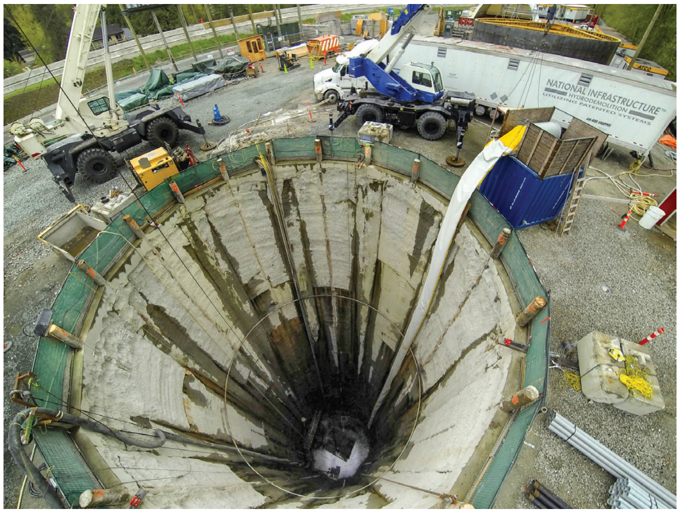
Excavations in the till are expected to be relatively stable provided that sand lenses that provide a high permeability water pathway are not encountered in a saturated and flowing condition. Precautions should be taken so that the excavation remains dry to avoid construction delays and difficulties with the development of concrete structures and permanent concrete linings.

Finally, it is noted that the proposed outlet portal for the Heritage Drive tunnel alignment may traverse the western slopes of the Bow River valley near the Heritage Meadows retail area. These slopes have a history of instability, which may be exacerbated if the slopes are disturbed during construction. A deep rock tunnel profile will mitigate this risk.

4.4.2 BEDROCK

Given the variability in the Paskapoo Formation, sandstone and mudstone beds are expected to be discontinuous along the tunnel alignment, leading to variability in rockmass quality over relatively short distances. Rock Quality Designation (RQD) values are generally expected to be above 60% as the tunnel will be deeper than the weathered zone.

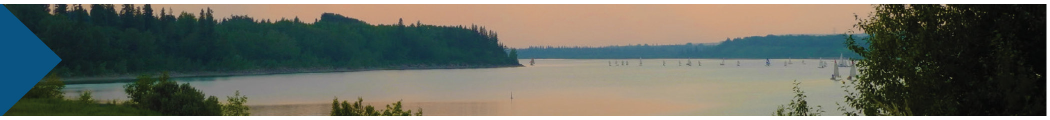
Site investigations have shown that in floodplains or along Macleod Trail, which is crossed by the Heritage Drive alignment, buried bedrock channels infilled with permeable soils should be expected. The use of geophysical methods, in conjunction with test hole drilling programs, can be used to detect these buried features.



4.4.2.1 Previous Experience

A number of small diameter (< 3 m) tunnels were constructed in Calgary using TBMs, starting in 2005, where considerable experience was obtained with the Paskapoo bedrock. This experience has been summarized by Crockford et al. (2012), with the following highlights (not necessarily in the order of importance):

1. The individual bedrock units are discontinuous, and correlations between test holes generally cannot be established.
2. The bedrock displays a high variability in strength and requires careful selection of the TBM cutterhead design and cutting tools.
3. Soft bedrock units are at times in a deteriorated and plastic condition that will slake and erode upon exposure. Clogging behaviour may potentially affect TBM tunnelling and should be considered in the TBM design and its operation.
4. The rockmass below the weathered horizon is relatively impervious; however, there are occasional zones of higher permeability. Water inflow estimated at 21 l/min/m was encountered within a 4 m long section of a tunnel in bedrock.



4.4.2.2 Geotechnical Considerations

At tunnel depths below the weathered horizon, the rock of the Paskapoo Formation is expected to fail readily along bedding planes. Blocky rockmass behaviour may also be encountered related to joints that are typically at right angles to bedding. Early support will therefore be needed to control overbreak around the excavation.

All related construction experience cited above involved the use of a casing or Shield TBM as opposed to an open main beam TBM with grippers. Using a Shield TBM would be advantageous in this ground as it provides the required early support to control overbreak.

4.4.3 Geotechnical Investigation

Prior to construction, a detailed site investigation should be performed along the preferred alignment. The goals of such an analysis are to:

1. Develop an initial three-dimensional geological model that can be used to estimate the geotechnical conditions at tunnel depth along the alignment;
2. Obtain samples of representative soil and rock units for laboratory testing to determine engineering parameters for design; and
3. Categorize the ground conditions into a series of geotechnical classes on the basis of geological model, including laboratory testing.

4.5 TUNNEL

The flood water will be conveyed from the inlet structure to the outlet structure through a tunnel measuring approximately 4.2 km in length along the preferred Heritage Drive alignment. The geometry of the proposed flood diversion tunnel has been established based on the two flow cases: 500 m^3/s and 700 m^3/s. As specified in **Section 4.1**, the flow velocity is anticipated to be 10 m/s for both cases, meaning a tunnel cross-sectional area of 50 m2 and 70 m2 would be required for each flow velocity, respectively.

4.5.1 Tunnel Depth

Both shallow and deep tunnel options have been considered for the Glenmore Reservoir Diversion Tunnel.

For the shallow option, excavation using a combination of cut and cover methods like what was used for the Calgary West LRT and shallow tunnels would be used to excavate along the alignment. This excavation would be through mixed ground (undifferentiated soils, tills and bedrock) and would have a depth of approximately 10 to 40 m. The intention of studying a shallow option was to maximize the use of lower cost cut and cover construction techniques over as much of the alignment as possible. Unlike the Calgary West LRT, however, the proposed Glenmore Reservoir Diversion Tunnel would need to follow busy street corridors. Cut and cover construction techniques would be very disruptive to people living and passing through the construction corridor, and this disruption can be partially mitigated by various methods of reinstating the surface above the work; however, these methods tend to add enough cost that it is similar to the deep tunnel option, which has almost no surface disruption along the alignment.

A deep tunnel option would involve tunnelling through bedrock along the entire length of the alignment. An outlet launch area and a deep inlet shaft (> 70 m) would be required for this option in order to achieve a suitable depth in bedrock to avoid buried river channels cut into the bedrock surface and to avoid highly weathered bedrock. The tunnel would have a very shallow grade, of approximately 0.2%.

4.5.2 Tunnel Profile

For the deep tunnel option, a suitable depth must be achieved along the alignment to ensure stability of the excavation and hydraulic performance. Additionally, the excavation must be deep enough such that the external pressure caused by the weight of rock above the tunnel is greater than the pressure of the water inside the tunnel. If this is not the case, in the event of leakage, the high pressure water will be able to fracture the surrounding rockmass through a process known as hydrojacking. This can lead to uncontrolled leakage. This is particularly important at the outlet area at the western slopes of the Bow River valley near the Heritage Meadows retail area. These slopes have a history of instability, which may be exacerbated if the slopes are disturbed during construction.

Given this, three criteria were used to select an appropriate tunnel depth:

1. On the basis that there are no hidden valleys along the alignment, rock cover equivalent to one tunnel diameter can be used for excavation stability purposes.
2. To prevent issues with cavitation, a 10 m cover depth between the tunnel crown and the hydraulic grade line (HGL) should be used.
3. Protection against hydraulic jacking and uplift by ensuring bedrock pressure at the tunnel crown is greater than the internal tunnel pressure for a factor of safety of 1.1.

These three criteria were used to develop a limiting tunnel crown elevation along the alignment for both static and steady state flowing conditions, based on the hydraulic information provided in **Section 4.1**. The result of this assessment is shown in **Figure 4-10**.

The proposed tunnel profile along the Heritage Drive alignment has an overall grade of 0.21%. The inlet shaft is expected to be 73 m deep, with 18 m excavated through overburden (undifferentiated soils and till) and 55 m excavated in bedrock. The outlet excavation will be 28 m deep, with 7 m excavated through overburden (pre-glacial and alluvial sand and gravel) and 21 m in bedrock.

A comparison was performed to determine the preferred shallow or deep option. A summary of the key considerations are shown in **Table 4-1**. With respect to cost and schedule, it is not expected that the shallow tunnel option will result in any significant savings. While Table 4-1 does not consider the relative importance of the differentiating considerations, there are enough benefits of the deep option to adopt it as the preferred approach at this stage. Based on this comparison, the deep tunnel is recommended as the preferred construction option for this project.

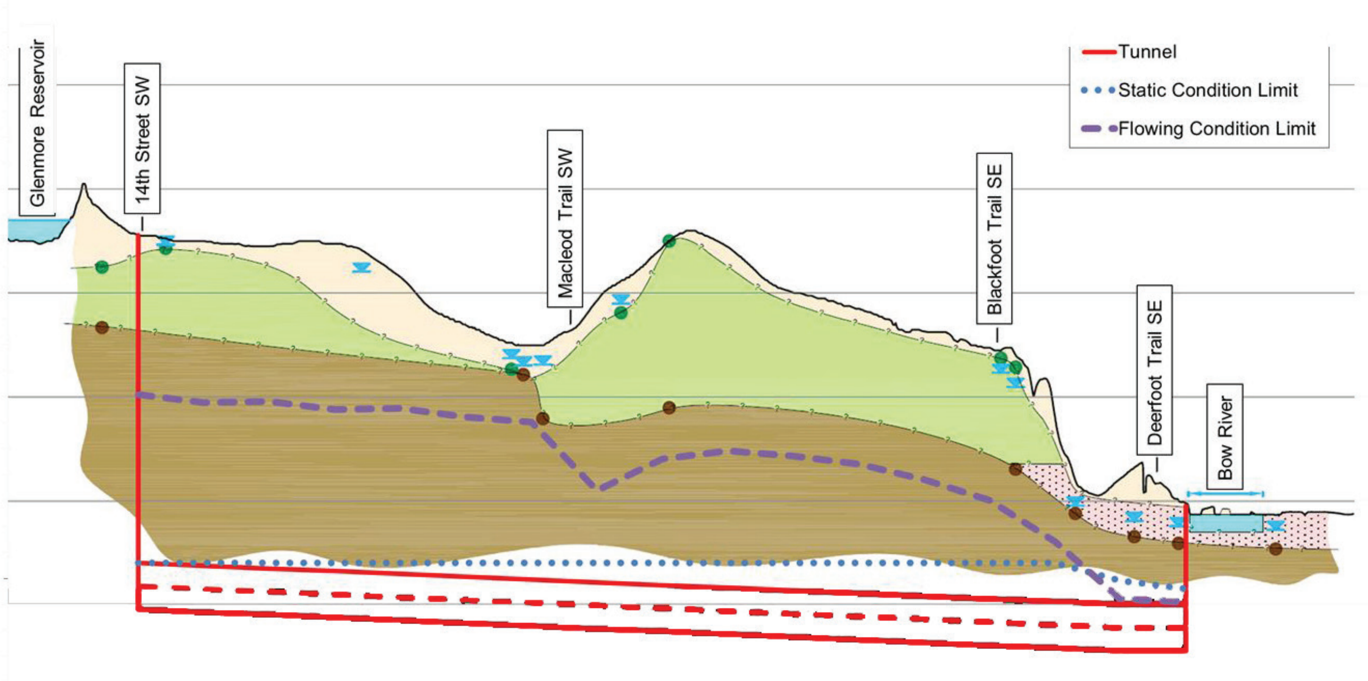


FIGURE 4-10 PROPOSED DEEP TUNNEL PROFILE ALONG THE HERITAGE DRIVE TUNNEL ALIGNMENT
(NOTE THAT A VERTICAL EXAGGERATION OF 1 M HORIZONTAL TO 20 M VERTICAL IS USED)

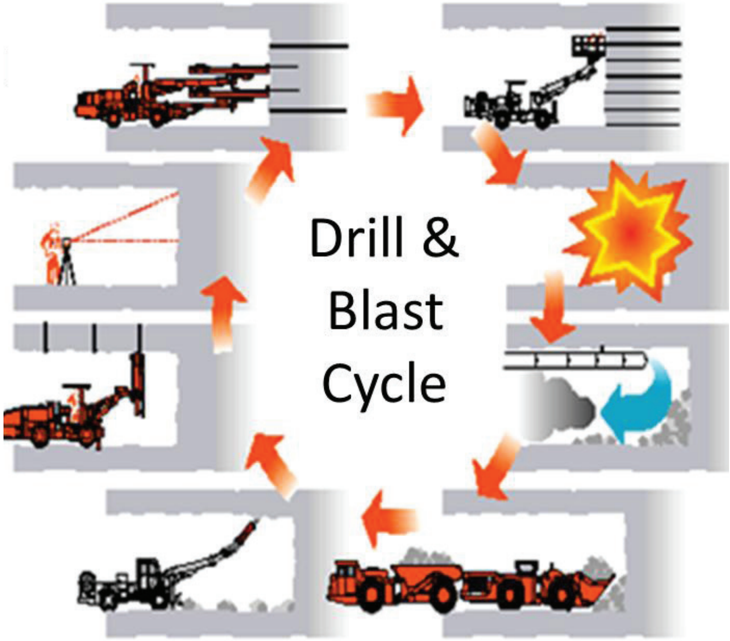


FIGURE 4-11 TYPICAL DRILL AND BLAST EXCAVATION CYCLE (COURTESY SANDVIK)

TABLE 4-1 CONSTRUCTION METHODS ASSESSMENT: SHALLOW VERSUS DEEP TUNNEL OPTIONS

DIFFERENTIATING CONSIDERATIONS	SHALLOW TUNNEL	DEEP TUNNEL	FAVOURED
Tunnel Lining	Twin Cell Box, Pressure tunnel design heavily reinforced to control water tight to control max internal pressure	Standard precast concrete	Deep - much less expensive lining
Utility Relocation	All cut and cover segments plus inlet and outlet	inlet and outlet only	Deep - less utility relocation
Traffic Disruption	All cut and cover segments and along entire route to major highways	Minimal except for intake, outlet adjacent to freeway	Deep - less traffic disruption
Business Disruption	All cut and cover segments plus inlet and outlet	Inlet and outlet only	Deep - less business disruption
Dewatering	Entire route	Inlet and outlet and limited section of active tunnel heading	Deep - less dewatering
Contaminated soil and groundwater	Potential to encounter near surface contaminated soil and groundwater	Avoids near surface contaminated soil and groundwater	Deep
Dust and Noise	Entire route	Inlet and Outlet only	Deep
Settlement Potential	Entire route	Minimal due to depth in rock	Deep
Weather related delays to construction	Possible over entire route, earthwork excavation, fill placement and paving can only occur in good weather	At Inlet and outlet only. Tunnelling will be year-round and protected from weather	Deep
Impacts to local drainage during construction	Disrupted at cut and cover sections	Not applicable along tunnel	Deep

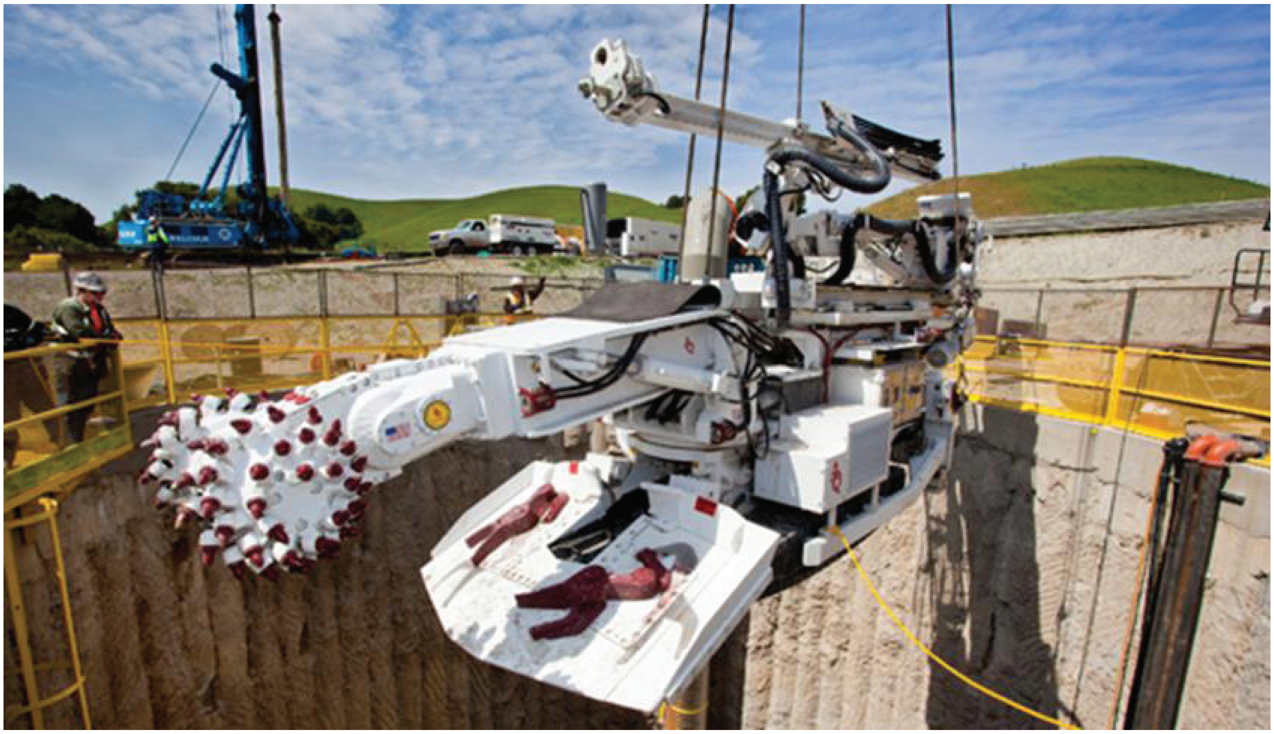


FIGURE 4-12 ROADHEADER FROM NEW IRVINGTON TUNNEL PROJECT

4.5.3 EXCAVATION METHOD

Excavating the tunnel can be completed using a number of different methods. These are typically grouped into conventional methods, consisting of drill and blast and roadheader excavations, and bored methods involving the use of a tunnel boring machine (TBM). Details regarding each construction method are presented below. A complete description of each is also provided in Appendix C.

4.5.3.1 Conventional Methods (Drill and Blast, Roadheader)

Underground excavation by drill and blast involves fracturing the rock through the use of explosives. The cycle starts with the drilling of a series of parallel horizontal holes in a predetermined pattern and length. After drilling is completed, each hole is packed with explosives and a time delayed detonator, often referred to as a blasting cap. To fire the round and hence fracture the rock, the detonators in each hole are connected together using either electrical wire or non-electric shock cord. Once connected, the entire pattern or "round" is detonated from a safe distance using a blasting machine that initiates all in-hole detonators. After the material has been blasted, the area is ventilated and the broken rock is removed from the newly excavated area, before support is installed. The drill and blast cycle is shown in **Figure 4-11**.

Drill and blast provides a flexible excavation method as the length of the round and the amount of face excavated for a given round can be changed depending on the ground conditions encountered. In good ground, a full face excavation approach can be used while a sequential excavation method (heading and bench) can be used in weaker ground to ensure excavation stability.

A roadheader is a tracked mechanical excavating device equipped with a rotating cutter head mounted on a swivelling boom, as shown in **Figure 4-12**. In general, the excavation cycle using a roadheader is simpler relative to drill and blast and the ventilation requirements can be less given that there are no blast fumes. Roadheaders operate within a smaller range of rockmass conditions than drill and blast. As such, the primary consideration in selection of a roadheader is whether or not the strength conditions of the rockmass will limit the achieved excavation rates and the associated cost effectiveness of the method, given the high initial capital expenditure for the equipment.

For both conventional methods, preliminary support is installed during excavation (bolts and shotcrete typically) while a permanent concrete lining must be installed after excavation is complete.

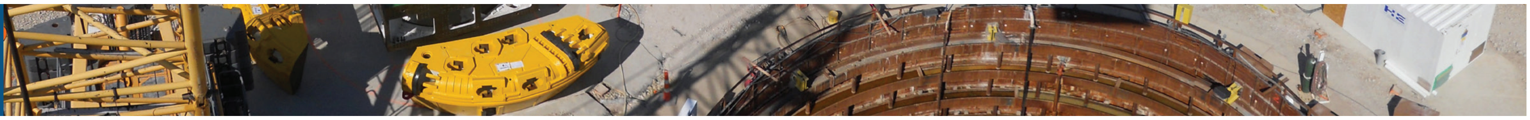
Figure 4-13 Euclid Creek Single Shield TBS (excavated diameter 8.2 m)

4.5.3.2 Tunnel Boring Machines

Tunnel Boring Machines (TBMs) excavate rock by using disc cutters intended to break the rock into small chips. This is accomplished by applying thrust through the cutterhead to the disc cutters on the face and applying torque to the cutterhead to overcome the rolling resistance of the cutters. The amount of cutterhead power required to overcome rolling resistance is influenced by the size of the tunnel face, the number of discs, disc shape, the penetration of the discs into the rock per revolution of the cutterhead, the mechanical properties of the rock and the orientation of any rock fabric or discontinuities relative to the direction of TBM advance. An example of a TBM is shown in **Figure 4-13**.

It is generally understood that TBMs are the preferred choice to excavate long tunnels; however, this must be factored against the prevailing ground conditions. At its peak performance, TBM excavation can be as much as four times faster than drill and blast, but more typically 2 to 3 times faster. TBM excavation begins to lose out to drill and blast when the rock is good to very good or very poor. Based on the current geotechnical information regarding the Paskapoo Formation, the rock quality is anticipated to be largely medium quality, which is optimal for TBM excavation.

Given the potential for slaking and general medium quality of the rockmass, a permanent concrete lining is needed for erosion protection. Permanent support and erosion protection for the rockmass can either be completed in a two-pass system, where preliminary support is installed during excavation and a final typically cast-in-place concrete lining is installed at some distance behind the machine, or through a one-pass system typically using precast concrete segments. Examples of precast concrete segment lining specifications and tolerances are included in **Appendix D**.



The equivalent minimum internal dimensions for a TBM excavation are summarized in **Table 4-2** for each flow case. An estimated outer diameter, based on an assumed grout annulus of 150 mm and an estimated precast concrete liner thickness, are also shown. A preliminary tunnel cross section is also shown in 334731-SK-06 in **Appendix A**.

TABLE 4-2 PRELIMINARY TUNNEL DIMENSIONS FOR TWO FLOW CASES

FLOW CASE	REQUIRED CROSS SECTIONAL AREA	CIRCULAR INNER DIAMETER	ESTIMATED LINING THICKNESS	ESTIMATED OUTER DIAMETER
500 m^3/s	50 m^2	8.0 m	350 mm	9.0 m
700 m^3/s	70 m^2	9.5 m	400 mm	10.6 m

A number of similarly sized tunnel excavations have been successfully completed in hard rock for water tunnels using precast concrete segments. These projects are summarized in **Table 4-3**.

TABLE 4-3 SIMILAR WATER TUNNEL PROJECTS EXCAVATED USING A TBM AND SUPPORTED WITH CONCRETE SEGMENTS

PROJECT	LOCATION	ROCK TYPE	MACHINE TYPE	LENGTH (km)	OUTER DIAMETER (m)
Coca Codo Sinclair Hydropower Project	San Miguel, Ecuador	Volcanic rock (basalt, rhyolite), sandstone, siltstone, slate	Double shield	24.1	9.0
Veligonda	Kurnool / Andhra Pradesh, India	Quartzite, slate, phyllite	Double Shield	19.2	7.9 10.0
Euclid Creek	Cleveland, Ohio	Shale, limestone	Single Shield	5.4	8.2
West Drainage Tunnel	Hong Kong, China	Granite, volcanic rock	Double Shield	10.3	8.3 & 7.2
Stormwater Management and Road Tunnel (SMART)	Kuala Lumpur, Malaysia	Limestone, marble, sand	Mixshield	13.2	9.2
Buckskin Mountains Water Conveyance Tunnel	Lake Havasu, Arizona	Complex sequence of andesitic lava flows and related volcanic deposits	Double Shield	11.0	7.2
Theun Hinboun Expansion Project	Laos	Primarily limestone and siltstone	Single Shield	5.5	7.6

4.5.3.3 Preferred Tunnel Excavation Method

The assessment of tunnel excavation methods is presented in **Table 4-4**.

TABLE 4-4 CONSTRUCTION METHODS COMPARATIVE ASSESSMENT: CONVENTIONAL VERSUS TBM EXCAVATION METHODS

DIFFERENTIATING CONSIDERATIONS	DRILL AND BLAST	TUNNEL BORING MACHINE (TBM)	FAVOURED
Mobilization	Equipment readily available, limited infrastructure requirements	Long lead time for TBM procurement, requires considerable power supply for TBM, conveyors and other TBM equipment, greater up front cost	Drill and Blast
Surface Impacts	Blast vibrations can cause surface disruption, explosives will need to be stored on site	Minimal disruption during tunnelling	TBM
Construction Conditions	Greater ventilation requirements due to fumes, increased risk due to explosives	Continuous excavation, more pleasant working environment	TBM
Advance Rate	Most often used on shorter tunnels, even with a second excavation heading expected to have lower advance rates compared to TBM	TBM excavation well suited for longer tunnels, able to achieve higher advance rates	TBM – reduced construction time offsets up front cost
Excavated Profile	Overbreak is generally larger with drill and blast, increases cost of mucking and concrete lining	Good profile control during excavation	TBM
Tunnel Lining	Two-pass system with preliminary support installed during excavation and final lining at a distance behind the face, adds to construction time	One-pass final lining installation of standard precast concrete segments, good quality control for production and installation of segments	TBM – reduced construction time offsets up front cost

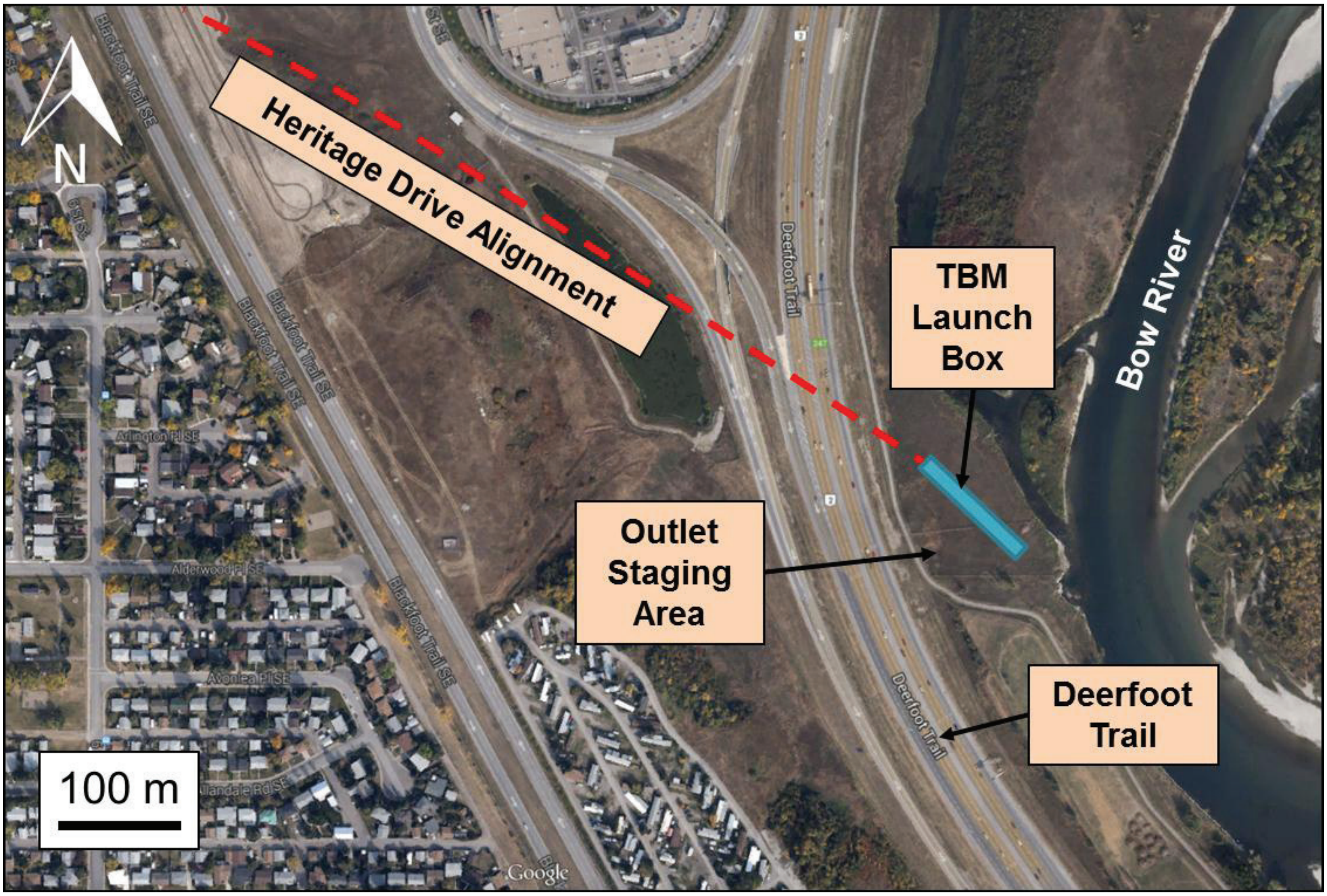


FIGURE 4-14 PROPOSED OUTLET LOCATION FOR THE HERITAGE DRIVE TUNNEL ALIGNMENT


Figure 4-15 TBM Launch Box for the Niagara Hydroelectric Project in Ontario


Figure 4-16 TBM Launch Box Excavation for the Stormwater Management and Road Tunnel (SMART), Kuala Lumpur, Malaysia

While both conventional and TBM excavation methods are feasible for this project, given the anticipated ground conditions and the length of the tunnel, a TBM excavation is considered to be preferred. While a longer lead time will be required for the procurement of the machine, faster advance rates can be achieved during excavation with a TBM than using a conventional approach.

Further, by using precast concrete segments, the tunnel will be largely complete at the conclusion of tunnelling, whereas a permanent lining will still need to be installed if drill and blast or a roadheader is used. Gasketed segments are also able to resist external and internal water pressures of up to 2.69 MPa, thus reducing the leakage from the tunnel and reducing the likelihood of slope stability issues at surface.

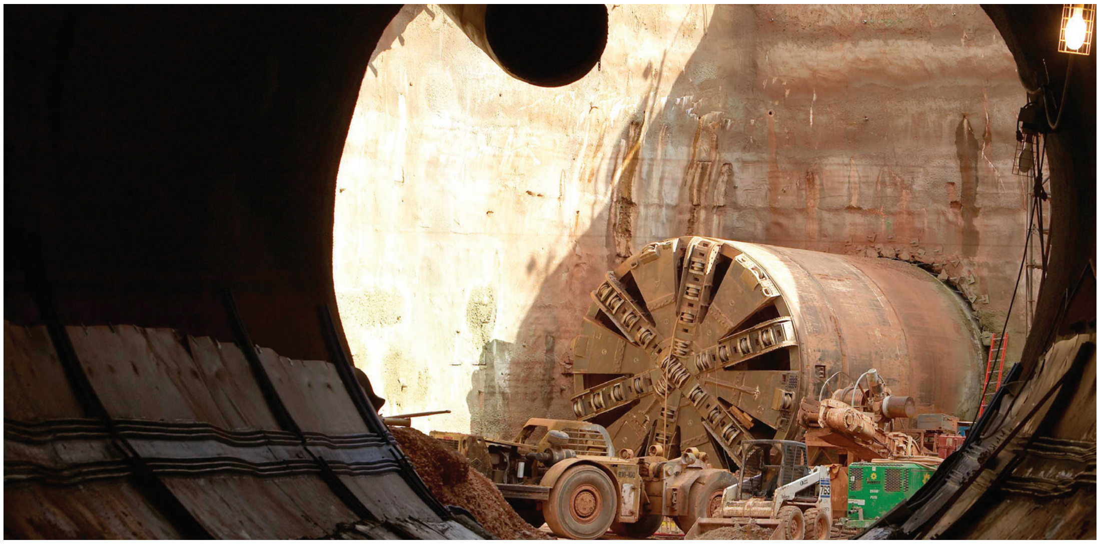
Given the lack of available space at the inlet area, it has been assumed at this stage that tunnel excavation will be completed using a single TBM. While a second TBM could be launched from the inlet shaft, the additional cost of the machine would need to be compared to the schedule savings to determine if it provided any cost savings. In the case of a second TBM, the maximum expected schedule savings would be 135 construction days, which amounts to approximately $135,000 of labour costs. When compared to the additional cost of a second TBM (approximately $21 million), it is clear that this option would result in significant additional project costs without appreciable savings.

4.5.4 Tunnel Construction

4.5.4.1 Outlet Area – TBM Launch Box

For the tunnel excavation, the TBM can either be launched from an open surface excavation or from a shaft. When launching from a shaft, there is insufficient space for the entire TBM and trailing gear to be assembled initially meaning the TBM must be assembled in pieces as excavation progresses. This results in slower advance rates initially as sections of the excavation must be stopped after a certain distance so additional TBM components can be brought down the shaft and assembled. Conversely, launching the TBM from surface allows the entire TBM to be assembled prior to excavation, thus eliminating these delays.

Based on the availability of space along the alignment, the outlet area is considered to be the preferred location for launching the TBM at this stage as there is sufficient space to construct a launch box on the surface. To do so, an excavation measuring approximately 90 m long, 20 m wide and 30 m deep will be constructed at the outlet area, between the Bow River and Deerfoot Trail (**Figure 4-14**). This is shown in 334731-SK-04 and SK-05 in **Appendix A**. The TBM components will then be lowered into the box and assembled prior to beginning excavation of the tunnel. Examples of similar TBM launch excavations are shown in **Figure 4-15** and **Figure 4-16**. An additional advantage to launching from the outlet side is that the TBM will be driven uphill, which reduces the possibility of flooding the face in the event of water inflow.



The launch box excavation depth will extend through 7 m of pre-glacial and alluvial sand and gravel and approximately 23 m of Paskapoo bedrock. The water table in this area is expected to be from 1 to 3 m below ground surface, given its proximity to the Bow River. Given the high permeability of the undifferentiated soils, the near-surface water table and the history of water inflow issues when excavating in Bow River gravels, a construction method will be required in the overburden that will provide a relatively impermeable barrier to support the construction of the TBM launch box. Such methods include:

- Sheet piles
- Slurry walls
- Secant piles
- Soil mixing
- Caisson sinking
- Ground freezing

The construction process, applicability and limitations of each of the above listed construction methods are discussed in Appendix E. For the basis of the cost estimate presented in Section 7, secant piles were used as the construction method in the overburden given their success in the Calgary area. Other construction methods should be considered in detailed design to assess their applicability.

Secant pile walls are constructed by excavating a series of adjacent, slightly overlapping, vertical holes using a large diameter auger drilling rig. To ensure excavation stability, the secant piles will extend from surface into the bedrock to a depth of approximately 5 m.

FIGURE 4-17 SECANT PILE WALL FROM THE STORMWATER MANAGEMENT AND ROAD TUNNEL (SMART), KUALA LUMPUR, MALAYSIA

Upon completion of excavation, an H-pile or steel reinforcing cage is typically placed within the hole and the hole is backfilled with concrete. Holes are drilled in an alternating pattern, so overlapping holes are drilled after the concrete in the adjacent holes has partially hardened. This process is continued around the perimeter of the excavation until the entire footprint is enclosed. An example of a completed secant pile wall is shown in **Figure 4-17**.

To further stabilize the excavation, anchors will be used to tie the secant piles into the more competent bedrock below. This construction method will be similar to that used for the Bow Building in downtown Calgary, which was excavated to a depth of 20.5 m through 0 to 0.5 m of fill, 5.5 to 7.0 m of well graded gravel and a similar bedrock unit. As slightly better ground is anticipated at the proposed outlet area, it is expected that fewer tiebacks will be needed to stabilize the excavation.

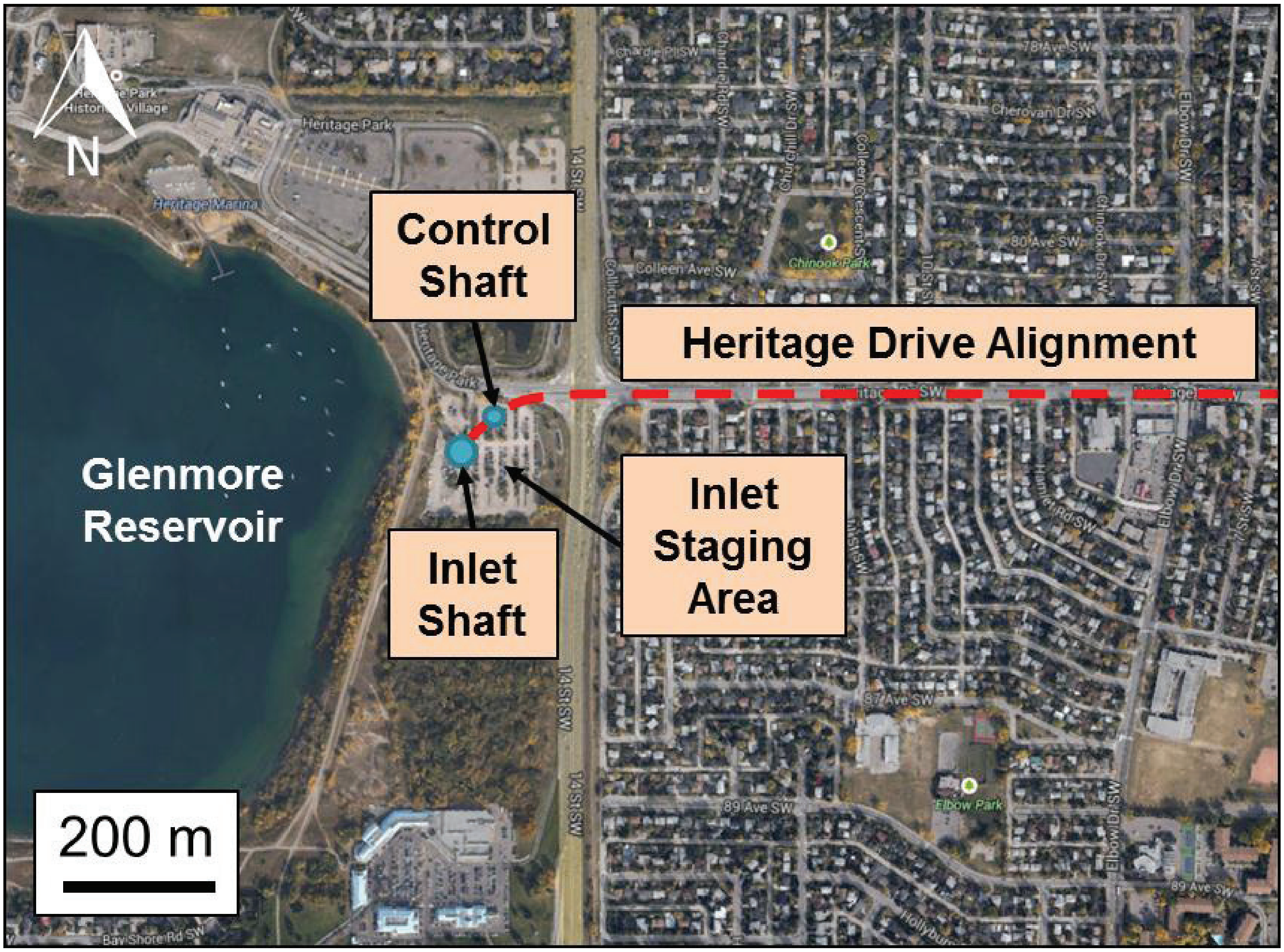


FIGURE 4-18 PROPOSED INLET SHAFT LOCATION FOR THE HERITAGE DRIVE TUNNEL ALIGNMENT

Conventional methods (drill and blast or roadheader) will be used to excavate the bedrock to the base of the launch box. Walls in the bedrock will be supported with shotcrete and tiebacks.

After the launch box has been constructed and the TBM assembled, tunnel excavation will commence uphill towards the inlet shaft area.

4.5.4.2 Inlet Area – TBM Receiving Shaft

The inlet area, located to the east of the Glenmore Reservoir and south of Heritage Drive (**Figure 4-18**), will be constructed concurrently with tunnel excavation. The construction of two shafts is required in this area; a larger diameter upstream shaft that will connect the surface inlet structure to the underground tunnel and will serve as the receiving shaft for the TBM, and a smaller diameter control shaft that will provide access to the valve maintenance area above the control gate. The shaft locations are shown in 334731-SK-02 and SK-03 in **Appendix A** and were selected based on the design of the surface inlet structure and size requirements for equipment, material handling and staging.

Both the upstream and control shaft will extend from ground surface to the tunnel level, and will need to be excavated through overburden (undifferentiated soils and till) and bedrock. The excavation depths for each unit are summarized in Table 4 5. Groundwater observations indicate groundwater water levels to be approximately 1 to 3 m below ground surface.

TABLE 4-5 APPROXIMATE EXCAVATION DEPTHS FOR EACH SHAFT BY UNIT

SHAFT	UNDIFFERENTIATED SOIL	TILL	BEDROCK	TOTAL DEPTH
Inlet Shaft	4 m	14 m	55 m	73 m
Control Shaft	4 m	14 m	43 m	61 m

As with the outlet excavation, concerns regarding the high permeability of the sand and gravel, the near-surface water table and the history of water inflow issues are also present at the inlet area. Given the depth of the shafts, control of risk during shaft construction is critical. As such, a secant pile construction method is recommended to minimize water inflow in the overburden and support the launch box excavation. These secant piles will extend from surface to approximately 5 m into the bedrock to ensure stability and provide support during excavation of the overburden. Blind shaft drilling may also be a possibility for the control shaft as this method has been used successfully to achieve shaft diameters of approximately 5.5 m to 6.0 m.

On completion of the secant wall installation, excavation of the shafts will proceed from surface. As both shafts are circular, no internal bracing is anticipated as the secant pile walls are capable of carrying the soil and groundwater loads in ring compression. After the overburden has been excavated, conventional methods (drill and blast or roadheader) will be used to excavate the bedrock to shaft bottom. Preliminary support in the bedrock will consist of shotcrete and rockbolts.

At the base of the upstream shaft, conventional methods (drill and blast or roadheader) will be used to excavate a transition structure that gradually reduces the excavation diameter from that of the inlet shaft to the size of the control gate. The gate structure will then be tied in with the control valve shaft excavation and control valve maintenance area. Conventional methods will further be used to excavate the section that will be steel lined. The end of this excavation (approximately 60 m from the inlet shaft) will serve as the breakthrough point for the TBM excavation.

Final support for the shafts will consist of an unreinforced, precast concrete lining. In the upstream shaft, this lining will be installed after the TBM has been removed. A waterproofing shield (e.g. membrane) will be installed on the secant pile wall for both the upstream and control shafts before the concrete lining is installed to prevent the build-up of water pressure against the shaft lining in the gravel overburden. Concrete forms will be used for the transition structure as well.

4.6 ENVIRONMENTAL IMPACTS

Impacts associated with the construction of the diversion tunnel are described in the following sections. A detailed list of potential environmental impacts during construction and operation of the tunnel, as well as potential mitigation measures, is included in **Appendix F**.

4.6.1 STAGING AREAS

Suitable staging areas for construction are characterized by good accessibility for delivery of equipment and material, and excavation spoil hauling; adequate size for equipment and material storing and staging; availability of utilities including a high voltage power supply (for the TBM); sewage and construction water; and other rules and requirements including environmental and work-related restrictions (e.g. noise, lighting, work time, etc.).

For this project, tunnelling will be staged from the outlet TBM launch box excavation and will advance to the reception shaft at the inlet site. Based on HMM's experience on recent tunnel and shaft construction projects, a required staging area of at least two hectares (5 acres) is anticipated for the launching of the TBM as well as site offices and material storage.

Based on a preliminary review of the Heritage Drive tunnel alignment, a 3 hectare area is available to the south of the launch box between Deerfoot Trail and the Bow River. An additional 4 hectares appears to be available further south in the event that a larger area is required. Given the close proximity of the proposed staging area to the Bow River, flood protection measures will be needed and environmental restrictions will need to be considered. A storm sewer pipe and ATCO gas pipeline may need to be relocated for this excavation: although opportunities to protect in place or to avoid these lines completely warrant further study during design.

At the inlet (receiving) shaft, a two hectare parking area adjacent to Heritage Park is located on the south side of Heritage Drive between the Glenmore Reservoir and 14th Street. This should provide an adequate staging area for the sinking of the inlet and control shafts, for TBM removal and for construction of the permanent inlet structure although coordination with current users of the parking lot is needed and some adjustments and constraints may be needed during detailed design.

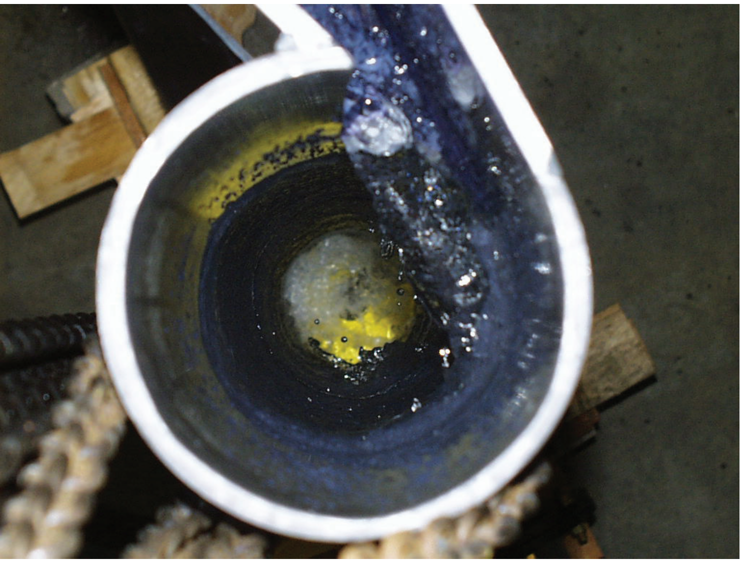
4.6.2 CONSTRUCTION IMPACTS

A number of construction impacts may be associated to some degree with the construction of the Glenmore Reservoir Diversion tunnel, including:

1. Potential disruption during investigation phase (i.e. surveying, drill rigs along alignment, geophysical studies, etc.)
2. Increased levels of noise and dust
3. Construction lighting used at night
4. Vibrations (due to conventional excavation at surface and TBM excavation at depth)
5. Potential excavation-induced ground subsidence
6. Construction traffic will be added to the local roads
7. General traffic disruption for surface work along alignment (surveying, settlement monitoring)
8. Changes to groundwater table and resources
9. Potential for groundwater contamination
10. Changes to stormwater runoff
11. Construction wastewater disposal
12. Loss of vegetation and micro-habitats during site clearing and mobilization

These impacts, and potential mitigation measures, are discussed briefly in the following subsections. A more detailed discussion is presented in **Appendix F**.

4.6.2.1 Surface Works



The areas with the greatest impact will be the inlet and outlet construction areas. To mitigate these issues, an Environmental Impact Assessment, Environmental Management Plan and monitoring during construction must be implemented to ensure potential noise, air quality and flora/fauna impacts in the proposed construction areas are minimized. In addition, the following mitigation measures can be used to address the potential construction impacts:

Noise and Vibrations – To ensure the project complies with City Bylaws, a construction schedule of five days per week with two 8-hour shifts has been assumed for production tunnelling with only limited work such as maintenance occurring on weekends in order to limit vibrations, noise and light issues while people are in their homes at night and on weekends. Temporary earthen berms and noise minimization equipment can also be used where needed. Noise and vibration levels will be monitored during construction to ensure compliance with all regulations.

Traffic: Traffic near the inlet and outlet areas will increase given the addition of construction vehicles, material deliveries and spoil disposal needs. This can increase congestion on local roads and increase greenhouse gas emissions. The Heritage Park parking lot located at southwest of Heritage Drive SW and 14 Street SW will also be fully or partly inaccessible during construction. To minimize this impact, a temporary waste material stockpile area should be considered to manage the timing of the waste material hauling during the day. Regular maintenance of vehicles and equipment will minimize emissions and prevent leaks of fuel, oil or grease. Dust can also be controlled by wetting roads and spoil piles with water.

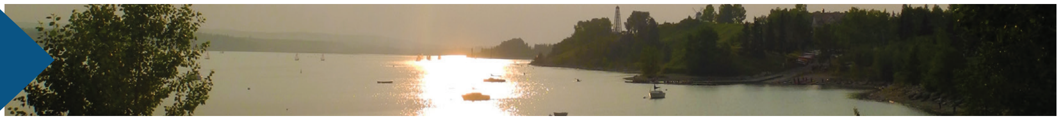
Groundwater Flow and Contamination: Potential for contamination exists during site preparation and construction of inlet and outlet structures. All fuels, oils and grease must therefore be stored in the appropriate containment systems that comply with regulatory requirements. Concrete mixing equipment can also be placed on a retention bund that limits the infiltration of wastewater into underlying soil and groundwater.

Surface Water: Disturbance of the near-shore environment of the Bow River, the Glenmore Reservoir and the Elbow River as well as discharge of potentially contaminated effluent into surface water bodies must be considered. To address this, all construction wastewater will be collected and treated on site prior to discharge to prevent contamination of surface water. Natural drainage will be maintained where possible and water recycling can be used. Site clearing will also be limited to areas needed for construction activities only. A sediment and erosion control plan can be developed and implemented for construction activities.

Flora and Fauna: Site clearing and preparation may lead to the loss of vegetation and micro-habitats. To minimize this impact, staging areas will be kept as small as possible and located away from sensitive areas where possible. An environmental management plan will be implemented and effluent will be maintained according to appropriate guidelines and regulatory requirements. If applicable, a habitat compensation program can be implemented if existing microhabitats are damaged.

4.6.2.2 Tunnel

By selecting a deep tunnel option, many potential impacts will be minimized along the proposed alignment. Surface disruption along the tunnel alignment is expected to be minimal, with only geotechnical investigation, surveying and settlement monitoring being performed along Heritage Drive.



The depth of the tunnel and the installation of precast concrete segments close to the face will minimize the risk of surface subsidence. Minimal groundwater disturbance is also anticipated during tunnelling provided best practices are followed.

Spoil generated by TBM excavation typically consists of well-graded materials ranging from 100 mm rock chips to fines. This material will be removed from the tunnel using rail-based spoil wagons or a conveyor. It is anticipated that a conveyor will be used for this excavation, given the large tunnel diameter and therefore large volume of material that will need to be transported.

After removal from the tunnel, a number of opportunities exist for spoil disposal. Currently, these opportunities include:

1. Provide for on-site spoil disposal
2. Providing fill material for new developments in the Calgary area
3. As daily cover at nearby landfills
4. For earthworks in the vicinity of the proposed tunnel
5. Wetland habitat restoration
6. Flood protection around the outlet and inlet staging areas or for other sensitive locations in the City of Calgary.

Table 4-6 provides an estimate of spoil volumes from the inlet/outlet structures and the tunnel. As a designated area for the waste material disposition has not been established, an average haul distance of 10 km (one-way) was assumed for the purposes of the cost estimate. The topsoil (in excess of 6,000 m^3) also should be temporary stockpiled at the intake structure area to be graded over the structure backfill.

The spoil disposal costs represents a significant portion of the project cost and there is opportunity for significant savings if a beneficial use the spoil at or adjacent to the TBM staging area could be developed.

TABLE 4 6 – PRELIMINARY SPOIL VOLUME ESTIMATE FROM SURFACE AND TUNNEL EXCAVATIONS FOR BOTH FLOW CASES

FLOW CASE	SOIL		TUNNEL (BEDROCK)
	Inlet	Outlet	
500 m^3/s	97 000 m^3	47 000 m^3	426 000 m^3
700 m^3/s	105 000 m^3	52 000 m^3	590 000 m^3

* Note: All spoil volumes provided in this table are neat line bank volumes without over excavation or bulking

4.6.2.3 Downstream Impacts

We understand there are concerns related to effects of the diversion tunnel by residents located downstream of the proposed Bow River outlet. By using the tunnel to divert flood flows from the Elbow River at the Glenmore Reservoir to the Bow River the flood flow from the Elbow River will only arrive at the Bow River approximately two hours earlier than flows without a diversion tunnel. There would be no increases in flood discharges in the Bow River from the use of the tunnel versus the existing flow path; only a minor change in the timing.

Hydrologically it could be argued the natural response of the Elbow River basin to a flood should occur prior to the response of the Bow River because it is a smaller drainage basin. This would mean the flood peak on the Elbow River should normally occur before the flood peak on the Bow River would occur. If the tunnel were being used the net effect downstream would be possibly a slight reduction to the peak flow due to the two-hour time shift of the Elbow River flow.

5

CONTRACT DELIVERY CONSIDERATIONS

This section describes contract delivery methods and form of contract that could be considered for the Glenmore Reservoir Diversion project. The implementation of a contractual approach to manage the risks associated with the interpretation of geotechnical information is also discussed in **Section 10.1**.

5 CONTRACT DELIVERY CONSIDERATIONS

5.1 CONTRACT DELIVERY METHODS

If a decision is made to proceed with the Glenmore Reservoir Diversion project, then it is likely that there will be an understandable desire for the project to progress quickly to have its benefits in place as soon as possible – hopefully before the next Elbow River flood event.

In general, three contract delivery models could be considered for the implementation phase of this project: 1) Design-Bid-Build; 2) Design-Build; and 3) Early Contractor Involvement. The following sections describe the advantages and disadvantages of each of these models relative to the requirements of this project.

Design-Bid-Build: Design-Bid-Build (DBB) is generally considered the traditional or base case procurement /delivery model. The City would enter into a contract with a prime design engineering services provider to design the project construction requirements by way of technical specifications, detailed design drawings, construction tender and construction contract documents. Once the design is substantially complete and through a competitive bid process, The City would award a contract to a general construction contractor to build the project.

In general, DBB is well-suited to projects where schedule may not be the main priority, and where the Owner desires to have the greatest control over all aspects of design and construction. Other advantages of the DBB process are: it is well established and widely applicable; it is well understood in the construction industry as the roles and responsibilities of the engineering team and construction contractor are well defined; the project requirements are well-defined prior to the bid process; and it provides for a competitive bidding process.

Disadvantages often cited with the DBB process include: it does not allow for the effective integration of construction inputs through the design process; it results in a longer overall project schedule; overall project costs may be greater. In this model, The City and its design consultants would be fully responsible for the design, and would retain the risk for design changes during the course of construction. Most infrastructure projects in Calgary are delivered in accordance with this model.

Overall, this traditional approach works well for straight-forward, low-risk projects, but may not work well for more complex projects such as the Glenmore Reservoir diversion tunnel that involves potentially challenging ground conditions and constructability aspects because:

- The resulting design needs to accommodate a wide range of bidder preferences and may be less optimized and less efficient than more explicit project delivery methods;
- Contractors will be reluctant to assume constructability risk when minimum constructability constraints are prescribed by the designer to protect the Owner from aggressive and optimistic low bids; and,
- Competitive bids may be difficult or impossible to obtain for specialized services.

On some major tunnel projects, the Owner elects to purchase the tunnel boring machine in advance of the general contractor bidding process. The TBM is then provided to the successful contractor, potentially saving up to 10 to 12 months in the overall project schedule. A disadvantage of this approach is that the Owner can be responsible for the risk of the performance of the TBM; in the event of a machine breakdown, potentially significant project delay claims can result.

Design-Build: The Design-Build (DB) procurement/delivery model is often selected by Owners when an accelerated project schedule is desired. The Owner would typically hire an Owner's Engineer (OE) to provide technical support to the design-build contractor procurement process. In general, the OE would be responsible for:

- advancing the design to a preliminary design completion stage to confirm the technical project requirements (that the project can work) and to update the construction cost estimate

- supporting the Owner in the preparation of Request for Qualifications (RFQ) documents and in the evaluation of proponent responses to the RFQ
- preparing technical reference documents that define the technical requirements and constraints of the project; these documents would form part of the Request for Proposal (RFP) information that would be provided to a short-list of firms selected from the RFQ process
- responding to technical Requests for Information (RFIs) and clarification requests from the short-listed proponents during the RFP process
- providing technical support during the evaluation of the proposal submissions from the short-listed proponents
- providing support to the Owner during the award of the DB contract
- providing technical input and responding to RFIs from the DB-Contractor during the DB-Contractor's design phase
- monitoring of construction including the DB-Contractor's quality control and quality assurance activities
- providing overall project management support to the Owner including cost and schedule control, document management, quality management oversight, etc.

The Design-Build Contractor (DBC) becomes responsible for all aspects of the design and construction. The DBC's engineer serves as the engineer of record, and works as a subcontractor (consultant) to the DBC.

Benefits of the DB approach include: allocating design risk directly to the DB-Contractor; establishing the contract price sooner; and potentially providing more incentive for the DB-Contractor to "own" the project. From a cost perspective, it is usually accepted that in return for fast delivery and transfer of risk there is a price premium to be paid for the DB model as the result of: Contractor's profit margins are typically higher on a DB project to offset bidding costs that include design costs; higher level of risks to the DB-Contractor by taking on the design responsibilities and all aspects of quality management. These price premiums can be offset by reduced escalation costs resulting from an advanced project schedule and design efficiencies that flow from contractor-design collaboration.

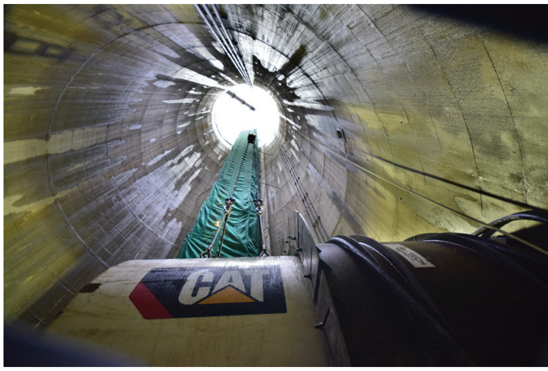
From a risk transfer perspective, benefits of the DB model include: the DBC is financially motivated to achieve target completion dates; the DBC takes on all the responsibility for integrating all work elements. There are, however, still plenty of risks associated under a DB contract model on a tunnel construction project. These include issues associated with geotechnical ground conditions (refer to **Section 5.2** below). Some risks such as property acquisition, major utility relocations, and third party issues can be mitigated if the Owner addresses these items separate from the DB contract.

It should be noted, however, that the close collaboration between designer and contractor that underlies successful design-build projects cannot be assured, and this has led to problems with some design-build tunnel projects in the past. Furthermore, the design-build structure, wherein the designer works for the contractor, makes it more difficult for the Owner to control the design without incurring excessive change order costs. To overcome this, the Owner needs to develop comprehensive design criteria that define how the design must proceed.

Los Angeles Metro has adopted the design-build approach for their upcoming transit tunnel expansions. This approach seems to be working well for the City of Los Angeles which has defined detailed design criteria, design manuals and standard specifications that give Los Angeles Metro control over the end product and allows it to define project requirements for bidders. Transit agencies in Edmonton and Vancouver are pursuing a similar approach that couples design-build contracts with public/private-partnerships.

Early Contractor Involvement: Typically, the Early Contractor Involvement (ECI) model involves selecting a contractor relatively early in the design development based on qualifications and commercial (pricing) criteria. Together, the Design Engineer and Contractor then advance the design while developing the cost and schedule. Often a Target Price is structured into the agreement with the Owner, with gain/pain provisions shared by the Owner and Contractor.

The ECI model has been widely used in the UK, and is in use by a number of western Canadian hydro power authorities. The US Corps of Engineers used this model to deliver a $350 million levee improvement project in New Orleans that had been damaged by Hurricane Katrina.



The ECI delivery method provides Owners with early input on key construction related decisions and contractor preferences, which allows the designers to focus on the preferred construction method option which in theory should result in a lower cost and more efficient project. ECI can offer better price certainty by involving the contractor in the construction cost estimate prior to funding approval. This also reduces the risk of late changes which could affect permit applications with resultant schedule impacts. ECI also incentivizes the contractor to collaborate and thereby share responsibility for design decisions that affect constructability. The advantage of ECI over design-build is that the engineer works for the Owner under the owner's control.

The disadvantage of the ECI approach is that the construction-phase contract is typically negotiated rather than competitively bid, although the contractor selection criteria can include bids for some elements of the construction phase (such as mark-up and unit prices). This means ECI is sometimes seen as offering less competitive prices for construction. Certain ECI models seek to mitigate this through adopting an initial design stage where two or three contractors are initially contracted to work on the design in separate teams, sometimes sharing ideas, but commonly not. This adds extra cost both in managing separate teams and through paying multiple teams for the same design services. However, in theory this is intended to be more than offset by the savings gained from working collaboratively early in the design.

5.2 PROCUREMENT AND FORM OF CONTRACT

Many jurisdictions are legislated to implement a lowest bidder procurement approach for public works construction projects. This method potentially rewards the most aggressive bidder (lowest price) who includes the least amount of risk mitigation in their bid, expecting to make up the difference in claims.

On many tunnel projects, public agencies are moving to selecting tunnel contractors based on an evaluation of best value versus lowest price. The best value evaluation incorporates qualifications, technical input, cost, schedule and other factors into the scoring process. This approach could be applied to all three of the project delivery options described in **Section 5.1** above.

Two basic forms of contract may be applicable to the Glenmore Reservoir Diversion Project: fixed-price and cost-reimbursable. Fixed-price is more commonly aligned with design-bid-build or design-build contracts. ECI contracts involve contractors normally being reimbursed on a cost-reimbursable basis often with aligned incentives. However, this is not always the rule.

Incentives can be tied to cost, schedule, quality and/or safety for either form of contract, and a common incentive involves including a target cost with a cost-reimbursable contract. Administrating fixed-price contracts is less labour intensive than cost-reimbursable contracts.

Owners typically prefer fixed-price contracts over cost-reimbursable contracts since they provide cost surety and place the risk of cost overruns with the contractor. However, contractors build the cost of this risk into their bids. Bidders will also have difficulty obtaining competitive bids and equitable subcontracting terms from subcontractors. Therefore, bidders will prefer a cost-reimbursable contract, and this form of contract may increase the quality and quantity of bidders, which would be advantageous to The City of Calgary.

The City may also wish to consider soliciting dual bids based on both fixed-price and cost-reimbursable forms of contract.

6

REGULATORY LEGISLATION REVIEW

The applicable legislations at the federal, provincial and municipal levels for the Glenmore Reservoir Diversion project are summarized in the following subsections:

6 REGULATORY LEGISLATION REVIEW

6.1 FEDERAL

It is expected that the proposed project will trigger a federal Environmental Assessment (EA) Review process based on the requirements of the following legislations and regulations.

6.1.1 Canadian Environmental Assessment Act

According to Section 6 of the Regulations Designating Physical Activities SOR/2012-147 pursuant to the Canadian Environmental Assessment Act 2012, the construction, operation, decommissioning and abandonment of a new structure for the diversion of up to 10 million cubic meters per second (m3/s) or more from a natural water body to another will be subject to the Canadian Environmental Assessment Agency's ("Agency") screening process. Diverting peak flow of between 500 and 700 m3/s of water for a seven day period during a flood event similar to the 2013 event will result in approximately 300 million m3/s of water being diverted from the Elbow River into the Bow River. Therefore, the project will trigger the Agency screening process that will likely involve other regulatory bodies such as the Department of Fisheries and Ocean Canada. Other trigger mechanisms for the federal EA review process include:

- Potential for the project to cause adverse effects on fish and fish habitats during the construction of the tunnel intake, discharge outlet as well as during the diversion process through the tunnel into the Bow River; and
- Obstructing the navigability of the Glenmore Reservoir as well as the Bow River.

To commence the process, a project description will be required and must be submitted to the Agency to make a determination if the proposed diversion tunnel has the potential to cause adverse environmental effects and if a federal EA review process is required.

6.1.2 Fisheries Act

The Fisheries Act is a federal legislation that is administered by the Department of Fisheries and Oceans Canada (DFO), as well as Environment Canada (EC). The Act is mainly for the management and protection of fisheries and their habitat during construction activities in or near a water body. For the proposed diversion project, the following sections of the Act have been identified to apply to the proposed project:

- Section 20 (1): the requirements to conduct studies, analysis, sampling and evaluation of the applicable water body if there is the likelihood that fisheries and/or their habitat could be impacted by the project
- Section 35 (1): Prohibition of harmful alteration, disruption or destruction of fish habitat; and
- Section 36: Prohibition of the release or discharge of deleterious substances in a river.

As mentioned in subsection 6.1.1, any work or activity that has the potential to cause a harmful alteration, disruption or destruction to fisheries and/or their habitat will trigger a federal EA review process due to the requirements to obtain an authorization from DFO. DFO will assess the project risk(s) to determine if the project will require an authorization, an operational statement or a letter of advice. DFO will only issue an authorization following the completion of the EA review process.

Typically, a proponent of a project will submit the project information to DFO for review and to enable DFO to make a determination whether the project will cause the harmful alteration, disruption or destruction of a fish habitat. Although the proponents of a flood control or water diversion projects are not required to submit project information to DFO for review, it is recommended that discussions with DFO occur to determine the necessity of the approval.

Section 36 of the Fisheries Act prohibits the release or discharge of deleterious substances into a water body such as the Elbow or the Bow River unless authorized by Environment Canada. Potential staging areas and shaft locations must be located away from these rivers and appropriate mitigation measures implemented to ensure excavated spoil, wastewater or leaks are not discharged into the Elbow River, Glenmore Reservoir or the Bow River.

6.1.3 Navigable Water Protection Act

The Navigable Water Protection Act is a federal legislation administered by Transport Canada to protect the right of all navigable waterways across Canada. Navigable water as defined in the Act includes any body of water created or altered as a result of the construction of any works; and any man-made structures, devices or thing, whether temporary or permanent, that may interfere with navigation.

Occupation of the part of the Glenmore Reservoir, the Elbow or the Bow River during construction activities without an approval will be deemed as a violation of the Navigable Water Protection Act. Therefore, it is necessary that an approval be sought from Transport Canada prior to the start of construction activity. Site plans are typically issued to Transport Canada for its review and if Transport Canada finds that the proposed project will not substantially interfere with navigation, the minister may make a determination to exempt the proposed project from the requirements to obtain an approval. If an authorization is required under this Act, then the CEAA will be triggered, meaning an EIA or a Comprehensive Study will be required by the regulators during the regulatory review process.

6.2 PROVINCIAL

Provincial legislations that are applicable to the proposed project have been identified and a high level summary of each of these legislations is provided as follows:

6.2.1 Alberta Environmental Protection and Enhancement Act

The Alberta Environmental Assessment (Mandatory and Exempted Activities) Regulation 111/1993 under the Environmental Protection and Enhancement Act (EPEA) provides a list of activities that are classed as mandatory and those classed as exempted. Any water diversion activity with a capacity greater than 15 m3/s is classed as a mandatory activity and would therefore trigger a provincial environmental review process. As noted above, the proposed project with a capacity to divert between 500 and 700 m3/s of water will trigger a joint federal and provincial EA process with Alberta Environment & Sustainable Resource Development (ESRD) being the lead regulator in accordance with the memorandum of understanding between ESRD and the agency.

6.2.2 Alberta Water Act

Diversion of water from the Glenmore Reservoir into the Bow River via the proposed tunnel is an activity that will require an approval under the Alberta Water Act. Other activities associated with the proposed project that will require approval include placing, constructing, disturbing, operating, maintaining, removing or disturbing ground in or near the intake at the Glenmore Reservoir as well as at the outlet at the Bow River.

6.2.3 Alberta Public Lands Act

It is anticipated that a license of occupation under the Public Lands Act will be required if part of the Glenmore Reservoir and/or the beds or shore of the Elbow or Bow Rivers will be occupied to facilitate construction activities. Other project activities that will require approval under the Public Land Acts include, but not limited to the following:

- Construction of erosion protection measures in or near any of the two water bodies
- Placement or removal of materials from the bed or shore of the Bow/Elbow River
- Construction of permanent structures on the bed or shore of the rivers.

6.3 MUNICIPAL

6.3.1 WATER UTILITY BYLAW 40M2006

The requirements of Sections 21 and 23 of the City of Calgary bylaw number 40M2006 have to be complied with prior to the commencement of the proposed project. Under these sections of the bylaw, permission has to be sought from the Director of Water Services to allow access or construction activity within the Glenmore Area, which is defined in the bylaw as ….. *"All lands acquired by the City for use in connection with the maintenance and operation of its Glenmore Reservoir and of its Water Services System and include all the land within the boundaries of Glenmore Park".*

Additionally, permission will have to be sought from the Director for the construction activities for the inlet at Heritage Drive. The bylaw also prohibits the placement of any "object" in the water of the Glenmore Reservoir without a permission of the Director.

6.3.2 GLENMORE PARK BYLAW 8018

Section of 20 of the Glenmore Park Bylaw prohibits the entry into any leased portion of the Glenmore Park unless authorized by the Director. Therefore, an authorization must be sought from The City of Calgary for occupation of any area of the Glenmore Park during construction activities.

7

COST ESTIMATE

A capital cost estimate to a ±25 percent accuracy has been prepared for this project, which is consistant with an ASTM E2516 Class 4 estimate and corresponds to a project definition level. A comprehensive estimate of the probable cost of engineering, project management and construction has been prepared that includes estimates based on quantities, the development schedule and provisions for other development costs, such as owner's management costs and property acquisition.

7 COST ESTIMATE

This estimate has been prepared in Canadian dollars assuming a mid-2014 bid date. The focus of the estimate has been placed primarily on the tunnelling and underground components as they dominate the overall cost and risk provisions. These costs have been estimated drawing from the HMM proprietary cost estimating method TED (tunnel estimating database), which adopts estimating methods similar to those used by tunnelling contractors.

7.1 BASIS OF ESTIMATE / ASSUMPTIONS

- The cost estimate includes the following elements:
- Procurement & mobilization of equipment & materials
- Site setup
- Outlet launch box excavation in soil and rock (includes secant pile wall)
- Shield TBM bored tunnel (includes assemble and disassemble costs) with precast concrete tunnel lining
- Inlet shaft excavation (includes secant pile wall)
- Inlet transition section
- Control shaft excavation (includes secant pile wall)
- Control gate area excavation
- Construction water (tunnel inflows) treatment facilities and disposables
- Final concrete lining for inlet and control shafts
- Transport and disposal of excavation muck
- Excavation including topsoil removal
- Construction of concrete inlet/outlet structures
- Fabrication, installation and commissioning of all gates (includes guides, provisions for hydraulic & control system)
- Service shaft (includes consideration of ladder, dewatering system, air circulation fan and a housing)
- Indirect costs
- Construction contingency

7.2 COST ESTIMATE

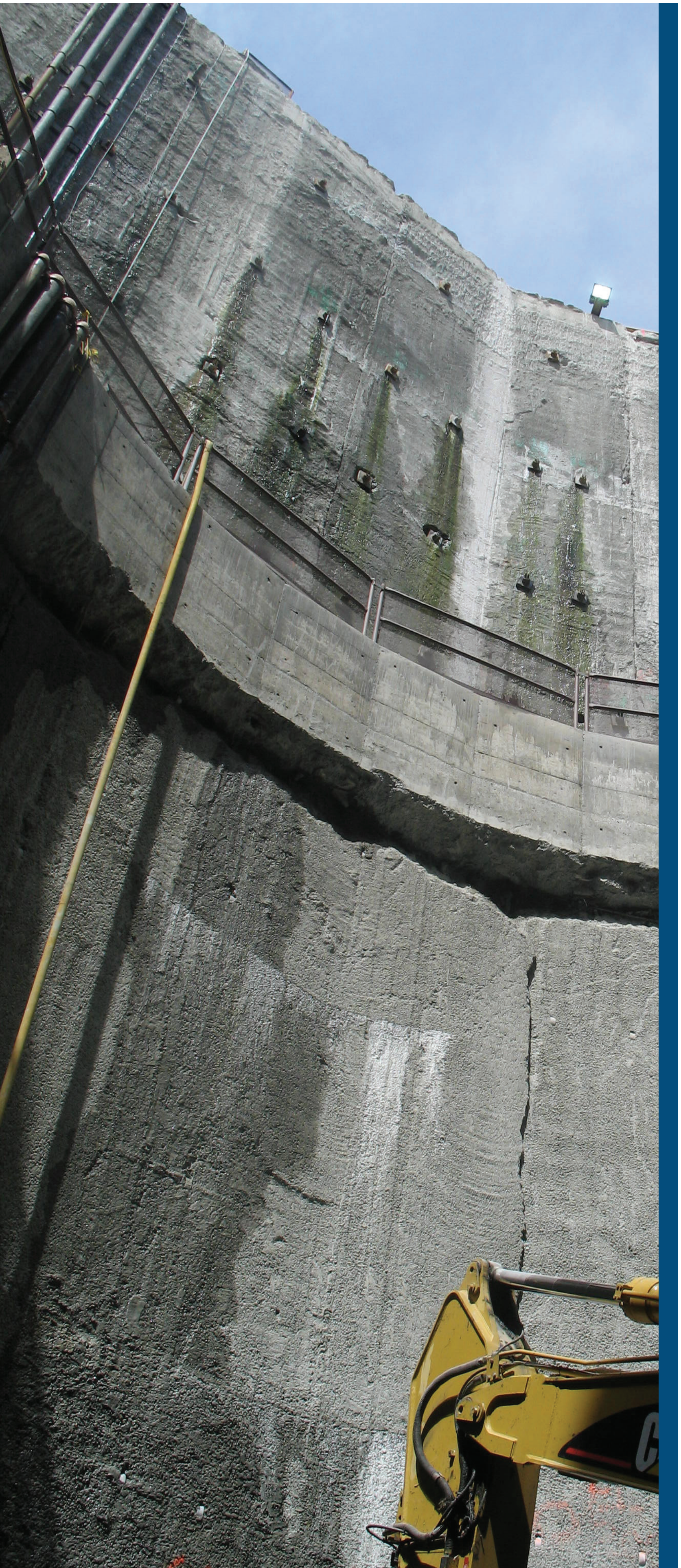
A summary of the cost estimate for the Heritage Drive alignment is provided in **Table 7-1**. Detailed cost estimate information is included in **Appendix G**.

TABLE 7-1 SUMMARY OF TOTAL PROJECT COSTS FOR THE DEEP TUNNEL OPTION ALONG THE HERITAGE DRIVE TUNNEL ALIGNMENT (millions of dollars)

FLOW CASE	CONSTRUCTION CAPITAL COSTS	ENVIRONMENTAL MITIGATION	PROFESSIONAL SERVICES	RIGHT OF WAY	TOTAL
500 m^3/s	\$ 362.4	\$ 5.4	\$ 90.6	\$ 0.1	\$ 458.6
700 m^3/s	\$ 393.8	\$ 5.9	\$ 98.4	\$ 0.1	\$ 498.2

Notes:

1. All costs in millions of Canadian dollars and assume a mid-2014 bid date (excluding GST).
2. Operational and maintenance costs are expected to be between \$1.8 to \$2.0 million per year.
3. Refer to Appendix G for a breakdown of Construction Capital Costs.
4. Environmental mitigation costs are assumed to be 1.5% of the construction capital costs.
5. Professional services are assumed to be 25% of the construction capital costs and include final design services, construction management and additional costs to the owner (e.g. permit and agency fees for plan check, inspections and testing, and engineering fees for design consultants retained by city agencies or project stakeholders). This is based in part on The American Society of Civil Engineers Manual of Practice 45 “How to work effectively with consulting engineers”.
6. Right of Way costs for a temporary construction easement are assumed to be 5% of the assessed land value. This will need to be confirmed with the City of Calgary. The total area of subsurface easement is estimated at 3,000 m^2.

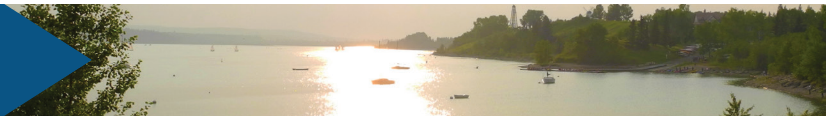


8

CONSTRUCTION SCHEDULE

A preliminary construction schedule for the tunnel and inlet/outlet structures has been developed based on the length of the individual construction activities. The schedule is based on an average daily tunnel advance of 15.5 m/day for the 500 m^3/s flow scenario and 15.0 m/day for the 700 m^3/s scenario. This includes excavation, mucking and installation of the precast concrete segments over the entire tunnel length.

8 CONSTRUCTION SCHEDULE



The schedule is represented by the time-distance diagram shown in Figure 8 1, which depicts the construction activities for the 500 m^3/s flow case. As shown in this plot, a construction period of approximately 33.7 months is anticipated. For the 700 m^3/s flow case a construction period of 34.0 months is anticipated.

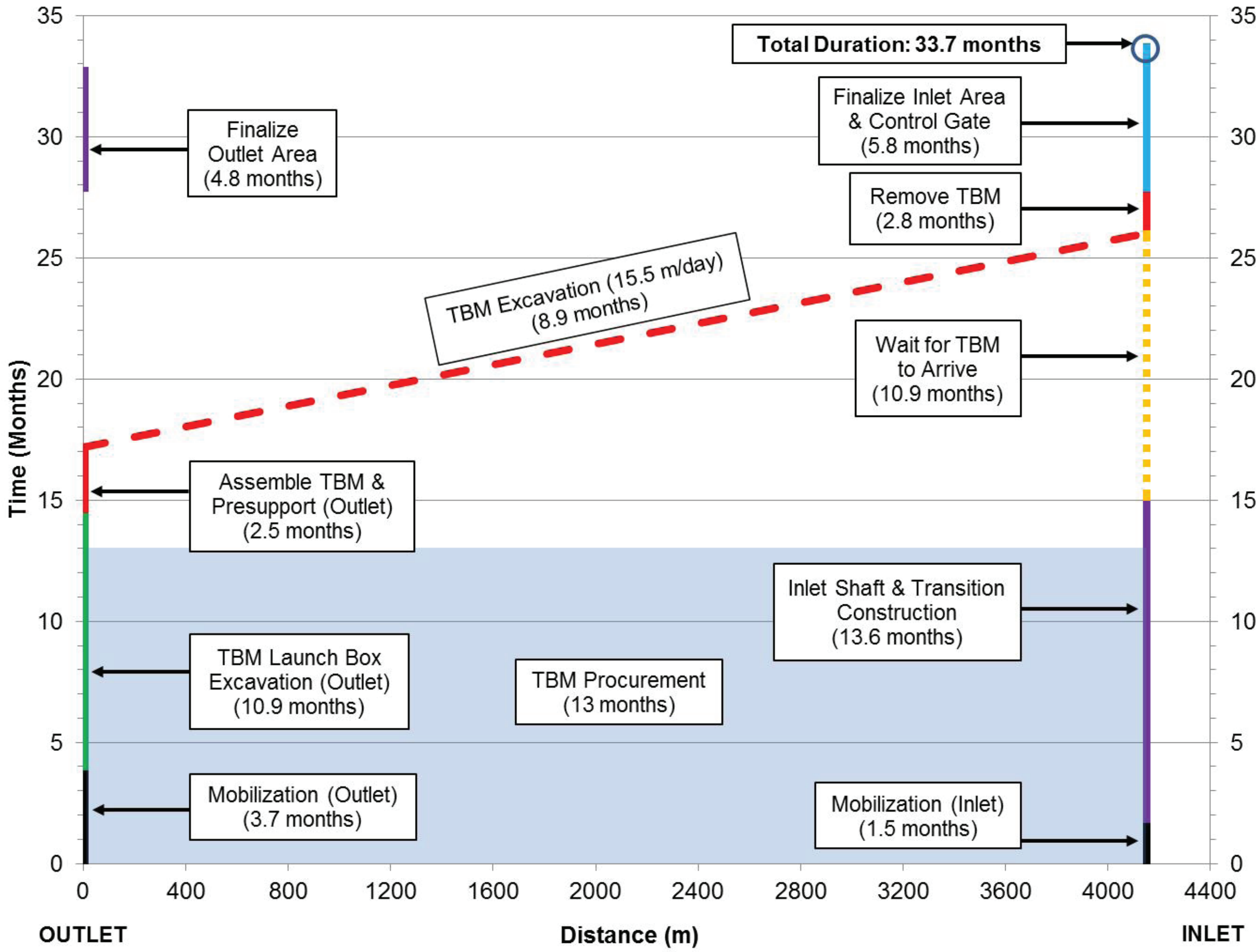
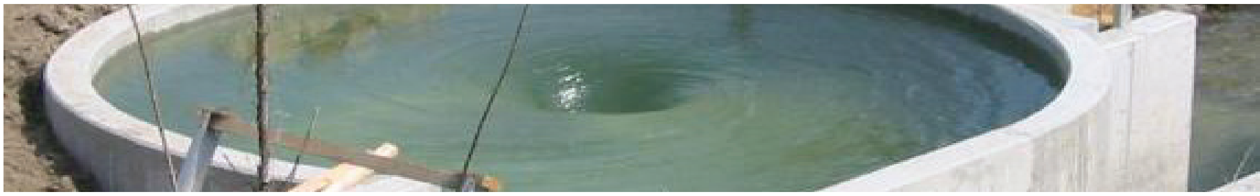


FIGURE 8 1 Time-Distance Diagram for the 500 m^3/s Flow Scenario

This schedule also demonstrates the advantages of the proposed TBM excavation over a conventional excavation approach. As the construction period of the outlet launch box is longer than the TBM procurement period, TBM procurement is not on the critical path. As such, excavation of the tunnel would begin at the same time regardless of excavation method selected. For drill and blast, it is assumed that tunnel excavation would proceed from both the inlet and the outlet for a combined advance rate of 10 m/day. When compared to the 15 m/day advance rate for the TBM, it is estimated that the tunnel excavation period would be 50% longer when using conventional excavation methods.



9

COST / BENEFIT ANALYSIS

This section presents the analysis of the costs versus benefits for the Glenmore Diversion Tunnel. Costs are based on the estimated capital and operational/maintenance costs presented in **Section 7**. Benefits are based on the quantification of flood damage costs as outlined in **Section 9.1** below. The cost / benefit analysis has been carried out using two different methods that are further described in following sections:

1) Net Present Value Analysis – **Section 9.2**
2) Four-Quadrant Analysis Decision Support Tool – **Section 9.3**

9 COST / BENEFIT ANALYSIS

9.1 DAMAGE (BENEFIT) ANALYSIS

The primary benefit of proceeding with the Glenmore Reservoir diversion tunnel will be the ability of the City, Province, residents and business owners to avoid financial, social and environmental losses similar to those caused by the floods in June 2013. Typical damages incurred during large flood events like that of 2013 include:

- Damage to structures and their contents: residential, commercial, and institutional
- Damage to transportation systems: bridges and roads
- Indirect economic damage (business/services)
- Cultural losses
- Environmental losses: aquatic and terrestrial
- In some extreme cases, loss of life

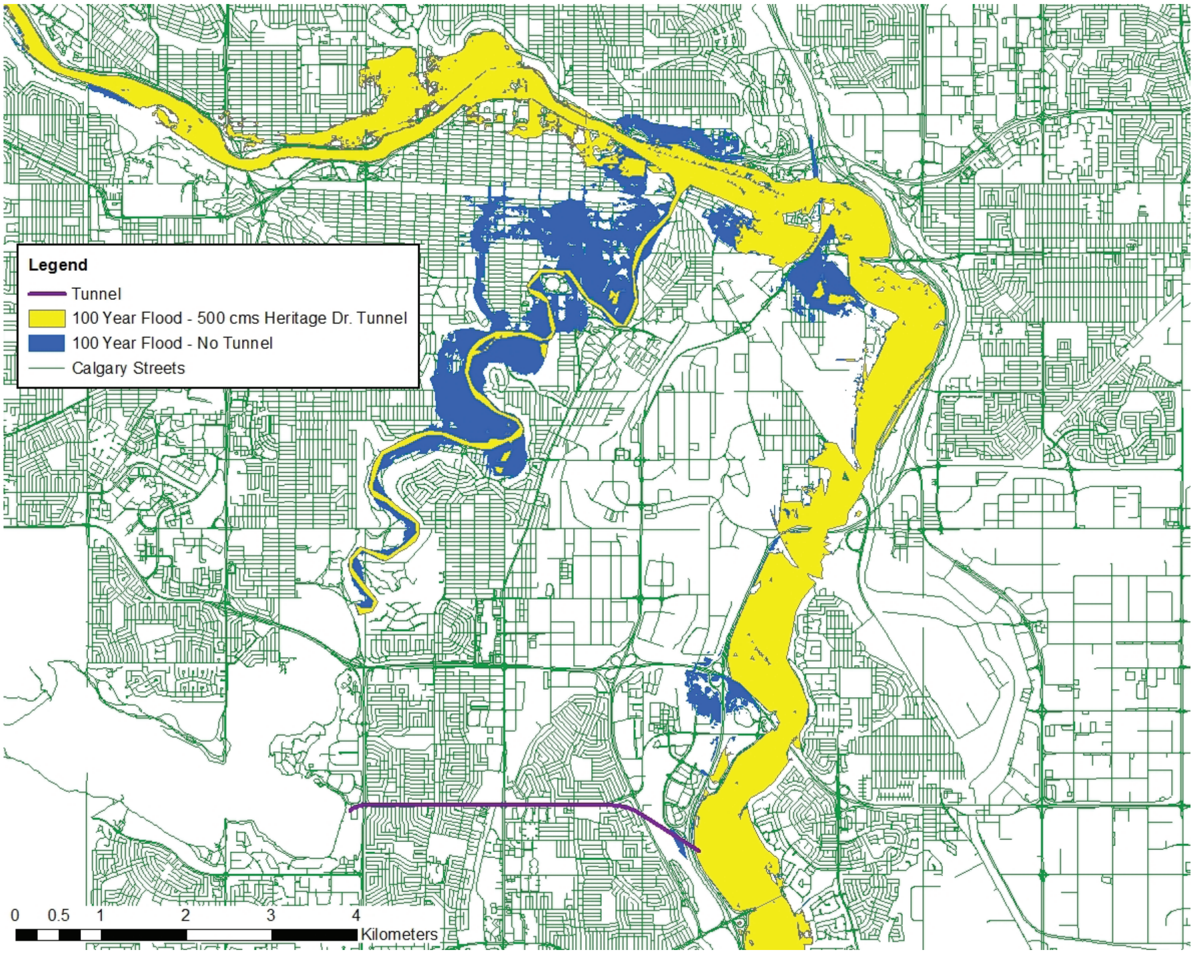


Figure 9-1 100-year flood inundation: with and without diversion tunnel

The expected magnitude of most of these losses is directly dependent on the extent of flooding associated with a particular event. To assist in the damage assessment, flood levels and corresponding inundation extents were therefore assessed for a variety of scenarios, both with and without the tunnel project in place. The analysis of these flood damages proceeded as follows:

- The HEC RAS model, developed for The City in 2012, was used to assess expected water levels along the Bow and Elbow Rivers for a series of flood events. Two versions of the model were used: i) a model that represents the existing state of the rivers (i.e. with no diversion tunnel in place); and ii) a second model that represents how floods would be passed with the tunnel project in

place. Regarding the latter, the existing model was modified to extract the appropriate amount of flow (500 m^3/s for the 100-year flood tunnel design and 700 m^3/s for the 200-year flood tunnel design) from the Glenmore Reservoir on the Elbow River, and re-introduce this flow back into the Bow River at the Heritage Drive alignment outlet location. provides an example of the difference in flood inundation that is expected to result with the construction of a tunnel capable of passing 500 m^3/s. The areas in blue shown along the Elbow River and the Bow River below its confluence with the Elbow represent areas in which flood levels would be significantly reduced. Note that the Glenmore Reservoir Diversion Tunnel would provide little benefit to flood damaged areas upstream of the confluence of the Elbow and Bow Rivers.

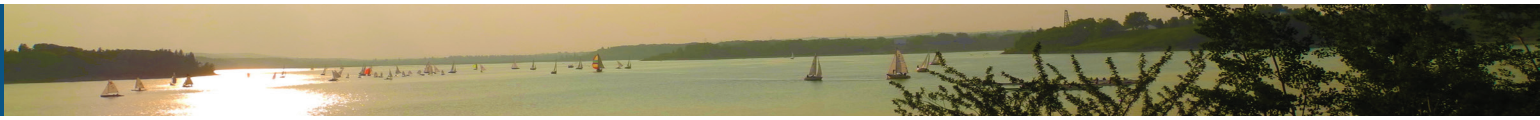
- GIS based data was obtained from The City showing the exact building footprint associated with all development along and near to each river. These geospatially referenced building/structure locations were then mapped and linked to an appropriate HEC RAS model river station and were also mapped to existing topographic models to select a minimum topographic elevation for each building. A comprehensive list of all buildings within the expected floodplain was created, along with corresponding attributes such as the HEC RAS River Reach, interpolated HEC RAS cross-section, building code, building area, and house elevation. Using this information, and linking it to results from the 2012 HEC RAS model, the water surface elevations at each house location for each flood scenario were estimated. The water surface elevation was compared to the house elevation in order to determine the occurrence and degree of flooding. It should be noted that inundation shape files from The City's 2012 flood study also included areas not captured directly by the HEC RAS model. To ensure these areas would be included in the analysis for use in the damage assessment, the HEC RAS cross-sections and corresponding database of potential affected buildings was extended.

- For each scenario, the approximate value of each flooded building was estimated based on the type of building (as determined from the GIS database) and the level of flooding. A number of building types were identified within the floodplain, but the majority were identified as being either residential, or commercial in nature. A value per square meter was assigned to each type of building so that the approximate value could be determined based on the building type and footprint area. An average market value of \$700/m^2 of building area was eventually adopted for both residential and commercial buildings based on a review of published tax roll information in this area. It was assumed that building contents would also require replacement, and that the value of the replacement would be 50 percent of the building damage computed in the above step. Further, the level of calculated damage varied, depending on the level of flooding the building would experience. Flooding was assumed to begin at river levels that were 0.6 m below the main floor elevation (due to possible overland runoff entering through basement window wells etc.) and progressively increase with flood level. It was assumed that should flood levels exceed 2.4 m above the main floor level, that damages would be equal to 100% replacement of the full market property/content value.

Table 9-1 summarizes the expected damages to residential and commercial buildings located within the Bow River flood inundation area for 100-year and 200-year flood scenarios with and without the diversion tunnel.

TABLE 9-1 SUMMARY OF BUILDING AND CONTENT DAMAGES

DIVERTED FLOW	FLOOD MAGNITUDE	FLOOD DAMAGE WITH TUNNEL (MILLIONS)	FLOOD DAMAGES WITHOUT TUNNEL (MILLIONS)	DIFFERENCE (MILLIONS)
		Tunnel Designed for 100 Year Flood		
none	10-Year	$ 28	$ 28	$ 0
74 m^3/s	20-Year	$ 52	$ 78	$ 26
245 m^3/s	50-Year	$ 157	$ 313	$ 156
500 m^3/s	100-Year	$ 326	$ 787	$ 461
500 m^3/s	200-Year	$ 744	$ 1,186	$ 443
500 m^3/s	500-Year	$ 1,449	$ 1,687	$ 239
500 m^3/s	1000-Year	$ 1,789	$ 1,992	$ 203
		Tunnel Designed for 200 Year Flood		
700 m^3/s	200-year	$ 593	$ 1,186	$ 593



In addition to the damages to buildings and contents, the estimated costs associated with other damages resulting from the 2013 flood of the Elbow River are as follows:

• City of Calgary infrastructure costs:	$445 million
• Business economic losses (estimated by the Conference Board of Canada)	$302 million
• Calgary Stampede infrastructure (estimated by the Calgary Stampede)	$ 52 million
• Calgary Municipal Land Corporation – East Village area infrastructure	$ 22 million
• (estimated by CMLC)	
• Elbow Park, Rideau Park and St. Mary's Schools:	$ 28 million
Total	**$ 849 million**

Note that the above cost estimates do not include damages to other franchise utility infrastructure such as Enmax, ATCO, Telus and Shaw.

Table 9-2 below presents a summary of the estimated costs resulting from damage to residential and commercial buildings, City of Calgary infrastructure, Calgary Stampede infrastructure, CMLC infrastructure, schools as well as business economic losses for 100-year and 200-year flood scenarios with and without the diversion tunnel.

TABLE 9-2 SUMMARY OF FLOOD DAMAGES

DIVERTED FLOW	FLOOD MAGNITUDE	FLOOD DAMAGE WITH TUNNEL (MILLIONS)	FLOOD DAMAGES WITHOUT TUNNEL (MILLIONS)	DIFFERENCE (MILLIONS)
Tunnel Designed for 100 Year Flood				
none	10-Year	$ 52	$ 52	$ 0
74 m³/s	20-Year	$ 93	$ 143	$ 50
245 m³/s	50-Year	$ 280	$ 574	$ 294
500 m³/s	100-Year	$ 600	$ 1,482	$882
500 m³/s	200-Year	$ 1,328	$ 2,175	$ 847
500 m³/s	500-Year	$2,586	$ 3,093	$ 507
500 m³/s	1000-Year	$ 3,193	$ 3,651	$458

9.2 NET PRESENT VALUE ANALYSIS

The net present value (NPV) cost-benefit analysis was carried out in accordance with the parameters established in the City of Calgary Triple Bottom Line Policy. Based on the flood damage estimates for a variety of flood frequencies an annualized flood damage cost of $46.3 million is estimated for the scenario without the tunnel; an annualized flood damage cost of $27.2 million is estimated for the scenario with the 500 m³/s (100 year) tunnel in place. This results in a net annualized difference in damage of $19.1 million.

Other parameters for the NPV analysis include:

- 100-year economic analysis period
- Escalation rates equivalent to NPV discount rates
- Annual operating and maintenance costs of $1.8 million
- Costs as referenced in **Section 7.2**

The result of the analysis is a positive Net Present Value of $1.25 billion; therefore, an economically viable project. Sensitivity tests indicate that the overall Internal Rate of Return (IRR) for the project is estimated to be approximately 4%. Therefore, at discount rates that are greater than approximately 4%, the project costs begin to outweigh the benefits, and the benefit cost ratio will drop below one.

9.3 FOUR-QUADRANT ANALYSIS DECISION SUPPORT TOOL

The Four-Quadrant Analysis (4QA) decision support tool is used to assess the cost versus benefit of the diversion tunnel while incorporating sustainable development criteria within the assessment. This tool is based on the principle of balancing lower cost with project footprint / impacts simultaneously. 4QA provides a graphical means to aid decision makers in selecting between project alternatives or to assess the benefits of projects. It relies on measuring both fiscal and non-fiscal project parameters and presenting them in two dimensions for judgment by the appropriate practitioner.

Each project alternative was evaluated for a cost parameter (e.g. net present value - NPV) and its ratio to the selected base case established for the study. It was also evaluated for its “Project Footprint” parameters, which correspond to a set of impacts that act as a proxy for the more global concept of an environmental / social footprint. These parameters were then aggregated, with agreed rankings and weightings, and plotted against the cost parameter.

The 4QA tool allows the presentation of project alternatives in two dimensions simultaneously. Financial criteria can be presented, as usually preferred, without any form of risk weighting or adjustment. A second dimension is added with environmental / social and, if desired, engineering functionality footprint criteria, or other desired criteria, to allow assessment of these objectives with the same level of rigour and use of discrete values as financial criteria. Experience tells us that the most effective advantage in the application of the 4QA tool is the ability to identify project alternatives that represent a better outcome in terms of both cost and Project Footprint.

The project alternatives that provide the most favourable eco-efficiency, that is lowest cost with the lowest Project Footprint, are those located in the top right hand quadrant of the 4QA graphic, as illustrated in **Figure 9-2**.

An additional third dimension can be added to the analysis. This dimension is typically used to present risk, as different project alternatives sometimes have different levels of risk, or perhaps uncertainty, associated with them. This dimension is presented through the use of different size markers on the chart.

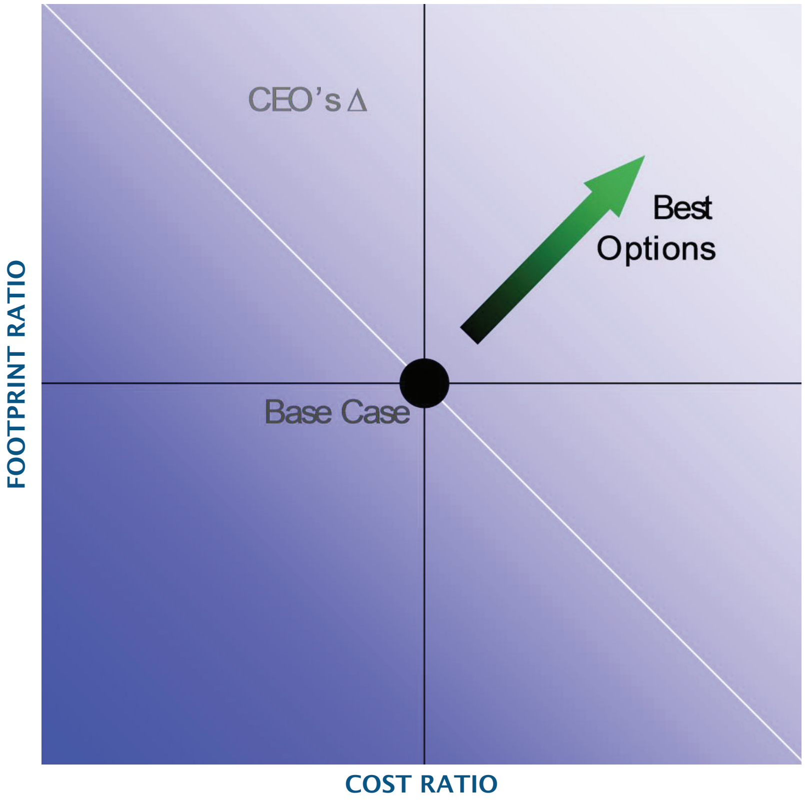


Figure 9-2 4QA Structure

9.3.1 PROJECT ALTERNATIVES

For the purposes of this study, the 100-year flood event was selected as the base case. This base case was then compared to four alternatives:

- 1:100 year flood event with (500 m^3/s) tunnel in place
- 1:200 year flood event with no tunnel in place
- 1:200 year flood event with (500 m^3/s) tunnel in place
- 1:200 year flood event with (700 m^3/s) tunnel in place

9.3.2 PROJECT OBJECTIVES

For the purposes of the assessment, the following project objectives were confirmed with The City of Calgary and used in the analysis:

- Manage flood events with an engineered solution (engineering functionality);
- Improve public safety;
- Maintain public access;
- Protect property values; and,
- Conserve ecosystem functions.

9.4 DECISION CRITERIA

The five project objectives or key criteria were further broken down into sub-accounts. For each of these key criteria / accounts (e.g., Engineered solution, Public safety, Public access, Property values and Ecosystem functions), a data matrix was developed within which the base case and alternatives were assessed against a set of sub-accounts. Each of the five key criteria was assigned a relative weighting value following a review by the project team as follows:

- Manage Flood Events (Engineered solution) 10%
- Public Safety: 30%
- Public Access: 20%
- Property Damage/Clean Up Value: 30% and,
- Ecosystem Functions: 10%

The sub-accounts for each of the five key criteria were assigned a unit of measure and a unique weighting corresponding to the relative significance of each of the selected indicators.

Information from The City of Calgary (e.g. GIS data base, previous studies) was consulted as a source for the quantification of the potential residual impacts and benefits of each alternative. The selected sub-accounts and agreed ranking and weighting of each sub-account was agreed in consultation with The City of Calgary.

The matrix was populated with the sub-account quantity results for each of the project alternatives considered. A numeric relative ranking was assigned for each project alternative by key criteria in relation to the base case (1:100 year flood event). This process was undertaken for each of the five key criteria and the results entered into the 4QA model for aggregation.

The estimated cost of each project alternative, whether a damage value in the case of the 100 and 200 year flood events or an engineered solution cost for the remaining alternatives, was entered into the model. As shown in the 4QA graphical output below, project alternatives that are more expensive and offer fewer benefits than the base case alternative appear in the bottom left hand quadrant whereas alternatives that offer improved social and environmental benefits at a lower cost than the base case appear in the upper right quadrant.

9.5 FINDINGS

- A 1:200 year flood event without an engineered solution is significantly more damaging than the base case 1:100 year flood event.
- Diverting 500 m^3/s during a 1:200 year flood event would result in greater benefits at a lower cost than the damage cost of a 1:100 year flood event without an engineered solution.
- Diverting 700 m^3/s during a 1:200 year flood event would offer improved benefits versus the 500 m^3/s case at a relatively higher cost. But again these greater benefits would be at a lower cost than the damage cost of a 1:100 year flood event without an engineered solution.
- A further improvement of benefits is evident for the engineered solution of the 500 m^3/s and the 700 m^3/s cases during a 1:100 year flood event.

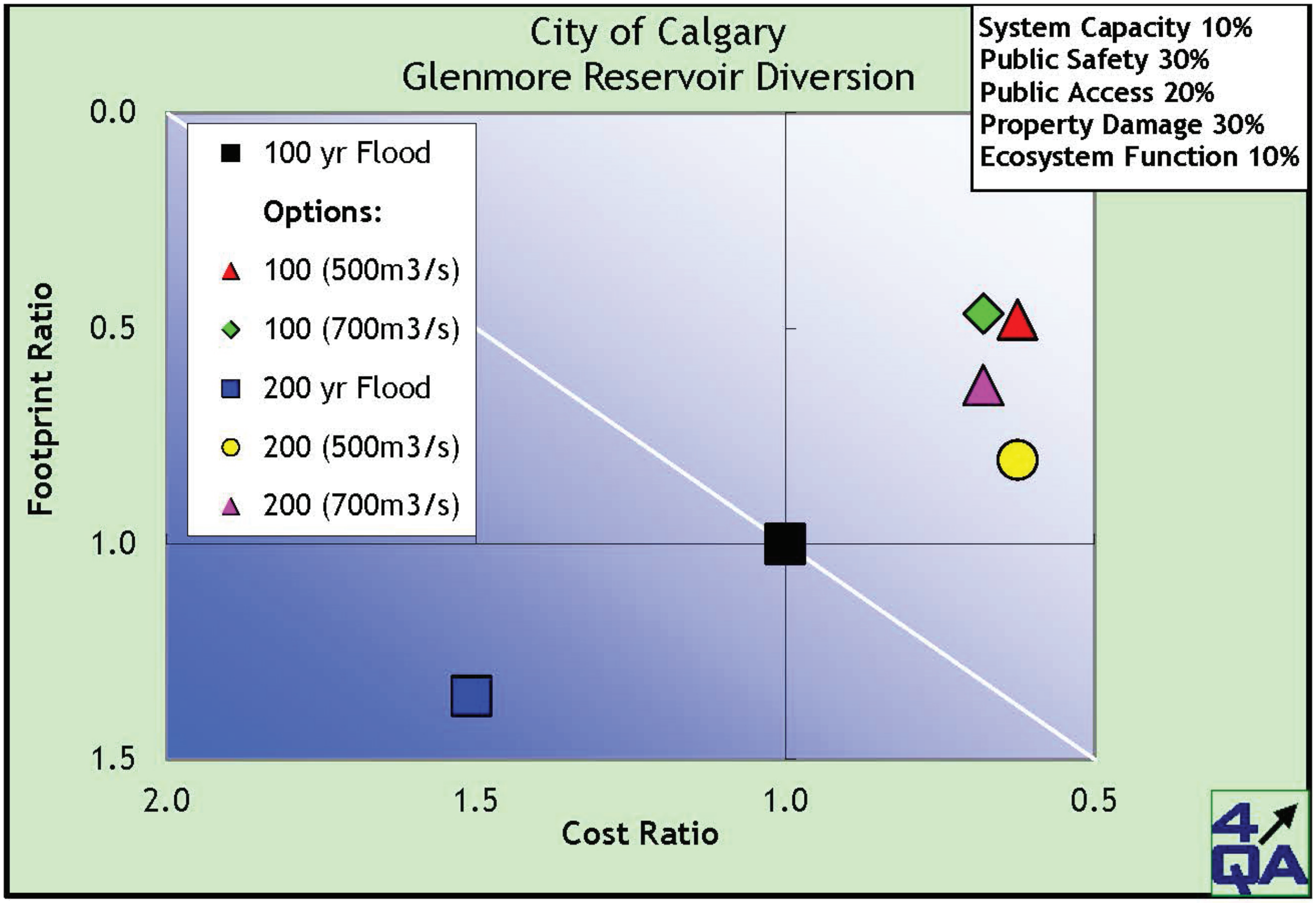


Figure 9-3 4QA Results

10

CONSTRUCTION RISKS

Tunnel projects carry unique risks because the ground is largely unknown except at widely spaced boring locations, and yet the ground dictates the appropriate construction method. Since tunnels are linear and accessible only from the ends, there are limited opportunities to work around a problem if the construction method becomes unsuitable for the conditions encountered. Fortunately, the ground conditions in Calgary are relatively consistent and there is ample tunnel construction experience from which to guide constructability and bidding decisions.

Never-the-less, risk should be considered at every stage of a tunnel project. An initial set of general construction risks associated with the Glenmore Diversion Tunnel and some general discussion on recommended approaches for managing these risks are addressed in this section. These initial risks are:

- Contaminated soil and groundwater;
- Surface settlement which could damage existing utilities and adjacent buildings;
- Groundwater control difficulties;
- Flooding;
- Unanticipated (or differing) subsurface conditions;
- Schedule delays;
- Precast concrete lining damage during installation; and
- Encountering methane gas.

10.1 RISK MANAGEMENT APPROACHES

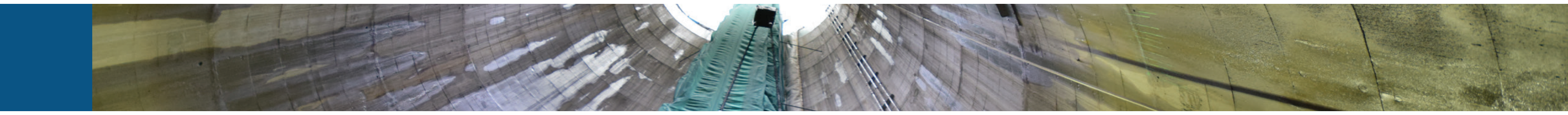
There are various ways to manage construction risk and reduce the potential for claims, cost increases, adverse construction impacts, disputes and delays during construction. Special contract provisions such as: Contractor Prequalification, a Geotechnical Baseline Report, Dispute Review Board, and Escrow Bid Documents, and a formal risk management process have been very effective in risk management for tunnelling projects. These provisions are briefly described below.

Some risks can be covered by insurance; however, insurance is a last resort solution, as it is usually more desirable to try to avoid insurance claims if at all possible. Risks typically assigned to the contractor that insurance can address include compensation to workers for injury on the job, to the public for injuries or property damage, and to the contractor for accidental damage to partially completed work, plant and equipment. Insurable risks that the owner typically carries include risk of default on the part of the contractor, and risk of accidental damage to permanent structures. Insurance is not discussed in terms of being a risk management approach for this project because we assume that the City's standard insurance provisions address these matters adequately. However, the insurance provisions should be reviewed and discussed during final design.

Although an extensive discussion of risk allocation is beyond the scope of this study, our general recommendation is to evaluate each risk and to develop an approach for equitable sharing of the project risks, to the extent possible. Considering the uncertainties involved with underground construction, this approach is usually the most pragmatic in terms of encouraging teamwork on the project and true "partnering" when unanticipated conditions are encountered. In the past, some owners have tried to minimize their risk by allocating all of the project risks to the contractor. This approach has seldom resulted in lower overall project costs, as the courts in resolving claims have often reallocated many risks that the owners thought they had allocated to the contractor. Owners eventually recognized that they were paying for the risks twice, once in bid contingencies and secondly in the settlement of claims in court. Sharing of project risks can also result in lower overall project costs, provided the risks are clearly identified and the responsibility for dealing with each risk is clearly established in the Contract Documents.

Most risks can, by contractual arrangement, be assigned to the owner, to the contractor, or be shared between them. Usually, the primary responsibility for addressing a specific risk should be with the party that is the in the best position to control it, although there is always some risk that unanticipated conditions could be encountered. This means that risks involved with construction methods and execution of the work are normally assigned to the contractor, whereas, risks involved with subsurface conditions and construction impacts on third parties are normally shared between the owner and the contractor. Risks involved with the requirements of local and provincial agencies or agreements with adjacent property owners would normally be assigned to the owner.

The following sections describe specific risk management tools to be considered for this project.



10.1.1 FIELD EXPLORATIONS

One approach for reducing risk is to perform thorough and adequate field explorations of subsurface conditions. The more that is known about the subsurface conditions the less the owners risk is relative to unanticipated conditions and associated cost increases, schedule delays, and contractor claims. In addition, in many situations, completing an adequate field exploration will also result in lower overall project costs.

10.1.2 SPECIFICATION REQUIREMENTS

One approach for reducing risk is to establish minimum requirements aimed at precluding certain levels of risk-taking by bidders. This often takes the form of curtailing high risk construction methods or providing design for some temporary works within the main contract. The intent is to level the bidding playing field so all bidders are bidding to the same risk profile.

10.1.3 CONTRACTOR QUALIFICATIONS

Successful completion of a tunnelling project depends on the efforts of an experienced contractor who has the proper equipment spreads and trained personnel necessary to carry out the work. Owners can use various combinations of pre-qualification, specified qualification criteria and best value procurement methods that emphasize qualifications in evaluation of bids as means of procuring a well-qualified construction team.

10.1.4 GEOTECHNICAL BASELINE REPORT

The primary purpose of the Geotechnical Baseline Report (GBR) is to establish a contractual baseline of the geotechnical conditions anticipated to be encountered during construction (ASCE, 2007). Nothing can eliminate the risk of encountering a differing site condition during construction. However, the potential for costly disputes and possible litigation over what constitutes a differing site condition is greatly reduced with a well-defined geotechnical baseline that is included in the Contract Documents.

Use of a GBR that establishes a contractual baseline of anticipated conditions has been found to result in more uniform bid prices and less exposure to claims resulting from overly optimistic interpretations of subsurface data by bidders. If the conditions encountered during construction are found to be consistent with or better than the baseline conditions, it is unlikely that an unfounded claim will be submitted. If the actual conditions are materially worse than the baseline and the contractor can demonstrate a financial impact, then the contractor may be entitled to additional compensation. Therefore, the contractor accepts the risk for coping with conditions within the baseline, and the City of Calgary would accept the risk for the cost of coping with conditions more difficult than the baseline.

When a clear geotechnical baseline is established in the Contract Documents, contractors tend to build less contingency into their bids to protect against unforeseen conditions. The result is that the costs of such unforeseen conditions would be paid by The City only if those conditions are actually encountered. The role of the GBR in risk management is to clearly define anticipated subsurface conditions to avoid unnecessary claims and cost increases due to alleged differing site conditions.

10.1.5 DISPUTES REVIEW BOARD

The purpose of a Disputes Review Board (DRB) is to provide a panel of experts who can be asked to resolve a dispute during construction that cannot otherwise be resolved between the owner and the contractor (ASCE, 1991). Potential disputes could involve differing site conditions; interpretations of the Contract Documents; causes of delays, acceleration, and scheduling impacts; extra work; or design changes. The board members are kept apprised of the progress of the work through periodic progress reports and occasional site visits. During the site visits, board members have an opportunity to discuss any concerns regarding the progress of the work with the owner and the contractor. In the event of a dispute, sessions are convened at the jobsite to hear both sides of the dispute, to review records, to view site conditions, and to ask questions of both parties. Following a relatively short period of deliberation among the board members, recommendations for resolution of the dispute are provided to the owner and contractor.

With an established DRB to address disputes as they arise, construction can continue with both the contractor's and City of Calgary's efforts focused on the work, not on the claims. Delays can be avoided and costs kept under control because the dispute can be resolved quickly, in a timely manner, as soon as the DRB is engaged in the resolution process. Contractor feedback has been that they tend to reduce contingencies in their bids when a DRB is provided for, knowing that the DRB will provide them with fair treatment if they have a valid dispute.

10.1.6 Escrow Bid Documents

The purpose of Escrow Bid Documents (EBD) is to preserve the basis of the contractor's bid so that it can be accessed during the work to assist in resolving financial adjustments to the Contract, if necessary (ASCE, 1991). These documents (which include assumptions, quantity take-offs, quotes, production rate estimates, labour and equipment costs, etc.) are typically required to be submitted by one or more of the lowest bidders, within several days following the opening of bids. Prior to award of the Contract, the documents of the low bidder would be briefly reviewed for completeness by selected representatives of The City of Calgary and the contractor. The documents are then placed in escrow with a third party, and can be reviewed at the request of either party in the presence of both City and the contractor to assist in resolving a dispute.

The benefit to The City of Calgary is that the EBD's document is the basis of the contractor's bid at the time of bid. In the absence of an EBD provision, The City of Calgary might be presented with "bid sheets" that have been prepared mid-way through the job, and configured to support the contractor's position in a claims dispute. This provision can protect The City of Calgary against financial consequences of an inflated claim or change order in cost negotiations for claims related to project risks.

10.1.7 Contract Payment Provisions

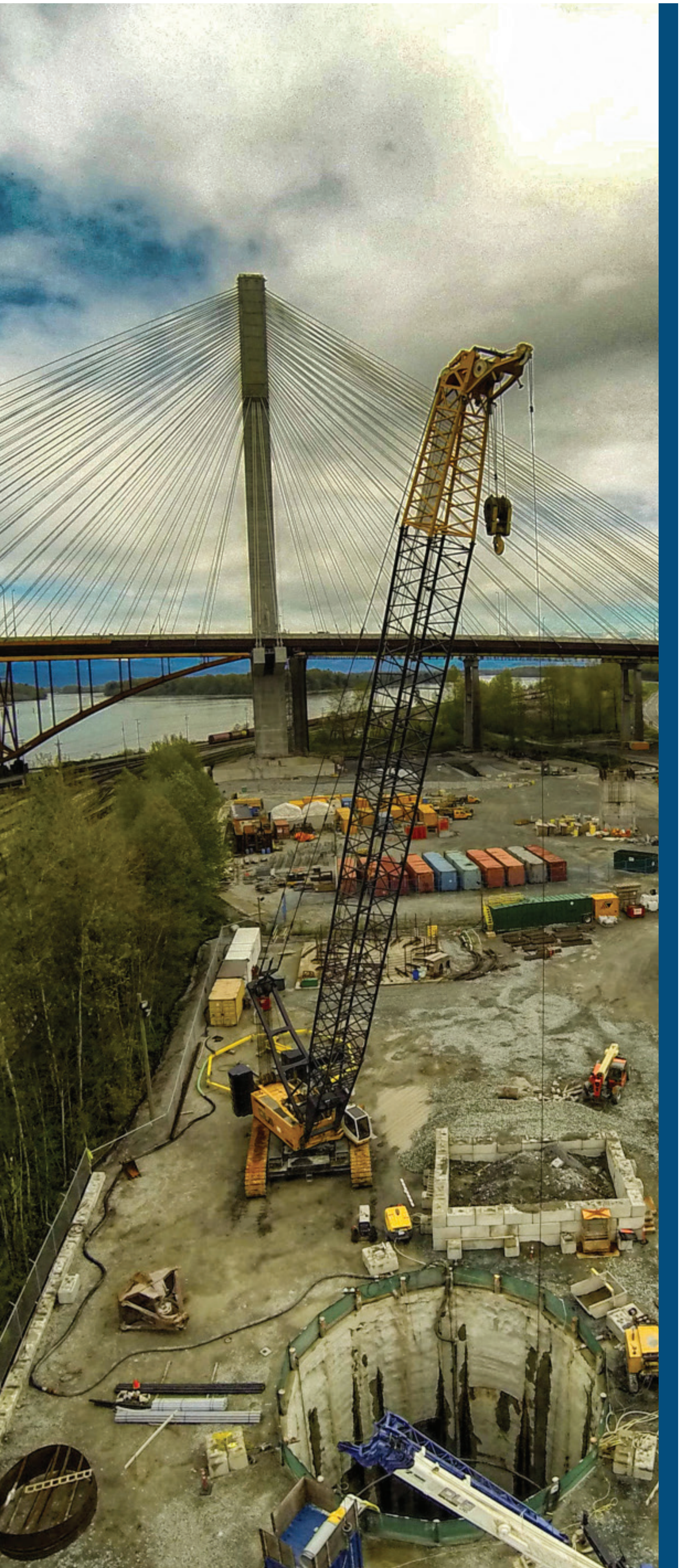
The form of contract (generally classified as either fixed (or forward) priced versus cost reimbursable or any variation in between) can be structured to manage risk of overrunning the project budget in numerous ways. A comprehensive discussion is beyond the scope of this study, but the typical approach would be some form of forward priced contract consisting of a series of lump sum and unit price items with pre-established quantities, and possibly some allowances or provisional sums to address risks like encountering contaminated soil or groundwater.

10.1.8 Formalized Risk Management Process

The use of a formalized Risk Management process should be employed as a means of identifying, evaluating, mitigating and/or allocating risks. This process typically involves a risk register as a means of documentation and follows guidelines such as the Code of Practice for Risk Management of Tunnel Works by the International Tunnelling Insurance Group (2012).

10.2 RECOMMENDED RISK MANAGEMENT APPROACH

Project risks can be effectively addressed by utilizing the various risk management approaches discussed above. Each risk factor requires a unique approach, and in most cases, more than one risk management technique to address it adequately. There are many risks involved with tunnel construction and successful completion of a tunnelling project requires the risks to be identified; avoided, if possible; and, if not, managed using a clear and well-thought out approach. These approaches will have to be discussed further with The City of Calgary and evaluated in detail during final design to develop specific requirements for the project that meet the needs for risk management.



11

CONCLUSIONS & RECOMMENDATIONS

The following provides a summary of the conclusions and recommendations resulting from the findings of this feasibility study of the Glenmore Reservoir Diversion.

11 CONCLUSIONS & RECOMMENDATIONS

1. Tunnel Alignment: As compared to 58th Avenue, Heritage Drive is the preferred route for the tunnel alignment for the following main reasons:

- It provides for a better intake location within the bank of the Glenmore Reservoir
- The Heritage Drive tunnel alignment (approximately 4.2 km) is marginally shorter than the 58th Avenue alignment (approximately 4.9 km)
- Requires a smaller diameter tunnel than the 58th Avenue tunnel if it were necessary to locate the intake for the 58th Avenue tunnel downstream of the Glenmore Reservoir.

2. Tunnel Capacity and Diameter: A 100-year flood event could be accommodated with a tunnel flow capacity of 500 m^3/s. A 200-year flood event requires a 700 m^3/s tunnel flow capacity. It is recommended that the maximum average tunnel flow velocity be restricted to 10 m/s. This requires an internal tunnel diameter of 8.0 m for the 100-year flood event and 9.5 m for the 200-year flood event.

3. Tunnel Flow Control: Control of tunnel flow near the upstream inlet end of the tunnel is recommended to mitigate the need for more extensive tunnel lining and a deeper outlet that would be required to resist static load internal pressures resulting from a control structure at the downstream outlet end.

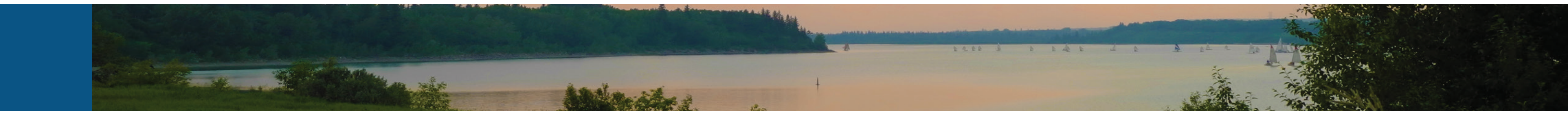
4. Intake: The recommended intake configuration is a horizontal intake complete with a deep regulating gate to provide maximum control of tunnel discharges and velocities. It is proposed that the intake would be constructed along the east bank of Glenmore Reservoir. The inlet shaft is expected to be approximately 73 m deep with 18 m excavated through undifferentiated soil and till and approximately 55 m excavated in bedrock.

5. Inlet Area: Two shafts will be constructed in the inlet area: a larger diameter upstream shaft to connect the intake to the tunnel; and a smaller diameter control shaft to provide access to the valve maintenance area above the control gate. The inlet shafts will be constructed using secant pile walls through the overburden to ensure stability and using conventional hard rock excavation methods (drill and blast or roadheader) in the bedrock.

6. Outlet Works: It is proposed to reduce tunnel outlet flow velocities from 10 m/s to 2.5 m/s prior to discharging to the Bow River through a diffuser with a controlled expansion aligned to provide a streamlined re-entry of flow into the Bow River. The excavation required to launch the tunnel excavation equipment at the tunnel outlet will also form the excavation for the construction of the diffuser. The outlet excavation, located between Deerfoot Trail and the Bow River, will be approximately 90 m long, 20 m wide and 30 m deep; 7 m excavated through overburden and 23 m in bedrock. Conventional methods (drill and blast or roadheader) will be used to excavate the bedrock to the base of the launch box.

7. Tunnel Profile / Depth: The proposed tunnel will slope downwards from west to east at an overall grade of 0.21 percent. As compared to a shallow tunnel that would include cut and cover sections, a deeper tunnel is recommended as the preferred construction option for several reasons: less extensive tunnel lining; fewer utility relocations required; less impact on traffic, businesses, public; less requirement for dewatering; avoids potentially contaminated soil areas; less potential for settlement; less potential for weather delays during construction; and less impact on local drainage.

8. Tunnel Excavation: Excavation of the tunnel by a single tunnel boring machine (TBM) is preferred. As compared to conventional drill and blast methods it provides for faster advance rates; better resists external and internal water pressures; and allows for a precast concrete tunnel liner to be installed as the boring machine advances. Tunnelling will advance from the outlet TBM launch box excavation to the upstream shaft at the inlet area.



9. Downstream Impacts: With the Diversion Tunnel in place, the flood flows from the Elbow River will arrive at the Bow River approximately two hours earlier than would flows without the tunnel. Under natural flood response conditions by the Elbow and Bow Rivers to flood conditions, the net effect downstream of the tunnel outlet would probably be a slight reduction to the peak flows in the Bow River due to the time shift of the Elbow River flow.

10. Contract Delivery: The preferred contract delivery method (design-bid-build, design-build, or early contractor involvement) is largely dependent on The City of Calgary's preference. It is generally recommended, however, to implement an approach that provides for appropriate sharing of project risk between the Owner and Contractor.

11. Regulatory Requirements: Applicable regulatory requirements for the project include Federal (Canadian Environmental Assessment Act, Fisheries Act, Navigable Water Protection Act), Provincial (Alberta Environmental Protection and Enhancement Act, Alberta Water Act, Alberta Public Lands Act) and Municipal (Water Utility Bylaw 40M2006, Glenmore Park Bylaw 8018).

12. Cost Estimate: Total project costs for the project are estimated at $458.6 million and $498.2 million for the 8.0 m (500 m^3/s flow case) and 9.5 m (700 m^3/s) diameter tunnels, respectively.

13. Construction Schedule: Construction duration is estimated at approximately 34 months.

14. Flood Damage Costs: Over a 100-year economic analysis period, annualized flood damage costs are estimated at $46.3 million without a tunnel. This reduces to $27.2 million if a 500 m^3/s capacity tunnel is in place; a net annualized difference of $19.1 million.

15. Cost Benefit Analysis: The net present value (NPV) of the 500 m^3/s (100year) tunnel is $1.25 billion which strongly supports the economic viability of the project.

16. Risk Management: Recommended specific risk management tools include: thorough and adequate field explorations of subsurface conditions; providing a level bidding playing field by all bidders by implementing appropriate technical specification requirements; use of a Geotechnical Baseline Report to establish a contractual baseline of geotechnical conditions; establishment of a Disputes Review Board for dispute resolution; implementing a contractual requirement for the contractor to submit Escrow Bid Documents to document the basis of the contractor's bid; establishment of appropriate contract payment provisions; and establishment of a formalized rick management process throughout the entire project duration.

17. Next Steps: Recommendations for the next steps for the development and implementation of the projects are:

- Completion of preliminary design
- Additional geotechnical investigation and analysis to confirm subsurface conditions along the alignment and at the intake and outlet locations
- Environmental investigations to assess the environmental impacts of the project
- Initiation of the regulatory approval process
- Consultation with public and other stakeholders

Based on the findings of this feasibility study, the Glenmore Reservoir Diversion tunnel project is economically viable and can provide the City of Calgary with a significant reduction of flood impacts. The flood impacts would be reduced primarily along the Elbow River downstream of Glenmore Dam and to the Bow River reach between the confluence of the Bow and Elbow Rivers to the tunnel exit just upstream of Anderson Drive.

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Land Use Bylaw
1P2007

The Land Use Bylaw 1P2007 is comprised of thirteen parts.
This binder encompasses Parts 1-9 and 11-13.

Division 2: Definitions and Methods

General Definitions

13 (1) In this Bylaw, the following terms have the following meanings.

(1.1) "***+15 Skywalk System***" means an environmentally controlled public pedestrian walkway system consisting of ***+15 Skywalk System walkways*** and ***+15 Skywalk System bridges*** which operates through and between ***buildings*** in the Downtown. *33P2013*

(1.2) "***+15 Skywalk System bridge***" means an environmentally controlled pedestrian route located outside of a ***property line*** and which spans a road right-of-way in order to connect ***+15 Skywalk System walkways*** between ***buildings***. *33P2013*

(1.3) "***+15 Skywalk System Fund***" means a civic fund as defined in the +15 Policy. *33P2013*

(1.4) "***+15 Skywalk System walkway***" means a publicly accessible pedestrian route through and across the second floor of a ***building*** and which is entirely contained within the ***property lines*** of a ***parcel***. *33P2013*

(2) "***accent lighting***" means outdoor lighting that is entirely used to illuminate architectural features, art, landscaping features, monuments, or trees and is only directed at such features.

(3) "***actual front setback area***" means the area of a ***parcel*** defined by the ***front property line***, the ***side property lines*** that intersect with the ***front property line***, and a line parallel to the ***front property line*** measured at the farthest ***building setback*** from the ***front property line***.

(4) "***actual side setback area***" means the area of a ***parcel*** defined by a ***side property line*** and a line parallel to that ***side property line*** measured at the farthest ***building setback*** from the ***side property line*** and terminating where that area meets the ***actual front setback area***, the ***rear setback area*** or another ***actual side setback area***.

(5) "***adjacent***" means contiguous or contiguous if not for a ***street***, ***lane***, river or stream.

(6) "***amenity space***" means a space designed for active or passive recreational use.

(7) "***ancillary structure***" means, with reference to ***building height***, an essential component, other than a ***sign*** or flag pole, that protrudes above the roof of a ***building*** and which is necessary for the functioning of a ***building*** including, but not limited to: *68P2008, 39P2010*

(a) an elevator housing;

(b) a mechanical penthouse;

(c) a chimney;

(15) "***basement***" means that portion of a ***building*** which is located below the first floor and is either partially or wholly below ***grade***.

(16) "***bay window***" means a window that projects outward from the façade of a ***building*** but does not include an opening that is intended to give access to a ***building***.

(17) "***bicycle parking stall***" means an area approved as ***bicycle parking stall – class 1*** or ***bicycle parking stall – class 2*** that is equipped to store a bicycle and must include a device:

(a) specifically designed to park a bicycle;

(b) designed to allow a bicycle frame and both wheels to be secured; and

(c) designed to support the bicycle frame and both wheels; and

(d) that is anchored to a hard surface or fixed structure.

(18) "***bicycle parking stall – class 1***" means a ***bicycle parking stall*** in a secured or controlled area.

(19) "***bicycle parking stall – class 2***" means a ***bicycle parking stall*** in an unsecured or uncontrolled area.

(19.1) ***"blade"*** means an element of a Wind Energy Conversion System rotor that extracts kinetic energy from the wind. *33P2013*

(20) "***building***" includes anything constructed or placed on, in, over or under land but does not include a highway or public roadway or a bridge forming part of a highway or public roadway.

(21) *deleted* *3P2010*

(22) "***building coverage***" means the area of a ***parcel*** which is covered by a ***building*** excluding: *5P2013*

(a) portions of the ***building*** located entirely below ***grade***;

(b) portions of the ***building*** greater than 2.4 metres above ***grade*** and with a depth less than 1.0 metres, measured from the wall directly below;

(c) portions of eaves, roofs, pergolas and other similar elements with a depth less than 1.0 metres, measured from the wall directly below;

(d) ***patios***, and any covered or enclosed area located below; and

(e) ***decks***, ***landings***, uncovered stairs, and any external areas located below.

(23) "***building depth***" means the distance from the ***front property line*** to the farthest portion of a ***main residential building*** excluding ***decks***, eaves, ***landings*** and ***patios***, determined by: *5P2013*

26P2010, 33P2013, 13P2017

(57.2) *deleted*

33P2013, 13P2017

(57.3) *deleted*

(58) "***eaveline***" means the line formed by the intersection of the wall and roof of a ***building***.

9P2012

(59) "***expressway***" means a ***street*** identified as a Skeletal Road in the Transportation Bylaw.

(60) "***fence***" means a structure which may be used to prevent or restrict passage, to provide visual ***screening***, sound attenuation, yard décor, protection from dust or the elements, or to mark a boundary.

(61) "***flood fringe***" means those lands abutting the ***floodway***, the boundaries of which are indicated on the Floodway/Flood Fringe Maps that would be inundated by floodwaters of a magnitude likely to occur once in one hundred years.

(62) "***floodway***" means the river channel and adjoining lands indicated on the Floodway/Flood Fringe Maps that would provide the pathway for flood waters in the event of a flood of a magnitude likely to occur once in one hundred years.

(63) "***floor area ratio***" means the quotient of the total ***gross floor area*** of all ***buildings*** on a ***parcel*** divided by the area of the ***parcel***.

51P2008

(63.1) "***floor plate area***" means the horizontal cross-section of a floor, between the floor and the next floor above, measured to the glass line, or where there is no glass line, to the outside surface of the exterior walls and includes all mechanical equipment areas and all open areas inside a ***building*** that do not contain a floor, including atriums, elevator shafts, stairwells and similar areas.

51P2018

(63.2) "***freight rail corridor***" means one of the following fifteen rights-of-way for a freight rail operation excluding spur lines, as indicated, by area, on Map 3.1:

(a) Area 1: means areas between Centre Street S and 15 St SW;

(b) Area 2: means areas between 15 Street SW and south of 16 Avenue NW;

(c) Area 3: means areas between south of 16 Avenue NW and west to the City limits;

(d) Area 4: means areas between east of 12 Street SE and south of Bow River;

(e) Area 5: means areas between south of Bow River and 64 Avenue NE;

(f) Area 6: means areas between 64 Avenue NE and north to the city limits;

(g) Area 7: means areas between 12 Street SE underpass and 26 Avenue SE;

(93) "***mounting height***" means the vertical distance between the lowest part of the ***light fixture*** and the ***grade*** directly below the ***light fixture***.

51P2008 **(94)** "***multi-residential district***" means any one or more of the land use districts described in Part 6 and the CC-MH and CC-MHX districts contained in Part 11.

(95) "***non-conforming building***" means a ***building***:

- (a) that is lawfully constructed or lawfully under construction at the date a land use bylaw affecting the ***building*** or the land on which the ***building*** is situated becomes effective; and
- (b) that, on the date the land use bylaw becomes effective, does not, or when constructed will not, comply with the land use bylaw.

(96) "***non-conforming use***" means a lawful specific use:

- (a) being made of land or a ***building*** or intended to be made of a ***building*** lawfully under construction, at the date a land use bylaw affecting the land or ***building*** becomes effective; and
- (b) that on the date the land use bylaw becomes effective does not, or in the case of a ***building*** under construction will not, comply with the land use bylaw.

9P2012 **(96.1)** "***Officer***" means a Bylaw Enforcement Officer or a Peace Officer.

(97) "***open balcony***" means a ***balcony*** that is unenclosed on three sides, other than by a railing, balustrade or ***privacy wall***.

(98) "***overland flow area***" means those lands abutting the ***floodway*** or the ***flood fringe***, the boundaries of which are indicated on the Floodway/ Flood Fringe Maps that would be inundated by shallow overland floodwater in the event of a flood of a magnitude likely to occur once in one hundred years.

32P2009 **(99)** "***parcel***" means

- (a) the aggregate of the one or more areas of land described in a certificate of title or described in a certificate of title by reference to a plan filed or registered in a land titles office; and
- *24P2014, 15P2016, 4P2017* (b) in the R-C1L, R-C1Ls, R-C1, R-C1s, R-C1N, R-C2, R-1, R-1s, R-1N, R-2, R-G and R-Gm districts, includes a ***bare land unit*** created under a condominium plan;

47P2008, 5P2013 **(100)** "***parcel coverage***" means the cumulative ***building coverage*** of all ***buildings*** on a ***parcel*** excluding, **Accessory Residential Buildings** which in aggregate are less than 10.0 square metres.

(101) "***parcel depth***" means the length of a line joining the mid-points of the ***front property line*** and the ***rear property line***.

Division 3: Floodway, Flood Fringe and Overland Flow

Floodway, Flood Fringe and Overland Flow

55 For ***parcels*** located in the ***floodway, flood fring***e or ***overland flow area***, the requirements of this Division apply and prevail when there is any conflict between the requirements of this Division and any other requirements of this Bylaw. *33P2013*

Floodway Regulations

56 **(1)** For ***parcels*** located in the ***floodway*** on which a ***building*** existed and the use of that ***parcel*** was approved as of September 9, 1985, the use may continue as a ***permitted*** or ***discretionary use*** provided that the ***use*** is listed in the land use district that the ***parcel*** is designated.

(2) Subject to subsection (1), in the ***floodway*** only those ***permitted*** and ***discretionary uses*** which are listed below, and which are also listed in the land use district for which the ***parcel*** is designated, may be allowed as ***permitted*** and ***discretionary uses***:

(a) **Extensive Agriculture**;

(b) **Natural Area**;

(c) **Outdoor Recreation Area**;

(d) **Park**; and

(e) **Utilities.**

New Buildings and Alterations

57 **(1)** No new ***buildings*** or other new structures are allowed in the ***floodway***, except for the replacement of existing **Accessory Residential Buildings**, **Backyard Suites**, **Duplex Dwellings**, **Secondary Suites**,**Semi-detached Dwellings** and **Single Detached Dwellings** on the same ***building*** footprint. *32P2012, 11P2014, 24P2014*

(2) An addition to a ***building*** in the ***floodway*** may only occur if it does not increase the ***building*** footprint or increase the obstruction to floodwaters.

(3) In the ***floodway***, nothing must be stored outside of a ***building***.

Alterations to the Floodway and Riverbanks

58 On those areas of land within the ***floodway*** that are subject to municipal jurisdiction, no alterations shall be made to a ***floodway*** and no structures including, but not limited to, berms, ***decks***, docks, ***fences***, gates, ***patios***, rip-rap or walls shall be constructed on, in or under a ***floodway*** unless those structures are being constructed by, or on behalf of, the ***City*** for the purpose of erosion control, where the primary purpose is to protect public infrastructure. *11P2014*

32P2012, 11P2014

Fringe and Overland Flow Area Regulations

59 **(1)** Only those goods that are easily moveable may be stored on a ***parcel*** in the ***flood fringe*** or the ***overland flow area***.

(2) Unless stated in subsection (3), all ***buildings*** must be set back 6.0 metres from the edge of the ***floodway***.

(3) Where a ***parcel*** was vacant on July 22, 1985, all ***buildings*** must be set back the greater of the following distances:

(a) 60.0 metres from the edge of the Bow River;

(b) 30.0 metres from the edge of the Elbow River, Nose Creek, West Nose Creek; or

(c) 6.0 metres from the edge of the ***floodway***.

13P2008, 32P2012, 11P2014

Building Design in the Flood Fringe

60 **(1)** All ***buildings*** in the ***flood fringe*** must be designed in the following manner:

(a) to prevent structural damage by floodwaters;

(b) the first floor of all ***buildings*** must be constructed at or above the ***designated flood level***; and

(c) all electrical and mechanical equipment within a ***building*** must be located at or above the ***designated flood level***; and

(d) a sewer back up valve must be installed in every building.

43P2016

(2) The rules regarding ***building*** design referenced in subsection (1) do not apply to:

(a) an addition that does not increase the ***gross floor area*** of the ***building*** by more than 10.0 per cent of the ***gross floor area*** legally existing as of June 09, 2014; and

16P2018

(b) a ***fence,*** gate, ***deck, landing, patio, skateboard and sports ramp***, air conditioning unit, satellite dish, hot tub, above ground private swimming pool, and an **Accessory Residential Building**.

(3) Notwithstanding subsection **(1)** and **(2)**, in addition to the conditions listed in section 38, additions to ***buildings*** that increase the ***gross floor area*** of the ***building*** by more than 10.0 per cent but less than 75.0 per cent of the ***gross floor area*** legally existing as of June 09, 2014 must:

(a) provide electrical isolation for the entire ***building*** through the placement of the master switch above the ***designated flood level***; and,

(b) install a sewer back-up valve in the building.

(4) Notwithstanding subsection **(1**), **(2)** and **(3)**, in addition to the conditions listed in section 38, additions to ***buildings*** that increase the ***gross floor area*** of the ***building*** by at least 75.0 per cent of the ***gross floor area*** legally existing as of June 09, 2014 must:

(a) fully mitigate as per subsection (1).

Building Design in the Overland Flow Area *32P2012, 11P2014*

61 **(1)** All ***buildings*** in the ***overland flow area*** must be designed in the following manner:

(a) to prevent structural damage by floodwaters;(b)

(b) the first floor of all ***buildings*** must be constructed at a minimum of 0.3 metres above the highest ***grade*** existing on the street abutting the ***parcel*** that contains the ***building***;

(c) all electrical and mechanical equipment within a ***building*** must be located at or above the first floor of the ***building*** referenced in subsection (b); and

(d) a sewer back up valve must be installed in every building.

(2) The rules regarding ***building*** design referenced in subsection (1) do not apply to: *43P2016*

(a) an addition that does not increase the ***gross floor area*** of the ***building*** by more than 10.0 per cent of the ***gross floor area*** legally existing as of June 09, 2014; and

(b) a ***fence,*** gate, ***deck, landing, patio, skateboard and sports ramp***, air conditioning unit, satellite dish, hot tub, above ground private swimming pool, and an **Accessory Residential Building**. *16P2018*

(3) Notwithstanding subsection **(1)** and **(2)**, additions that increase the ***gross floor area*** of the ***building*** by more than 10.0 per cent but less than 75.0 per cent of the ***gross floor area*** legally existing as of June 09, 2014 must:

(a) provide electrical isolation for the entire ***building*** through the placement of the master switch a minimum of 0.3 metres above the highest ***grade*** existing on the ***adjacent street***; and,

(b) must have a sewer back up valve installed in every building.

(4) Notwithstanding subsection **(1)**, **(2)**, and **(3)**, additions that increase the ***gross floor area*** of the ***building*** by at least 75.0 per cent of the ***gross floor area*** legally existing as of June 09, 2014 must:

(a) fully mitigate as per subsection (1).

City Exhibit J

Please see City of Calgary online Flood Mapping – interactive flood maps found here.

Climate Change Impacts in the Elbow River Watershed

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Climate Change Impacts in the Elbow River Watershed

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Abstract: The Elbow River Watershed originates in the foothills of the Rocky Mountains and is a primary source of water for the City of Calgary. Consequently, the long-term protection and investment of this resource is a primary interest to the City of Calgary. While droughts and water shortages are a serious concern to Albertans, spring freshet flooding may lead to enormous costs virtually overnight. The impacts of climate change on spring flooding in the Elbow River Watershed were determined using both a statistical analysis of historical hydro-climatological data and a modelling analysis using the Canadian Regional Climate Model (CRCM) forcing to the SSARR Watershed model, which is used by Alberta Environment for flood forecasting. Statistical analyses revealed that there were significantly increasing trends in annual mean temperature in the eastern most part of the watershed (+0.007°C/yr) caused by significant trends during February and March only. Significantly increasing trends in annual mean temperature in the western portion of the watershed were also observed (+0.056°C/yr) and were primarily due to increases in January, March, April, July and August. There were no demonstrated trends in total annual precipitation but significant decreases in snowfall were observed in the eastern portion of the watershed. Conversely, increases in snowfall were observed in the western portion near the foothills. No significant trends were observed in discharges within this watershed. Modelling spring freshet flooding using the SSARR and CRCM models showed that spring time flooding due to expected increases in precipitation during the month of May can nearly double flood peaks.

Résumé : Le bassin de la rivière Elbow prend naissance dans les contreforts des Rocheuses et constitue la principale source d'eau pour la ville de Calgary. Par conséquent, la protection à long terme de cette ressource ainsi que les investissements qui la concernent revêtent un intérêt prioritaire pour la ville de Calgary. Bien que les sécheresses et les pénuries d'eau représentent une sérieuse préoccupation pour les Albertains, les crues nivales de printemps peuvent entraîner des coûts énormes presque du jour au lendemain. Les incidences du changement climatique sur les crues printanières dans le bassin de la rivière Elbow ont été déterminées à la fois au moyen d'une analyse statistique de données hydroclimatologiques historiques et d'une analyse faisant appel au Modèle régional canadien du climat (MRCC) avec forçage

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du modèle informatisé de bassin SSARR, dont se sert Environnement Alberta pour la prévision des crues. Les analyses statistiques ont révélé d'importantes tendances à la hausse de la température moyenne annuelle dans la partie la plus à l'est du bassin hydrographique (+0,007 ˚C / an), provoquées par des tendances importantes au cours des mois de février et de mars seulement. D'importantes tendances à la hausse de la température moyenne annuelle dans la partie ouest du bassin ont également été observées (+0,056 ˚C / an) et étaient principalement attribuables à des hausses survenues en janvier, mars, avril, juillet et août. Aucune tendance n'a pu être dégagée pour ce qui est de la précipitation annuelle totale, bien que l'on ait observé des diminutions considérables des chutes de neige dans la partie est du bassin. Réciproquement, des augmentations des chutes de neige ont été observées dans la partie ouest près des contreforts. Aucune tendance importante n'a été observée dans les débits d'eau à l'intérieur de ce bassin. La modélisation des crues printanières à l'aide des modèles SSARR et MRCC a révélé que les crues du printemps attribuables aux hausses prévues des précipitations au cours du mois de mai peuvent presque faire doubler les débits de pointe de crue.

Introduction

The 2005 flood in the Elbow River Watershed and other parts of southern Alberta resulted in $17.2 million dollars in damage that included both municipal operating expenditures arising from the flood as well as damage to infrastructure (City of Calgary, 2005). The last time a major flood of similar magnitude occurred in the Elbow River Watershed was ten years prior. The 1995 and 2005 floods both occurred in the month of June, with persistent heavy rainfall during the days leading up to the flood peaks. Within this same time period, Albertans experienced some of the driest years on record.

The Elbow River Watershed supplies approximately 40% of the drinking water for the City of Calgary. The Glenmore Reservoir, created by the Glenmore Dam located within the boundaries of the City of Calgary, provides storage for the water supply system. Spring runoff is captured for use throughout the remainder of the year. Recent urban development in the Elbow River valley has increased the flood damage potential within the floodplain downstream of the Glenmore Dam. This increased potential for flood damages, coupled with the events of 2005, has prompted efforts to improve the operations of the reservoir. The Glenmore Reservoir must now be operated to provide protection against flooding in addition to meeting the drinking water needs of the City of Calgary. These operational improvements must be achieved within the context of climate change, which may pose greater or lesser risks of flooding. Understanding how climate change may influence future floods is therefore critical to the long-term efforts to manage the water resources of the Elbow River Watershed.

Flooding in the Elbow River Watershed

The headwaters of the Elbow River are located on the eastern frontal range of the Rocky Mountains. The river flows through the foothills and plains into the Bow River at Calgary, at an average slope of 9.5 m/km (Figure 1). The Elbow River drains an area of roughly 1220 km^2 upstream of the Glenmore Dam, yielding an average annual flow of approximately 9.3 m^3/s at the dam. The watershed can be subdivided into the 787 km^2 *Upper Elbow River Watershed* draining through the front ranges and foothills of the Rocky Mountains to the Town of Bragg Creek, and the 393 km^2 *Lower Elbow River Watershed* which drains through mostly prairie land down to the Glenmore Dam.

Xiang (2004) indicates that the majority of total annual discharge in the Elbow River occurs in May, June and July with a very large portion of flow in this three month period being generated upstream of Bragg Creek. This would suggest that snowmelt is a large contributor to springtime flooding occurring in May and June (NRCACH, 1983).

According to climatological data collected at the Calgary Airport (Station YYC in Figure 1) and the Elbow Ranger Station (Station EBRS in Figure 1) the snowpack levels accumulated from the previous October to the following May in both 1995 and 2005 were 75-80% lower than normal. These low snowpacks occurred concurrently with close to normal temperatures in the months of February, March, April

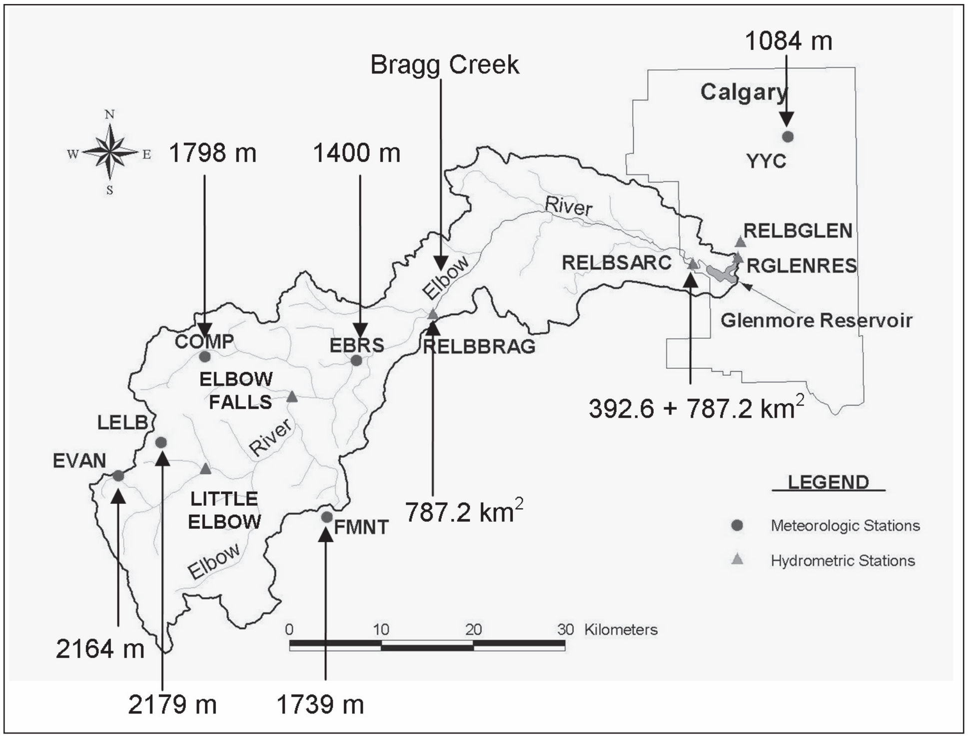

Figure 1. The Elbow River Watershed with gauge locations.

and May. Had greater snowpacks existed, snowmelt may have contributed more significantly (City of Calgary, 2006), but persistent heavy rainfall saturating the soil in the days leading up to the flood peaks are believed to be significant contributions to the peaks in both these floods.

In the period of May 1 to June 5 (the first day of flooding) in 1995, 74.7 mm and 186.1 mm of precipitation fell at the Calgary Airport and the Elbow Ranger Station, respectively. Flow and precipitation data seem to indicate that the lag times for both the Upper and Lower watersheds are less than 24 hours. Rainfall the day of the peak flow in 1995 was 25.2 mm at the Calgary Airport and 51.2 mm at the Elbow Ranger Station. Similarly, the rainfall that fell in 2005 on the day of the peak at the Calgary Airport and Elbow Ranger Station was 46.2 mm and 96.9 mm, respectively. The rainfall depths that fell between May 1 and the day of the first 2005 peak on June 6 were 120.6 mm and 175.6 mm at the two stations, respectively. These rainfall records indicate persistent heavy rainfall leading up to the floods of 1995 and 2005.

Figure 2 shows the peak discharges in the Elbow River at the Bragg Creek hydrometric station (Station RELBBRAG in Figure 1) and the Sarcee Bridge hydrometric station (Station RELBSARC in Figure 1) observed (or estimated) between 1935 and 2005. The data clearly demonstrate that high discharges, defined as being greater than 170 m^3/s, occur in a narrow time period between roughly the last week of May and the last week of June. The stated threshold of 170 m^3/s corresponds to the discharge downstream of the Glenmore Dam where flooding begins to occur. The timing of the high discharges and resulting flooding under the current climate regime suggest that these high flows are influenced by snowmelt and spring rains in this watershed (NRCACH, 1983).

Climate Change Impacts on a Mountain Fed Watershed in the Prairies

A handful of statistical studies have been conducted to investigate trends in hydro-climatological data in Prairie watersheds in an effort to determine the potential impacts of climate change on hydrology. The majority of these studies, however, have focused on average or drought conditions with little attention to the impacts to flooding (for example, Gan, 1998 and Rood

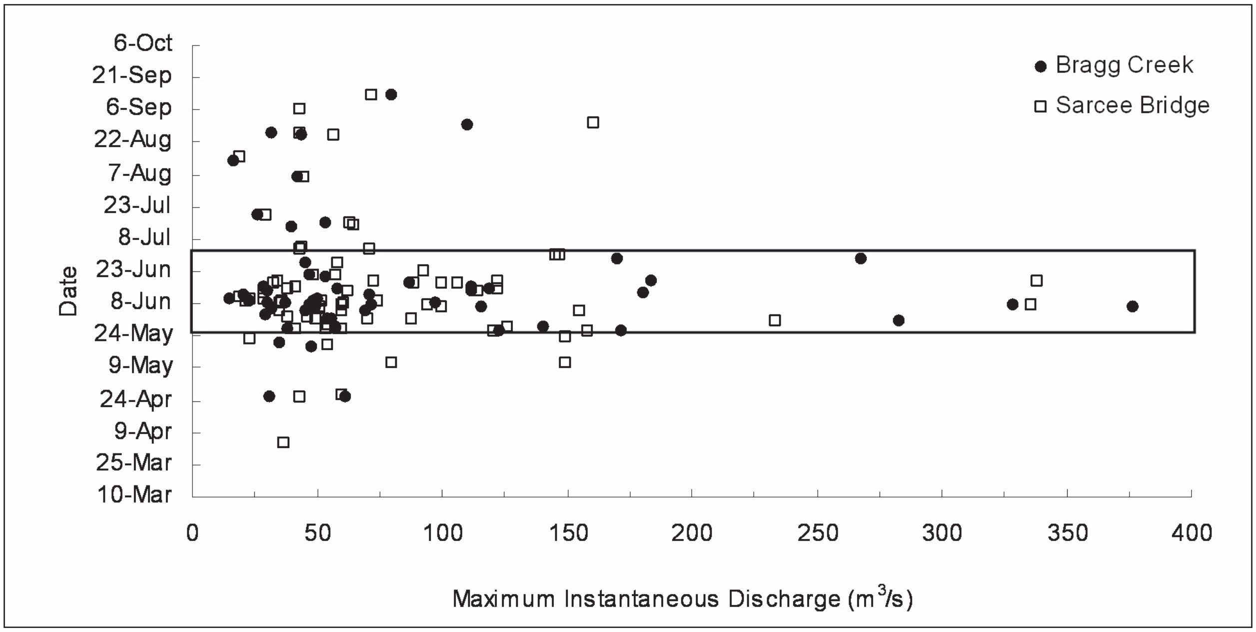

Figure 2. Occurrences of instantaneous maximum discharge for the last 72 years. Values for Sarcee Bridge between 1932 and 1978 were estimated using gauge data at Glenmore Dam and 2005 value at Sarcee Bridge is suspect due to overtopping of banks.

et al., 2005). Adamowski and Bocci (2001) observed significantly increasing trends for mean July discharges in the Prairie and Pacific regions, and an increasing trend in annual maximum daily flow for the Prairie regions. Burn and Hag Elnur (2002) generally did not observe any trends in either maximum annually daily flow or April flows for stations residing within Alberta foothills. Douglas *et al.* (2000) observed no trends in flood flows in the Midwestern USA. However, Zhang *et al.* (2001) observed generally decreasing maximum annual daily mean flow and increasing March and April mean monthly flows for southern Canada. Burn *et al.* (2004a) did observe increasing flows during spring freshet for two watersheds in the Mackenzie River Basin. The results are mixed on whether flooding or flood producing hydrological conditions are eminent under a warming climate. The conclusion that most studies seem to agree on is that earlier ice-off dates are occurring all across Canada (Burn *et al.*, 2004a; Zhang *et al.*, 2001).

Impacts of climate change on flood hydrology using climate simulation models would require a time scale of one day or less. Attempting to model flood events at small timescales is considered difficult due to numerous issues including confidence in climate model output and temporal and spatial downscaling of the climate information. Töyrä *et al.* (2005) noted that 11 Global Climate Model replications of air temperature and precipitation in the Prairies for the period of 1961-1990 showed reasonable reproduction of mean air temperature but an over-estimation of precipitation (particularly during winter and spring months). Sung *et al.* (2006) wanted to examine the impacts of climate change on navigation and transport in the Mackenzie River. They used a two-stage procedure in which base climate model output for temperature and precipitation fields were generated by the Canadian Meteorological Centre Global Environmental Multi-scale Model (GEM) (Côté *et al.*, 1998a; Côté *et al.*, 1998b; Yeh *et al.*, 2002) and used as input to WATFLOOD (linked to River1D). In the second stage CGCM2, HADCM3 and CSIR-Mk2b temperature and precipitation forecasts were used to generate future climate parameters (with no spatial scaling) that would provide a measure of the expected changes to temperature and precipitation values with respect to the base condition. This then provided a measure of expected changes to flow levels (at a roughly daily timescale). The modelling suggests that the navigation season which is governed by ice-off dates will increase. Cheng *et al.* (2007) used a statistical method to downscale climate model output to an hourly time-step and showed that incidences of freezing rain events are likely to increase in parts of northern Ontario but decrease in southern Ontario in future climatic conditions.

Objectives

The objectives of the current work are to answer two questions: (a) can we observe changes or trends in meteorological or hydrological parameters that govern flooding in the Elbow River Watershed? and (b) what would be the expected changes in flooding given possible climate change? Each question is considered separately and the methodology, results and discussion are provided in turn for each.

Observing Trends in Meteorological and Hydrological Parameters Governing Discharge in the Elbow River Watershed

Methodology

Climatological and hydrometric data were collected from stations within and around the Elbow River Watershed at various intervals depending on the data available. There are four hydrometric stations along the Elbow River and six meteorological stations in the Elbow River Watershed. The locations of the six meteorological stations and the four hydrometric stations are provided in Figure 1 along with the elevations of the meteorological stations.

Meteorological data were obtained from Environment Canada for the Calgary International Airport (YYC) from 1884-2005; the Elbow Ranger Station (EBRS) from 1965-2005; Evan Thomas Station (EVAN) from 1985-2000; Forget Me Not Station (FMNT) from 1984-2000; Little Elbow Summit Station (LELB) from 1984-2000; and Compression Ridge Station (COMP) from 1984-2000. Parameters tested for trends were mean annual temperature, mean monthly temperature, total monthly and total annual precipitation, as well as total annual values of rain and snow. However, COMP and LELB were excluded from the testing due to significant amounts of missing data and FMNT and EVAN were only tested for trends in total annual precipitation as that was the only data available.

Mean monthly discharges, mean annual discharges, as well as maximum instantaneous discharges were obtained from Environment Canada and Alberta Environment for the Elbow River at Bragg Creek (05BJ004, RELBBRAG in Figure 1) from 1935-2005; Sarcee Bridge (05BJ010, RELBSARC in Figure 1) from 1935-2005; Elbow River above Glenmore Dam (05BJ005, RELBGLEN in Figure 1) from 1934-1977; Elbow Falls (05BJ006) from 1967-1995; and the Little Elbow River above Nihahi Creek (05BJ009) from 1965-1995. Parameters tested for trend included mean annual discharge, mean June discharge, mean May discharge and annual instantaneous maximum discharge. However, station 05BJ005 was excluded from testing due to technical issues with the gauge and that any trends here should be mirrored in trends observed at Sarcee. Station 05BJ009 was only tested for trends in May and June mean monthly flows due to missing data preventing the computation over entire years.

The statistical test for trend used in this study is the Mann-Kendall Test for Trend (Mann; 1945; Kendall, 1975; Burn, 1994; Valeo *et al.*, 2003). This non-parametric test is particularly useful for non-normally distributed data as it provides a normally distributed trend test statistic (z) for series greater than ten data points. This test also provides p-values associated with the computed z value and a robust estimate of the slope β for the trend (Hirsch *et al.*, 1982). Serial correlation was considered using the method illustrated in Burn *et al.* (2004b), which utilized the trend free pre-whitening approach of Yue *et al.* (2003). However, assessing the impacts of spatial correlation on trend detection by determining field significance (via Livezey and Chen, 1983) was not conducted in this study.

Results and Discussion

Tables 1 and 2 only list the significant trends (at the 0.05 significance level) observed in all the hydrological and climatological data sets that were tested.

Temperature

Table 1 lists the significant temperature trends observed in data sets that were tested. A significantly increasing annual temperature trend is observed at YYC but only February and March exhibited significant trends (increasing) in monthly mean temperature at this station when monthly data were tested. These trends are also shown in Figure 3b, along with the annual temperature trend provided in Figure 3a (the trend lines shown in some of the figures given in Figures 3 and 4 were plotted with least squares regression). Therefore, it is evident that the annual temperature trend only results from the presence of significant trends in February and March, as no other month showed any kind of significant trend. The temperature trends identified in this analysis are consistent with observations of earlier ice-off dates occurring across Canada. A rate (according to β) of +0.038°C/yr in February and +0.018°C/yr in March could easily affect the energy balance of the snowpack and create earlier melt conditions, exacerbating spring related flooding. The annual increase at the Calgary Airport of 0.007°C/yr translates into an overall increase of 0.84°C temperature rise from the start of the recorded period to 2005.

Bearing in mind the very short time series available for the Elbow Ranger Station (EBRS), results derived from the EBRS data and reported in Table 1 should be treated with caution. A significant increasing trend for the annual mean temperature is indicated. Similar trends in mean temperature were identified for the month of January, the spring freshet months of March and April, as well as the summer months of July and August. The most significant of these trends (very low *p*-value) is the annual mean temperature, which shows a trend of +0.056°C/yr; such a trend translates into an increase of over 2°C in the last 40 years. Interestingly, no significant trend was found in the February data. A trend in February had been expected due to the presence of such a trend in the Calgary Airport data.

Figure 3c shows the available data from the YYC, the EBRS and the Little Elbow Summit (LELB) stations from 1965 to 2005 (the period of availability for EBRS). The figure reveals very similar patterns in all three data sets, with data at EBRS showing cooler temperatures while data at LELB are even cooler.

Precipitation

Table 2 shows the significant trends observed in precipitation patterns at YYC and EBRS. There was no trend in total precipitation at YYC for the 120 years of record. However, when the total precipitation data were split between rainfall and snowfall, the data showed a significant increasing trend of +0.425 mm/yr in rainfall totals and a decrease of 0.224 mm/yr in snowfall totals. These trends are shown in Figure 4a. The combination of these trends essentially produced no significant trend in precipitation totals at YYC. The reader must bear in mind that data collection efforts and instrumentation likely changed during the 120-year collection period at YYC, and thus, the snowfall/rainfall data series may not be homogenous throughout this period. An investigation of monthly precipitation data at the Calgary Airport (YYC) further reveals seasonal trends. There is a large significant trend for increased precipitation in June. This increase is offset by a significantly decreasing trend in snow accumulation over the winter months (from the previous October to the following April) at YYC, and small decreases in precipitation in the months of February and March.

The analysis of monthly precipitation totals recorded at the EBRS station revealed significant trends for the months January to May, as well as the month of October. These trends, reported in Table 2, were observed over a period of time ranging from 22 to 33 years, depending on the length of records available for each month. The month of April shows a large decreasing trend of 1.183 mm/yr. This decreasing trend is offset by large increasing trends in monthly precipitation identified from January to March, as well as the months of May and October. Despite the magnitude of these increasing precipitation trends, the annual totals series showed no significant trend. If the data are accurate, then it is also significant that snowfall in the mountainous part of the watershed is increasing prior to the spring freshet period, thereby potentially exacerbating springtime flooding. Figure 4b shows the data between 1977 and 2004 that was available for YYC and three other gauges in the mountainous part of the watershed (FMNT, EVAN and EBRS). The trends in precipitation for all the mountainous gauges look visually similar, particularly after 1991. The period between 1991 and 1998 shows some of the highest levels of annual precipitation in the time series at EBRS. The patterns show greater variability than

Table 1. Significant temperature trends in the Elbow River Watershed.

Station	Parameter	Years of Record	Statistics
Calgary Airport (YYC)	Annual Mean	1885-2004: 120	p=0.008, β= +0.007
	February	1885-2005: 121	p=0.0009; β= +0.038
	March	1885-2005: 121	p=0.036; β= +0.018
Elbow Ranger Station (EBRS)	Annual Mean	1965-2004: 40	p<<0.0001; β= +0.056
	January	1965-2005: 41	p=0.012; β= +0.133
	March	1965-2005: 41	p=0.042; β= +0.073
	April	1965-2005: 41	p=0.014; β= +0.06
	July	1965-2005: 41	p=0.001; β= +0.053
	August	1965-2005: 41	p=0.044; β= +0.04

Table 2. Significant precipitation volume trends in the Elbow River Watershed.

Station	Parameter	Years of Record	Statistics
Calgary Airport (YYC)	Annual Rainfall	1885-2004: 120	p=0.024*, β= +0.425
	Annual Snowfall	1885-2004: 120	p=0.019, β= -0.224
	February	1885-2005: 121	p= 0.035*, β= -0.049
	March	1885-2005: 121	p= 0.045, β= -0.051
	June	1885-2005: 121	p= 0.029, β= +0.224
	October to April	1885-2005: 121	p= 0.048, β= -0.228
Elbow Ranger Station (EBRS)	January	1977-1998: 22	p=0.021; β= +1.041
	February	1977-1998: 22	p=0.006; β= +1.154
	March	1977-1998: 22	p=0.043; β= +1.42
	April	1965-1997: 33	p=0.023; β= -1.183
	May	1965-1997: 33	p=0.035; β= +1.461
	October	1973-1997: 25	p=0.012; β= +1.372

*Significance (p-value) of Mann-Kendall statistics shown was computed using the trend free pre-whitened series. September precipitation at the Calgary Airport from 1885-2004 originally showed a significant trend but after serial correlation was taken into account, the trend free pre-whitened series showed no significant trend.

the YYC gauge but the annual total precipitation for all the mountainous gauges are at their lowest levels after 1998.

Discharges

Flow statistics for the four hydrometric stations along the Elbow River are shown in Table 3. Only one significant trend could be detected in discharges; specifically, in May, monthly mean discharges from the Upper Watershed at the Bragg Creek gauge are decreasing at a small rate. While no other parameters tested showed significant trends, the sign of the insignificant trend was provided along with the number of years of record. The "trends" are mixed as either increasing or decreasing with varying lengths of record. Figure 5a shows the May and June data available from 1935 to 2005 for

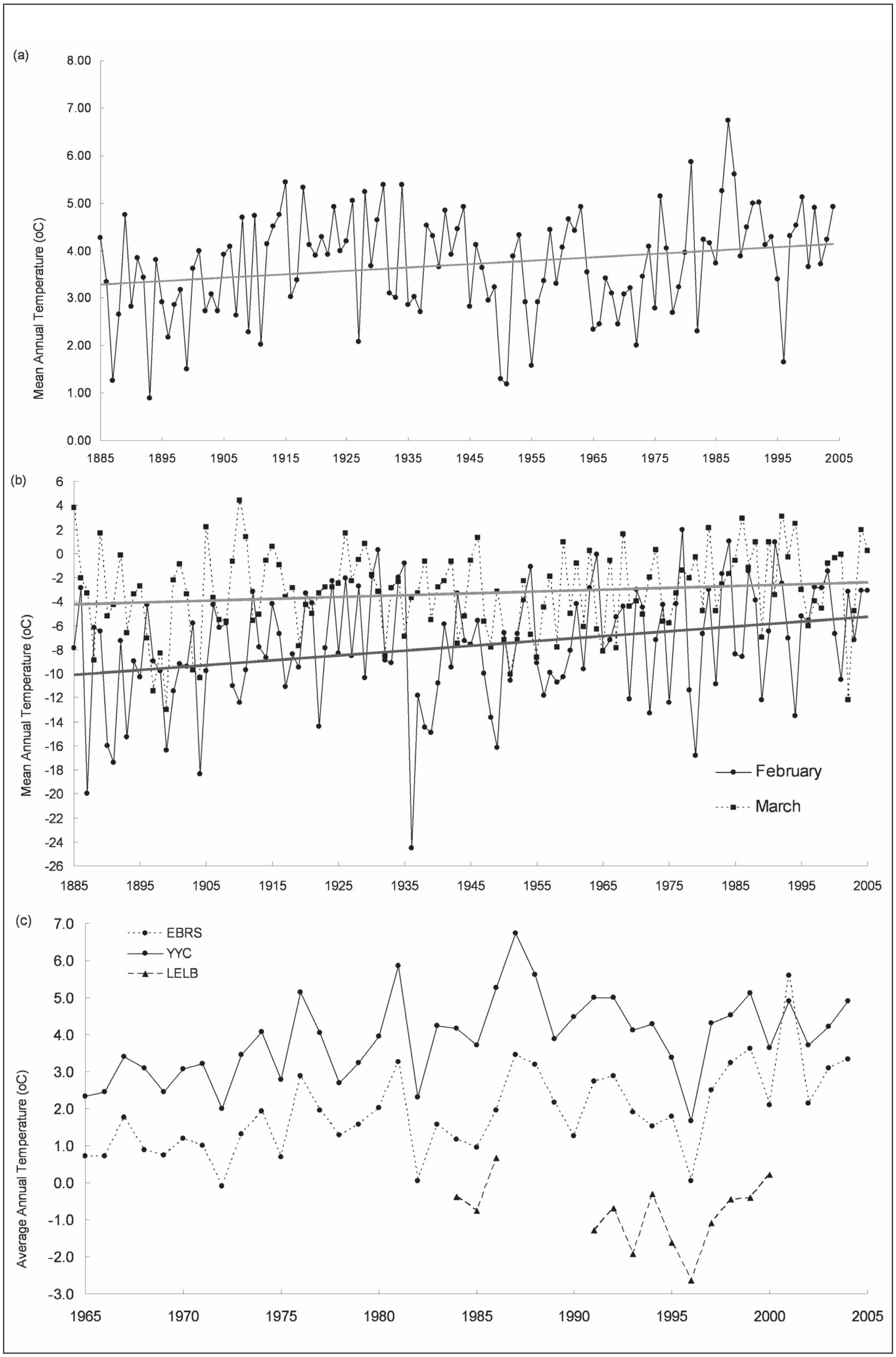

Figure 3. (a) Mean annual temperatures at Calgary Airport; (b) spring temperatures at Calgary Airport; and (c) mean annual temperatures at Airport and higher altitude stations.

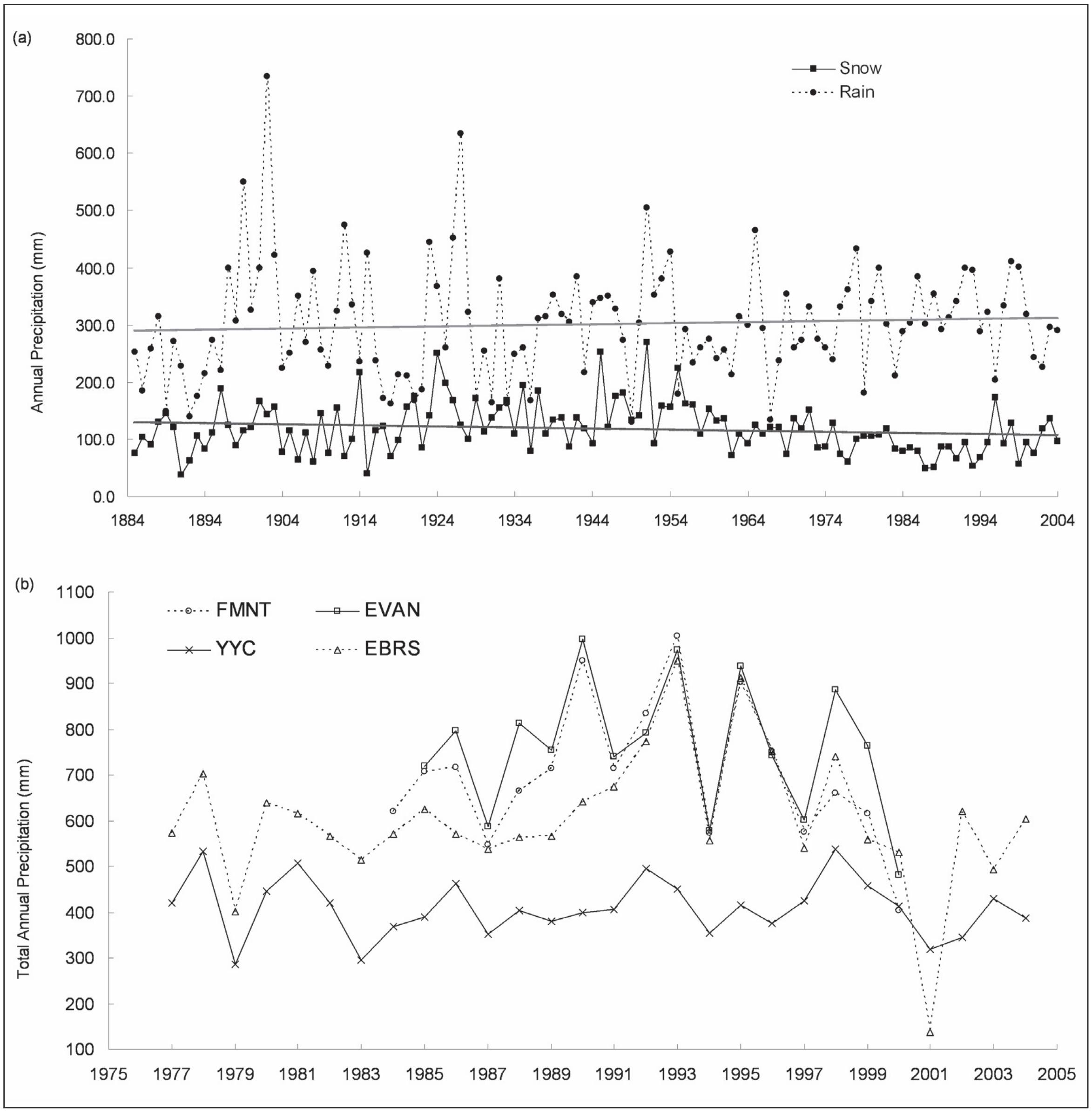

Figure 4. Total annual precipitation at (a) the Calgary Airport divided by Rain and Snow from 1885-2004; and (b) locations throughout the watershed in the last three decades.

the Bragg Creek gauge. It should be noted that the data from 1935-2005 are shown in Figure 5a, although the statistical analysis for May was only conducted for the years between 1945 and 2005 due to gaps in the first ten-year period. The statistical analysis for June was conducted for the years between 1935 and 2005. The graph shows very similar patterns in both May and June mean discharges. These similarities suggest that if the complete data set for May was available for years prior to 1945, the discharges in the month of May would lack any discernable trend. This confirms the fragility of such tests and their dependency on data set lengths. Figure 5b shows the instantaneous maximum discharges, mean May discharges and mean June discharges for the Sarcee Bridge gauge. All trends for these discharges are increasing but are deemed insignificant at the 5% level (see Table 3). Patterns of mean data naturally are similar to the pattern in instantaneous maximum data but are too short to reveal any conclusive information on trend. Figure 5b

Table 3. Flow statistics at various stations along the Elbow River.

Station	Parameter	Years of Record	Statistics
Bragg Creek	Annual Mean	1978-2004: 27	+
	Inst. Max	1950-2005: 56	-
	May	1945-2005: 61	p=0.019 β=-0.092
	June	1935-2004: 70	-
Sarcee	May	1989-2006: 16	+
	June	1979-2006: 26	+
	Inst. Max.	1935-2005: 72	+
Elbow Falls	June	1967-1995: 29	-
	May	1967-1995: 29	-
	Inst. Max.	1967-1995: 29	-
Little Elbow	May	1978-1994: 17	
	June	1978-1994: 17	

shows that in the brief period between 1985 and 2005, both the lowest and highest recorded instantaneous discharge occurred.

Watershed management practices that result in diversions or changes in land cover (examples include logging, urbanization, tourism, and oil and gas production), and natural phenomena such as pine beetle infestations and fires can change a catchment's water budget and lead to increases or decreases in monthly and annual stream flow measurements. This can impact trend detection analyses. Currently, the majority of the Elbow River watershed, or 63%, lies within Kananaskis Country, which is in a zoned Forest Reserve with the majority of that (58%) being protected against development. Another 22% of the watershed residing below Bragg Creek is primarily used for agriculture and cattle grazing, 13%, lies within the Tsuu T'ina Nation, and the remaining 2% within the City of Calgary (Elbow River Watershed Partnership, 2007). While studies on land-use changes in this catchment between the earliest year used in the statistical analyses (which is 1885) and the present day are unknown to the authors, a study by Hasbani (2007), which studied land-use change in the Elbow River Watershed between 1985 and 2006 indicates that the watershed experienced an almost zero change in the total amount of forested land, a decrease in the amount of agricultural land of approximately 2%, and an increase in the amount of urbanized land by 2.5% (amounts as percentages of the total area) in this period. Note that conversion from one land use to another varied in that period but the net differences over the 21-year period are small. While difficult to extrapolate these values (into the past), the authors feel that changes in land cover in this catchment have had relatively little affect on flows used for the purposes of examining trends in monthly or annual streamflow. This may change in the near future as there are plans to log significant portions of the unprotected Forest Reserve.

Data from the meteorological stations may be spatially correlated as can be flow data from hydrometric gauges positioned along the same river. Livezey and Chen (1983) show that significant trends in time series data may be detected simply by chance from stations that are spatially correlated, particularly when conducting multiple tests on data from the same set of stations. The temperature, precipitation and flow data used in this work are spatially correlated to some degree because they are influenced by weather systems that are larger in scale than the study area. In total, data from four hydrometric gauges provided information for a total of 12 tests on flow data, but only one significant trend was detected. This trend was also discussed in the previous section as being potentially misleading. For the meteorological data, 58 separate tests were conducted with 21 tests indicating significant trends (or 36% of the tests). While no evaluation of field significance has taken place, the work in Livezey and Chen (1983) for the level of significance employed

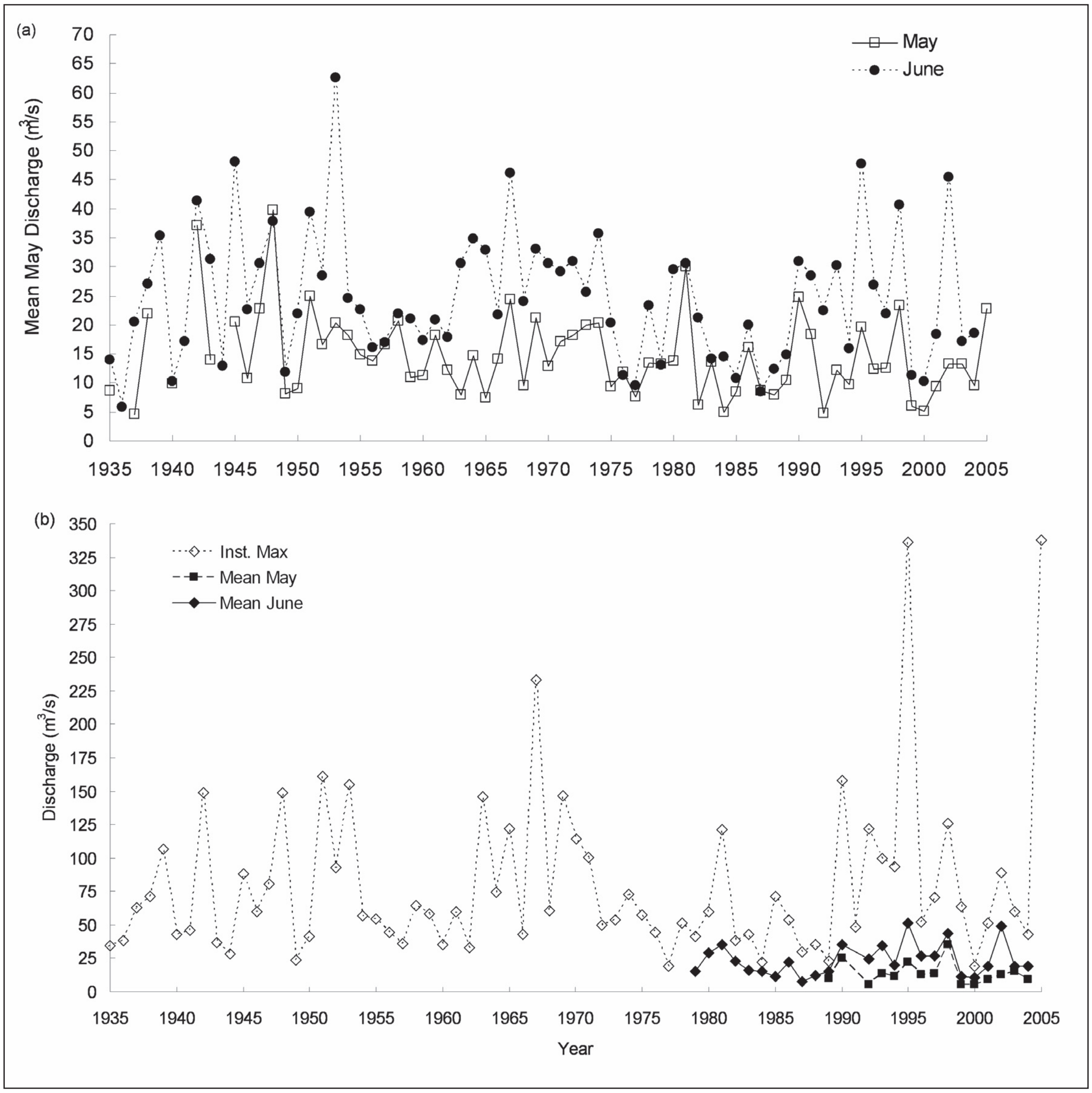

Figure 5. Stream discharges observed at (a) Bragg Creek in May and June; and (b) Sarcee Bridge.

here seems to indicate that it is unlikely for such a high number of detected trends to have occurred by chance. Note that not all of these trends were in the same direction as many trends in the mountainous regions did not emulate trends in the flatter downstream regions. The extreme difference in topography and landcover between the Upper Elbow River Watershed and the Lower portion of the watershed may serve to minimize the impacts of spatial correlation in this analysis. But again, an assessment of field significance would be needed to validate this conclusion.

Predicting Impacts of Climate Change to the Elbow River Watershed

Methodology

Regional Atmospheric Model Output

The methodology employed in the current study involves the use of a mesoscale atmospheric model to provide climate information that is subsequently used as forcing input to a hydrological model. The Canadian Centre for Climate Modelling and Analysis (CCCMA) developed the Canadian Regional Climate

Model (CRCM) (Laprise *et al.,* 1998). The CRCM is a regional scale model of atmospheric parameters for current, two CO_2 and three CO_2 concentrations. CRCM-II (V3.5) model output are available for a ten-year period from 1975-1984, representing the current level of CO_2 concentration. This information comes in the form of monthly temperature and precipitation values, as well as other climatological parameters not used in this work. Model output for 2040-2049 is regarded as resulting from a $2{\times}CO_2$ concentration scenario. The information was obtained for a single grid cell that encompasses the Elbow River Watershed. Because the area of this grid cell is only 1.7 times the area of the watershed, no spatial downscaling of the atmospheric information was performed.

Figure 6 shows the temperature and precipitation predicted by CRCM-II and observed at YYC and EBRS for the period 1975-1984 ("current conditions"). The graphs demonstrates a good fit in terms of temperature (Figure 6a) for most months, except the winter months (November to February) where temperature is predicted to be higher than those observed at YYC and EBRS. These observations are similar to the observations made by Töyrä *et al.* (2005). The interest here is in the difference between current conditions and $2{\times}CO_2$ conditions. If an annual average increase at YYC of 0.007°C/year is considered applicable for the next 40 years, this translates into a predicted increase from 1980-2045 of 0.462°C. CRCM-II predicts an average increase of 1.75°C between 1980 and 2045 in a $2{\times}CO_2$ scenario. The CRCM II prediction is used in this study because extrapolation based on a sustained annual increase in temperature of 0.007°C/year requires the assumption of an underlying linear process. The precipitation curves in Figure 6b are all similar in terms of which months have greater precipitation than others; although, YYC and EBRS have their peak precipitation in May while CRCM-II predicts peak precipitation in June. Furthermore, the precipitation predicted by CRCM-II is higher in the majority of months.

As the information provided by CRCM-II is at a monthly timescale, temporal downscaling is required, particularly in view of the fact that if the desire is to model flooding at a roughly hourly time step, a monthly time scale is insufficient as input to a hydrological model. Statistical regression-based downscaling methods often employ empirical relationships between local-scale predictands (such as temperature and precipitation) and regional-scale predictors (such as mean sea level pressure or relative humidity to name a few), to downscale monthly GCM scenario output to finer timescales (Cheng *et al.*, 2007). Gagnon *et al.* (2005) used these methods to simulate daily inputs of temperature and precipitation to the SSARR hydrological model (the model used in this study) and compared results to observed daily streamflow. They discovered precipitation and the poor simulation of spring melt as limiting factors. As flood simulations rely heavily on the accurate representation of precipitation, and as flooding in the Elbow River Watershed is generated during spring freshet, it is likely that these downscaling methods may negatively impact simulations in this study. It should be noted that studies using multiple scenarios can be used to assess the uncertainty of GCM modelling approaches; however, only a single regional scenario are employed in this work and thus, no uncertainty estimation is made of results produced by this model.

In studies like that of Cheng *et al.* (2007), the intent is to simulate hydrological variables in new climatic conditions. There is no consensus on how to conduct hourly modelling under future conditions using the output generated with current regional atmospheric models. Thus, the approach taken here is to assume that the monthly mean conditions leading up to the flood event are modified by the new atmospheric conditions through changes in temperature and precipitation but that the pattern (i.e., shape of the hyetograph for example) at the hourly scale within the month that the event is held remains roughly the same. Based on this approach, the following expressions were used to downscale the climate information temporally

$$f_{2CO_2}^{\text{month}} = \left[\frac{T_{2040-2049}^{\text{CRCM}}}{T_{1975-1984}^{\text{CRCM}}}\right]_{\text{month}} \tag{1}$$

$$T_{2CO_2}^{\text{hour}} = f_{2CO_2}^{\text{month}} \times T_{\text{observed}}^{\text{hour}} \tag{2}$$

Equation (1) is used to compute the ratios of parameters (in this case, temperature (T)) predicted by CRCM-II. These ratios, termed scaling factors (f), are computed at the monthly time steps generated by CRCM-II. The scaling factors are then used in Equation (2) to rescale historical observations of the parameters (T),

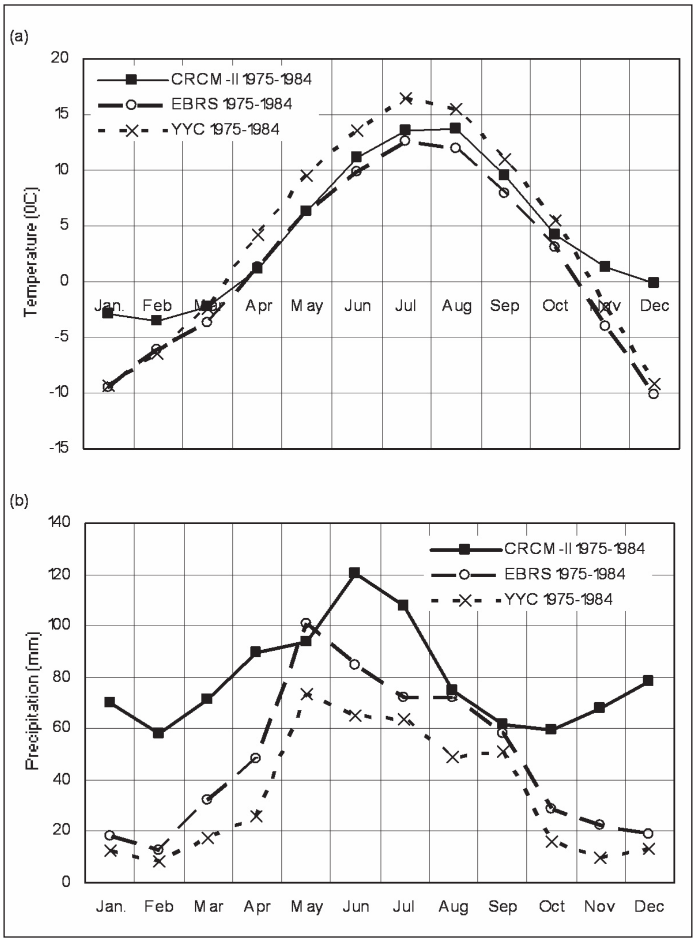

Figure 6. Monthly climatic normal (a) temperatures; and (b) precipitation totals, compared to predictions by CRCM.

thereby yielding hourly values under a climate change scenario (in this case, the 2×CO_2 scenario). Similar expressions can be developed for other parameters, such as precipitation, and for other scenarios, such as the 3×CO_2 scenario.

Figure 7 shows the graph of monthly temporal scaling factors used on the climate model output leading up to and including the flood events modelled in the next section. A factor of one indicates no change in that atmospheric parameter for that month. The graph shows greater increases in temperature for the early winter months. The graph also shows increases in precipitation in February, March and May (with the latter month being important since it is one of two key spring flooding months for the Elbow River Watershed). These precipitation increases are consistent with the trends reported for the Elbow Ranger Station in Table 2. Specifically, both the trend analysis and the CRCM-II predictions identify increasing precipitation in the months of February, March and May, while also indicating a decrease in precipitation for April. These similarities do not extend to the months of January and October (the other two months with significant trends reported in Table 2).

Hydrological Modelling

The climate change scenarios were used as forcing data onto the Synthetic Simulation and Reservoir Routing (SSARR) (USACE, 1991) model used by Alberta Environment to predict flood flows in Alberta's rivers during spring freshet. The SSARR model was calibrated two decades ago for the Elbow River Watershed but an evaluation of its predictive capabilities necessitated a second calibration which was conducted as part of this work.

Due to space limitations, equations for the SSARR model are not provided. It is sufficient to note that the SSARR model uses a snowmelt depletion curve model (USACE, 1951) and the Temperature Index Method, where temperatures are corrected for elevation and weighted. Melt-rate also varies with antecedent temperature.

The Soil Moisture Index (SMI) leading to runoff is a function of precipitation and the Evapotranspiration Index (ETI). The latter parameter is in turn a function of wind, humidity and temperature. It should be noted that only temperature and precipitation were modified in the future scenario conditions investigated in the current study. The study does not consider the effects of changes in land-use or land-cover. SSARR modelling was conducted using two sub-watersheds: the Upper (Bragg Creek gauge) and the Lower (Sarcee Bridge gauge). Manual calibration by trial and error was conducted using five years of data (1990, 1992, 1994, 1995 and 1998) at a three-hour time-step between April 1 to August 31 with initial conditions based on observations of accumulated snowpack and soil moisture for several wet, dry and medium years. The calibration was conducted by examining model performance on the five test years simultaneously and generated a single parameter set applicable for wet, dry and medium years for the entire watershed for several model parameters; however, with regard to routing parameters and the relationship between soil moisture and runoff percent, separate parameters were developed for the Upper Watershed and the Lower Watershed. This calibration was verified using the 2005 flood. The modelling efficiencies for flood events observed in each of these years are shown in Table 4. It should be noted that while the calibration was essentially conducted on in the period of April 1 to August 31 for a combination of five years of data, the objective of the calibration exercise focused on efficient modelling of the 1995 flood such that the predicted peak flood was within 5% of the observed peak flood, the predicted runoff volume was within roughly 5% of the observed volume, and the times to peak matched. For this flood event, the model produced a Nash and Sutcliffe efficiency of 83% with a recorded peak of 336 m^3/s and a predicted peak of 332 m^3/s. The verification using the 2005 flood event produced a relatively high NS values but the peak discharge could not be duplicated because the gauge value is considered suspect. However, the times to peaks and the hydrograph shape were both simulated very well.

The final stage in the hydrological modelling work performed in the current study was to predict the potential changes to flood peaks under a 2×CO_2 scenario. The floods of 1990 and 1995 were selected for this task. The 1990 and 1995 floods were selected because they represent two of the wettest years on record (see Table 4). The 1990 flood occurred in the last week of May as opposed to early June for the 1995 and 2005 floods. To predict flood events under a 2×CO_2 scenario, the historical temperature and precipitation data were rescaled using Equations (1) and (2), thereby amplifying the temperature and precipitation according to the scaling factors given in Figure 7. These rescaled data were subsequently used as input to the calibrated SSARR model. Table 5 shows the changes to peak discharges predicted by SSARR from a one CO_2 to a two CO_2 scenario. Figure 8 shows the expected changes to peak discharges if the events leading up to the 1990 and 1995 floods were to occur under a 2×CO_2 scenario.

Results and Discussion

Interpreting the flood hydrographs provided in Figure 8, events leading to the 1995 peak flood are expected to decrease while events leading to the May 1990 flood are expected to increase. When SSARR simulations were conducted solely with the predicted temperature changes, all estimated flows decreased where contributions by snowmelt ended earlier and did not exacerbate peak flows. Rainfall then becomes the primary factor affecting simulated peak discharges. Not surprisingly, when reviewing the predicted changes in precipitation defined by the scaling factors reported in Figure 7, all flood peaks that occur in May are expected to increase due to the large expected increase in precipitation in May. Conversely, peaks that occur in June are expected to decrease because the precipitation scaling factor for June was lower than one. This is demonstrated in Tables 4 and 5 which show that increases to peak discharges for events that peaked in May and decreases to peak discharges for events that peaked in June. The precipitation factor for May was 1.37 and the runoff peak in the 1990 simulation year increased 1.62 times. The precipitation factor in June was 0.93 and the peak discharge in the 1995 event decreased by a factor of 0.81. These changes are not expected to be linear but it does suggest that if

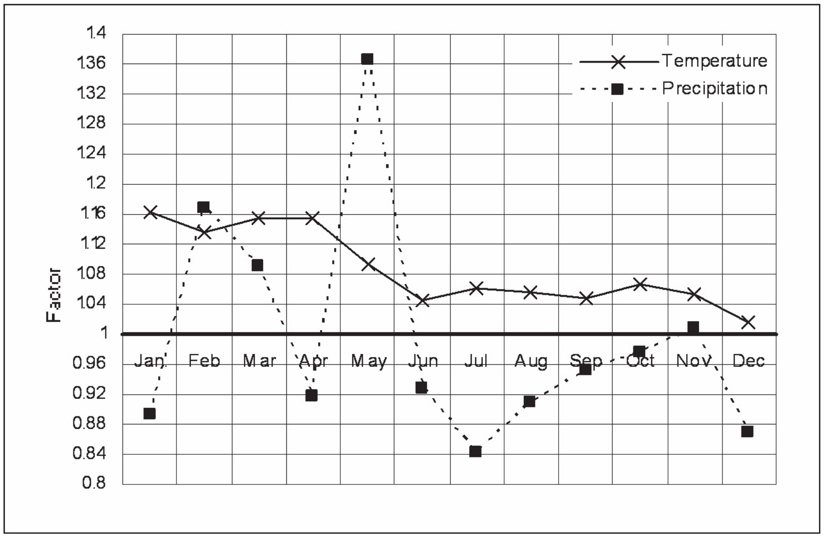

Figure 7. Temperature and precipitation factors used in application of climate change scenarios.

Table 4. Model performances in each of the five test years and the verification year.

Year	Type	Measured Sarcee Peak (m^3/s)	Date	SSARR Peak (m^3/s)	SSARR NS (%)
1990	Wet	158	May 26	161	92
1992	Medium	122	June 15	131	98
1994	Dry	94	June 7	92	96
1995	Wet	336	June 7	332	83
1998	Medium	126	May 28	143	85
2005	Wet	334[a]	June 18	540	78[b]

a) Note that this value of 334 m^3/s is not considered reliable as the river topped its banks at this point in time.
b) Computed over May 28–July 5, 2005.

Table 5. Changes to predictions at Sarcee Bridge by SSARR.

	% Change in Peak	% Change in Volume
1990	62	43
1992	-1	-15
1994	-18	-4
1995	-19	-17
1998	109	62

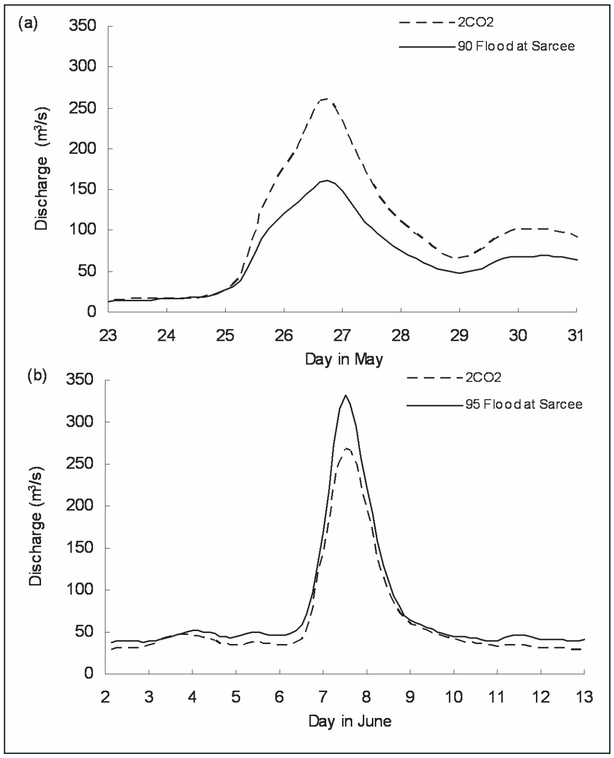

Figure 8. Impact on the (a) 1990 and (b) 1995 spring floods in the Elbow River Watershed due to climate change.

the weather system that led to the large rainfall event in 1995 occurred earlier within the month of May, the discharge in 1995 could double in a 2×CO_2 scenario. However, the conclusion should be regarded with some scepticism because the extent to which results of this type are the product of the method used (i.e., crude scaling factors and the assumption of linearity) is unclear at this time.

The notion that a week should make a difference in whether a peak discharge decreases or increases is not entirely valid and is an artifact of the crude methodology and climate model output. Climate models suggest an increase in precipitation in the spring. It is irrelevant whether the peak occurs in the month of May or June because the series of events leading up to the flood in this watershed are similar: high levels of continuous precipitation followed by very large rain volumes in 24 hours.

Snowmelt may exacerbate flooding if the trends seen in the mountainous part of the watershed, which suggest that snowpack may be increasing, are true. However, if the temperature increases expected in February and March are accurate and expected to continue, then it is likely that the contribution of snowmelt to flooding in this watershed will likely decrease. One should bear in mind that this is a simplistic modelling exercise attempting to illuminate the potential impact of climate change on flooding. It uses model output as input to another model and crude scaling factors are employed. As with all modelling exercises, awareness of the inherent uncertainty and errors involved is always wise, particularly when attempting to use the results to build robustness and resiliency in Canadian infrastructure.

Conclusions

The Elbow River Watershed is comprised of two hydrologically disparate units, the Upper Elbow River Watershed and the Lower Elbow River Watershed. The unit that contributes the greatest amount of flow is the Upper Elbow River Watershed which includes mountainous areas, the foothills and is primarily covered in forest. Trends in the watershed indicate that temperatures are increasing during February and March, but total precipitation remains unchanged. Trends in rainfall seem to be increasing in the Lower watershed. Snowpack in the Upper watershed may be increasing but it is decreasing in the Lower watershed. The climate change prediction models used in this work indicate an increase in May precipitation—one of the peak flooding months for this watershed. If this increase does occur, flooding in the watershed is likely to increase significantly.

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Disaster Risk Report

Calgary Emergency Management Agency (CEMA)

2018

Acknowledgements

The Calgary Emergency Management Agency (CEMA) would like to thank all stakeholders who provided their time, resources, and subject matter expertise to this risk assessment process.

The Disaster Risk Assessment (DRA) methodology utilized for this project was developed based on third-party content from the following organizations, policies, and standards:

- Australian Government Attorney General's Department
- Federal Emergency Management Agency (FEMA)
- ISO 31000:2009 Risk Management
- The City of Calgary Integrated Risk Management Policy and Framework

Disclaimer

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Some information in the report is withheld under the following exceptions of The Freedom of Information and Protection of Privacy Act (FOIP Act): Section 18(1) – Disclosure harmful to individual or public safety; and Section 25(1) – Disclosure harmful to economic and other interest of a public body.

Introduction

This report provides a summary analysis of the 2018 Disaster Risk Assessment (DRA). The DRA is a foundational component that supports broader Disaster Risk Management (DRM) activities through the identification, analysis, evaluation, and distribution of accurate disaster risk data. Accurate disaster risk data allows end-users to make informed decisions related to the allocation of resources and the development of key strategies to reduce disaster risk.

Purpose

The Calgary Emergency Management Agency (CEMA) coordinates periodic city-wide disaster risk assessments in order to understand Calgary's disaster risk environment, share disaster risk information with Calgarians, and prioritize activities towards reducing disaster risk. This is achieved by utilizing a standardized methodology to identify, analyze, and evaluate disaster risks.

Scope

The DRA is focused on ***disaster risk*** and does not replace or supersede existing risk management processes, procedures, or policies of contributing stakeholders. While this process does adhere to accepted international risk management principles and standards of practice, it focuses primarily on risk assessment related to disaster events, rather than the broader practice of risk management. The results of the Disaster Risk Assessment will support individual stakeholders as they make disaster risk treatment decisions for their organization, which may include identifying, designing, evaluating, executing, and monitoring disaster risk treatment activities for specific hazards and threats.

Situation

Calgary is vulnerable to a number of disaster-related risks due to the range of natural, biological, technological, industrial, and human-caused hazards and threats that exist in our city. When actualized, these risks impose significant consequences to our built, economic, natural, social, and government systems. This can include:

- Fatalities, injuries, and illness;
- Damage to public and private facilities, infrastructure, and properties;
- Direct and indirect financial costs and economic losses;
- Deterioration of biodiversity and environmental damage;
- Social and cultural losses; and
- Reductions and delays to the delivery of public services

Assumptions

The Disaster Risk Assessment is based on the following core assumptions:

- The risk assessment area is limited to the city of Calgary;
- The risk assessment is based on the most current city of Calgary data (i.e. demographics, economic data, etc.) available;
- The hazards and threats being assessed are based on input from subject matter experts and include those that have impacted Calgary historically or are possible to impact Calgary in the future;
- The hazards and threats were assessed based on their most probable worst-case scenario;
- The risk assessment is a point-in-time measurement and will need to be updated as the risk environment in Calgary changes;
- The risk assessors only assessed hazards and threats for which they are Subject Matter Experts (SMEs);
- The risk assessors relied on their expertise and knowledge as well as historical records, future trends, and other data in the course of undertaking the risk assessment; and
- The risk criteria utilized to assess risk is relevant to the Calgary context (geography, population, infrastructure, environment, economy, etc.).

Disaster Risk Management

Disaster Risk Management is focused on preventing new risk, reducing existing risk, and managing residual disaster risk in order to increase the resilience of people, communities, society, and systems. The foundation of DRM is based on identifying, understanding, and sharing disaster risk information derived through a robust risk assessment process.

Comprehensive EM Model

As identified in the graphic below, the Disaster Risk Assessment (DRA) is the foundational component that supports all of CEMA's strategic programming.

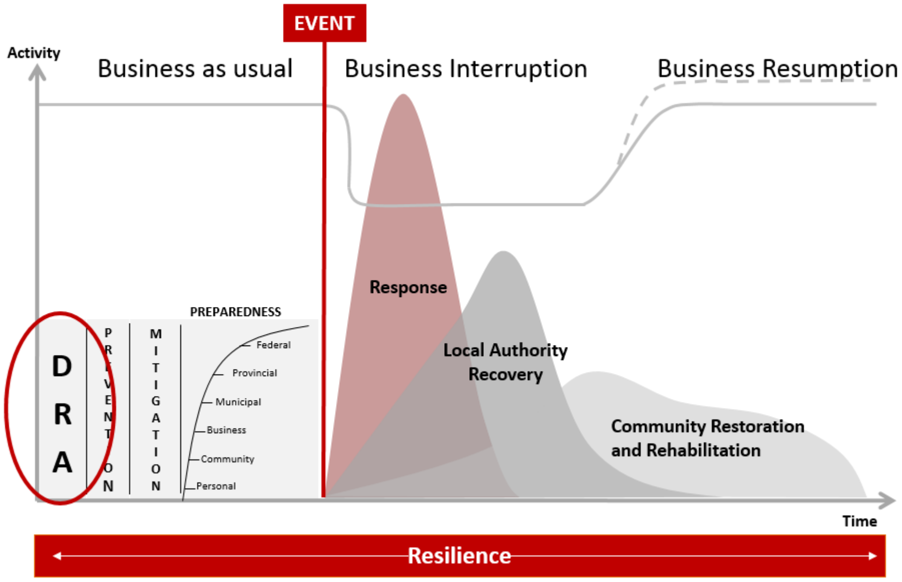


Figure 1 CEMA Comprehensive EM Model

CEMA Disaster Risk Assessment Process

CEMA utilizes a three-step disaster risk assessment process (Figure 2) to identify, analyze, and evaluate disaster risk. The output from this process is a comprehensive Disaster Risk Register that can assist key decision-makers research, evaluate, resource, and monitor risk treatment options.

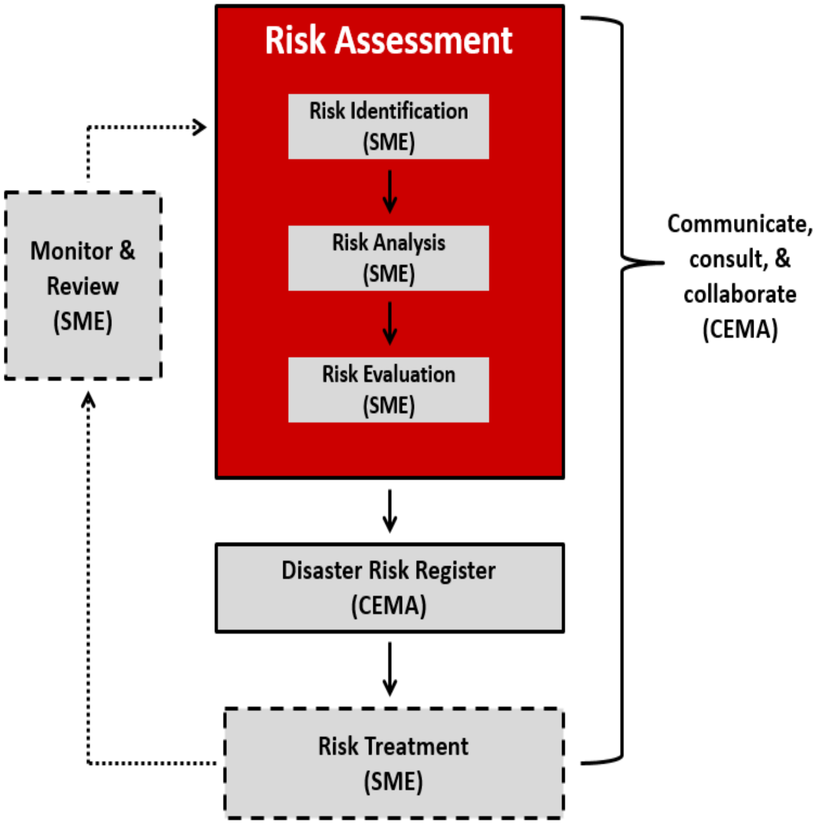


Figure 2 CEMA Disaster Risk Assessment Process

Risk Identification

This step describes the specific characteristics of the hazards and threats that exist in Calgary. This includes: source, duration, high-risk areas, high-risk seasons, impact, associated emergency events, existing controls, probability of occurrence, and historical events. This information is utilized for the analysis and evaluation of risk.

Risk Analysis

This step analyzes the level of risk for each identified hazard and threat. The analysis involves: consideration of potential consequences, determining the likelihood that the consequences will occur, assessing the effectiveness of existing controls, and determining the level of confidence in the analysis. The consequence is estimated using the probable worst-case scenario for the hazard or threat occurring in high-risk areas, during the high-risk season, and with all current controls in place. This is done to ensure the risk being assessed is the residual risk. The information collected during this step is critical to determining comparative levels of risk amongst the hazards and threats.

Risk Evaluation

This step utilizes the results of the Risk Analysis to assign priorities to each identified hazard and threat. The prioritization will assist decision-makers determine future actions related to risk treatment and the requirement for further detailed assessment (if necessary). The end result of this step is the completion of a Disaster Risk Register.

Disaster Risk Register

The risk register is a central repository that records details related to the identified hazards and threats of significance in Calgary. It captures all of the relevant data and information collected during the risk assessment process as well as the analysis and evaluation of risk. The risk register will be reviewed annually.

Risk Treatment

This step utilizes the data derived through the Risk Assessment process to assist stakeholders tasked with managing the risk associated with specific hazards and threats to identify, design, evaluate, execute, and monitor risk treatment activities. Risk treatment (or mitigation) is the partial or complete removal of a risk source or some improvement in the controls to modify the level of risk. Acceptable strategies to treat risks can include: eliminating or avoiding the risk; reducing or mitigating the risk (usually accomplished through additional controls); transferring or sharing the risk (i.e. insurance); or retaining (accepting the risk) or exploiting the risk in order to pursue an opportunity. Risk Treatment is the responsibility of individual decision-makers and not within the scope of the Risk Assessment process. The Disaster Risk Register will be circulated to key decision-makers that are responsible for leading risk mitigation activities and can guide prioritization of treatment actions.

Monitor and Review

The Disaster Risk Register will be reviewed annually in order to account for material changes that affect the evaluation of identified risks as well as to identify the emergence of new risks.

Determining Disaster Risk

A small risk assessment group comprised of subject matter experts from each of the hazard and threat fields was convened. These assessors applied a standardized risk assessment methodology to assess each of their assigned hazards and threats. This resulted in the prioritization of disaster risks for Calgary that will assist decision-makers determine which require immediate action, further analysis, or monitoring.

Risk Trend

Risk Trend is a modifier that is built into the risk assessment process in order to account for the dynamic nature of risk. This can include material changes to the specific hazard/threat or the human and natural systems that they are exposed to. Risk Trend can be scored as: Decreasing, Stable, or Increasing.

Likelihood

Likelihood is a measure of the probability that both the emergency event and all of the estimated impacts (e.g. deaths, injuries, costs, damage, etc.) will occur. Likelihood can be scored as: Extremely Rare, Very Rare, Rare, Unlikely, Likely, or Almost Certain.

* In the risk profiles section, Annual Exceedance Probability (AEP) is also identified as it is the preferred statistical measurement to easily explain the likelihood of an event to a non-expert. AEP is the probability that a given event will be equaled or exceeded in any one year. For example, a 100-year flood has a 1% AEP, meaning there's a 1% chance of it occurring each year.

Consequence

Consequence is a measure of the predicted impact to each of the assessed consequence areas: People, Economy, Natural Environment, Social, and City Administration & Services. The consequence is estimated using the probable worst-case scenario event for the hazard or threat occurring in high-risk areas, during the high-risk season, and with all current controls in place. It subsumes assessment of capacity and vulnerability. It can be scored as: Insignificant, Minor, Moderate, Major, or Catastrophic.

Risk Level

Risk Level = (Consequence x Risk Trend) x Likelihood

Overall Risk Level is assessed by estimating the probable consequences of an event, projecting the current risk trend, and identifying the likelihood of the event occurring with all predicted impacts. For example, a major consequence event that is extremely rare will not be prioritized as highly as a moderately consequential event that is almost certain to occur. Risk Levels can be scored as: Very Low, Low, Medium, High, or Extreme (see chart below).

	Consequence				
Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	*Medium*	*Medium*	*High*	*Extreme*	*Extreme*
Likely	*Low*	*Medium*	*High*	*Extreme*	*Extreme*
Unlikely	*Low*	*Low*	*Medium*	*High*	*Extreme*
Rare	*Very Low*	*Low*	*Medium*	*High*	*High*
Very Rare	*Very Low*	*Very Low*	*Low*	*Medium*	*High*
Extremely Rare	*Very Low*	*Very Low*	*Low*	*Medium*	*High*

Figure 3 Overall Risk Level Table

Calgary City Index

The specific attributes and conditions that make Calgary unique directly influence disaster risk by altering the behaviour, expected impact, and planning priority for hazards and threats while also contributing to the resilience of the city and its citizens.

City of Calgary population	1.25 million (est. 2017)
Total employment Calgary Economic Region (CER)	882,700 (2017)
Homeless population	3,200+ (2016)
Number of languages spoken in Calgary (2016)	120+
Average age	37.6 (2017)
% of population estimated to be 65+ by 2030s	15-20% (est.)
Unemployment rate (CER)	8.0% (March 2018)
Total land area (Calgary)	848 km²
Total parks and green space area (Calgary)	83 km²
Total 200 yr. flood inundation area (Calgary)	44 km²
Total 100 yr. flood inundation area (Calgary)	37.5 km²
% of office space in downtown core	62%
% of employment in downtown core	33%
% of downtown core in 200 yr. flood inundation area	47.7%
% of downtown core in 100 yr. flood inundation area	32.4%
Local real GDP	$115 billion (est. 2016)
Property value in 200 yr. flood inundation area	$80 billion (est. 2016)
Property value in 100 yr. flood inundation area	$55 billion (est. 2016)
Downtown office value	$17.4 billion (est. 2017)
2013 flood cost	$6.0 billion (Southern AB) $2.0 billion (Calgary)
GDP at risk to all threats in Calgary (U. of Cambridge)	$5.8 billion (est. 2017)
Total infrastructure gap (City of Calgary)	$5.6 billion (est. 2017)
Total head offices	124 (2017)
Head offices per 100,000	8.4 (#1 in Canada 2017)
Average salary per employee	$73,669 (2016)
Average annual rainfall (at Calgary)	326.4 mm
Average June rainfall (at Calgary)	80 mm
Total rainfall June 20, 2013 (at Kananaskis)	122 mm
Single day record rainfall (at Calgary)	95 mm (1927/07/15)
Record daily high and low temperatures	H 36.1C (1915/07/15) L -45C (1893/02/04)
WTI/WCS Price (USD, June 2013)	$95.80/$75.39
WTI/WCS Price (USD, June 2017)	$45.18/$35.80
Est. public/private disaster costs (insured losses, DRP, City response) per year in Calgary (avg. 2010-2016)	$600 million (incl. 2013) $400 million (excl. 2013)
Average # EOC and MEP activations per year and average activation duration (2010-2016)	5 EOC/MEP activations Avg. 46.5 hrs./activation

Source: Calgary Economic Development, Environment and Climate Change Canada, Government of Alberta, Insurance Bureau of Canada, Public Safety Canada, Statistics Canada, The City of Calgary, University of Cambridge, and the U.S. Energy Information Administration

Disaster Risk Trends

A "trend" is defined as a long-term pattern that is currently evolving and that could contribute to amplifying risks and/or altering the relationship between them. The following represent trends that are anticipated to be most impactful to Calgary's evolving disaster risk landscape and must be taken into consideration within disaster risk reduction planning and policy efforts.

Increasing Disaster Losses

Disasters have a negative impact on the economy in terms of output, income, employment, productivity, and investment opportunity. While there is some evidence to suggest that short-term spending may lead to higher output and employment during recovery and reconstruction, this positive effect does not take into consideration the totality of economic losses from a disaster, notably the loss of capital. Furthermore, it doesn't account for the delay or cancellation of other projects, programs, and services that are deemed less critical following a disaster event but whose loss will have a negative impact on the vitality of the economy and overall societal resilience in the long-term.

The upward trend in disaster losses since the 1980's can largely be attributed to the concentration of assets, economies, people, trade, capital, and wealth within high-risk urban environments. In absolute terms, over 60% of reported global economic losses are concentrated in high-income countries, reflecting the concentration of economic assets.[i] This is further explained by the fact that businesses, governments, and people now own more assets than previous generations and these assets are becoming costlier to replace. As these urban centres expand, they are likely to increase the density of new or existing development in highly vulnerable areas that have not been priced appropriately to the risks that are present.

This trend is expected to continue over the next century. According to a report by the TD Bank (Natural Catastrophes, 2014), the long-term financial impact of disasters is estimated to cost Canadians $5 billion per year in 2020 and $21-$43 billion by 2050.[ii] According to Swiss Re[iii], total economic losses globally from natural and man-made disasters in 2017 are estimated to be $306 billion, up from $188 billion in 2016. Global insured losses from disaster events in 2017 were approximately $136 billion, up from $65 billion in 2016, which is above the previous 10-year annual average ($58 billion), and the third highest on record since 1970.[iv]

Since its inception in the 1970's, the federal and provincial disaster financial recovery cost share program in Canada, i.e. Disaster Financial Assistance Arrangements (DFAA), has provided funding in the order of $8.35 billion (2014 dollars).[v] Of this, $6.5 billion has been for floods which, at nearly 80% of all payments, is by far the largest peril. These costs are likely to continue increasing. The Parliamentary Budget Office of Canada estimates that over the next five years (2017 to 2022), expected claims due to severe weather events will reach approximately $902 million per year.[vi]

As a result of this increasing financial liability, specifically those related to flooding, the federal government has been slowly shifting more of the cost-share to provincial governments. Other notable changes include high thresholds for federal disaster assistance, tightened rules for provincial assistance, increased public education efforts, and funding for preparedness (i.e. maps and risk assessments) and mitigation (i.e. small-scale structural protections). This is part of a larger overall strategy to undertake significant restructuring of the fiscal framework for flood risk management. This strategy includes taking a whole-of-society approach wherein there is tighter collaboration between the private sector and government.

Specifically, there is consideration being given to transferring certain levels of flood risk to the private sector and transitioning the government away from being the insurer-of-last-resort. To this end, new flood insurance markets have opened up in many provinces (including Alberta), thereby negating DFAA eligibility and further shifting the burden for cost recovery away from all taxpayers to specific at-risk property owners. Municipalities will also be expected to assume more responsibility for mitigating disaster risks. In the future, this approach could be applied to other geo-based hazards.

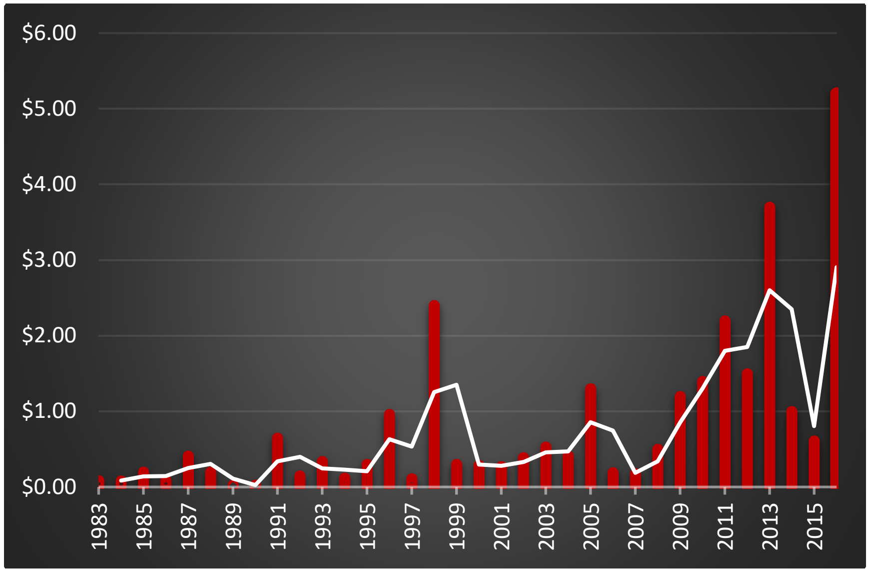
Insured Losses in Canada

As depicted in the following charts, insured losses in Canada caused by disaster events have seen a dramatic increase in recent years. Total insured losses have almost doubled in the last 9 years ($17 billion from 2008 to 2016) versus the previous 25 years ($9.9 billion from 1983 to 2007).[vii] In addition, 7 of the last 8 years are amongst the top 10 years with the most insured losses in Canadian history. Alberta has been particularly active with 7 of the top 10 costliest disasters in Canadian history having occurred in the province and 5 of 10 having impacted Calgary directly. Calgary also supported the Slave Lake and Ft. McMurray fires.

Top 10 costliest disasters in Canada (insured losses):

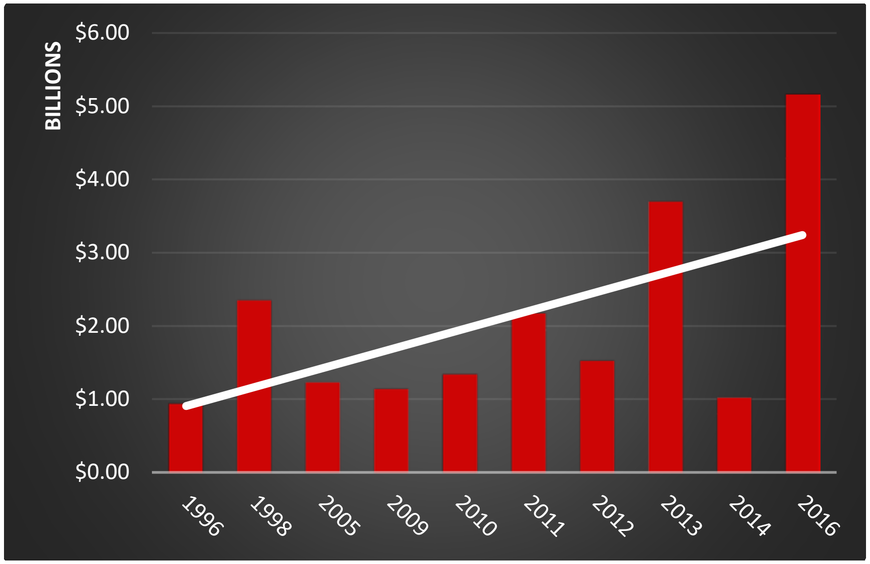
1. $3.82 billion - Ft. McMurray, AB wildfire (2016)
2. $1.95 billion - Eastern Canada ice-storm (1998)
3. $1.70 billion - Southern Alberta flooding (2013)
4. $1.01 billion - Southern Ontario flooding/wind (2013)
5. $794 million - Slave Lake, AB wildfire (2011)
6. $750 million - Ontario hail/tornadoes/wind (2005)
7. $593 million - Calgary, AB flooding/hail/wind (2012)
8. $584 million - Calgary, AB hail/wind (2010)
9. $583 million - Calgary, AB flooding/hail/wind (2014)
10. $532 million - Calgary, AB hail (1991)

Figure 4 Total insured losses (in billions) for disaster events in Canada 1983 - 2016



Source: Insurance Bureau of Canada (IBC).

Figure 5 Top 10 costliest years for insured losses in Canada



Source: Insurance Bureau of Canada (IBC).

Total Estimated Disaster Losses in Calgary

Since 2000, total public and private losses from disaster events in Calgary are estimated to be close to $5 billion.[viii] If you look at the period 2010 through 2016, the annualized direct losses from disasters were over $600 million ($400 million excluding 2013 flood).[ix] For The City of Calgary organization, estimated total losses for this period were close to $500 million, which is an average of greater than $70 million per year[x]. These numbers are based on data from the insurance industry, provincial Disaster Recovery Program (DRP), and the City of Calgary. While the best available data was utilized, the dataset is incomplete and the true total disaster losses are likely much higher. These numbers also don't include the full indirect costs of these events in terms of lost productivity, loss of investment, health impacts, environmental degradation, and numerous other opportunity costs associated with responding, recovering, and rebuilding from these events.

In addition, numerous small and recurrent events (extensive risk) may not be fully-accounted for as they are not covered by insurance or public recovery funding (i.e. DRP). These events do not reach minimum deductible or reporting thresholds, which results in costs being absorbed by the people and organizations affected. For municipal governments, the response and recovery costs from smaller events have also been slowly incorporated into their operational budgets over time and aren't accounted for when determining the true cost of mitigating, responding, and rebuilding.

Furthermore, although investments in risk reduction measures and regulation have led to a net reduction of extensive risk (low-severity/high-frequency events), the value of assets in hazard-prone areas has grown, generating an increase in intensive risk (high-severity/mid- to low-frequency events). For example, as noted by the United Nations (UNISDR, 2015), "investing in risk reduction measures to protect a floodplain against a 1-in-20-year flood may instill a false sense of security and encourage additional development on the floodplain in a way that actually increases the risks associated with a 1-in-200-year flood".[xi] The focus of disaster risk reduction measures cannot be based solely on past events, it must also take into consideration future scenarios of a higher magnitude and scale that may not have occurred recently on the historical record but are possible given the local risk landscape. This will require the adoption of risk-sensitive planning processes with risk being priced appropriately into new developments.

Urbanization

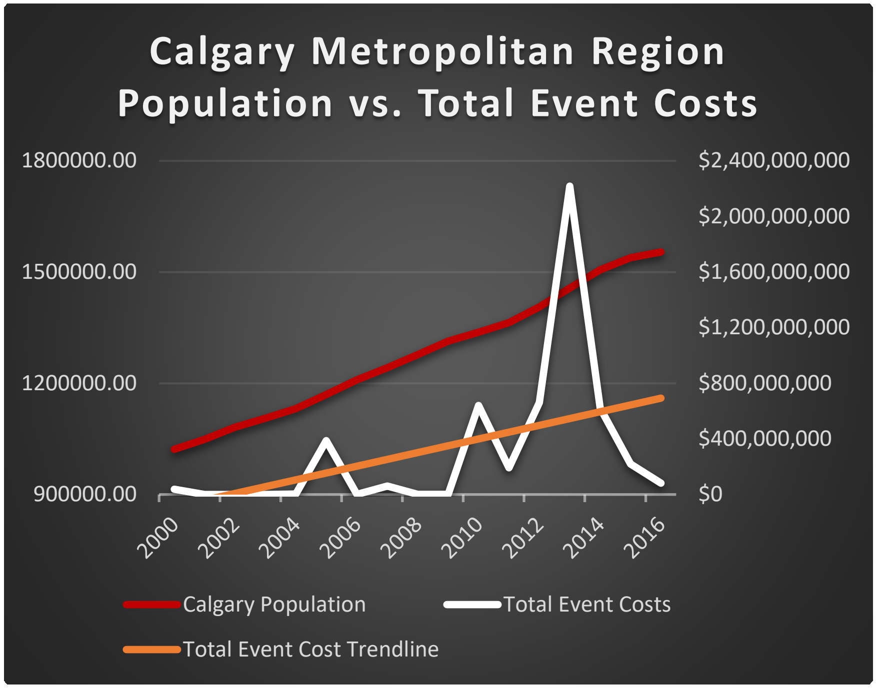
Global Cities are the economic drivers of the modern economy. By 2050, the UN estimates that two-thirds of the world's population (an estimated 6.3 billion people) will live in urban areas.[xii] In Alberta, there has been a complete reversal of the urban to rural population ratio in the last hundred years (1901: 25% urban and 75% rural / 2011: 83% urban and 17% rural).[xiii]

Urbanization acts like a multiplier for other risks. The concentration of people, economic activity, critical assets, capital, and services in large cities means that risks experienced in this environment have the ability to have societal-level impacts; amplifying risks beyond traditional borders into the regional, national, and global sphere. Lloyd's has analyzed the economic exposure from 18 threats to Calgary over a ten year period (2015-2025). They estimate that $5.8 billion of GDP is at risk to all threats in Calgary with flooding ($1.37 billion) and cyber-attack ($1.12 billion) as two of the more costly threats.[xiv] Poor land-use planning, environmental mismanagement, and a lack of regulatory mechanisms in cities both increase the risk and exacerbate the effects of disasters.

As Figure 6 (below) indicates, there is a moderate correlation between Calgary's population and the increase in disaster losses. While there are numerous other contextual and vulnerability factors beyond population that contribute to this increase, in general, the conclusion that can be drawn is that an increase in urban population in Calgary is indicative of an expected increase in losses from disasters. The principle driver of this increasing risk is the expanded exposure of people, assets, capital stock, and economic activity that are concentrated in hazard-prone areas of the city.

As cities are left to manage this upward trend in urbanization, they must consider how they can navigate the myriad challenges it poses in a risk-sensitive manner. This will require balancing development goals with the need to reduce the total exposure and vulnerability of people, systems, infrastructure, economies, and ecosystems to disaster risks. These two outcomes are not mutually exclusive; both can be achieved by remaining focused on developing a culture of resilience and supporting the vitality of our people, economy, environment, and infrastructure.

Figure 6 Calgary Metropolitan Region and total event costs



Source: The City of Calgary, IBC, Statistics Canada, Calgary Economic Development.

Aging Population

These urban populations are also getting older. By the mid-2030s, it's estimated that up to 1 in 5 Calgarians will be seniors.[xv] Older people are especially vulnerable during disasters. HelpAge International determined that 56% of those who died during the 2011 Japanese tsunami were aged 65 and over although this age group made up only 23% of the population.[xvi] Similarly in 2005's Hurricane Katrina in the US, 75% of those who died were 60 and over, even though that age group only made up 16% of the local population.[xvii]

Municipalities are the frontline providers of the social services and physical infrastructure required to support older citizens. Additional resources will be required in order to increase the resilience of this population and the infrastructure required to support them during emergencies through enhanced business continuity, emergency preparedness, and other risk reduction activities

Cyber-attacks and Hyper-connectivity

The number of people, devices, and "things" connected to virtual networks is increasing at a staggering pace. The rising hyper-connectivity of the modern world allows for access to near real-time data and information. This is forever altering the very idea of what constitutes a "community". People have created "virtual communities" upon which they rely for information exchange, validation, and platforms for mobilizing collective action. This has given greater importance to the role of the individual in society and increased the expectations placed on government. This tech-savvy population is becoming increasingly impatient with analog public services.

This hyper-connectivity has also given rise to new risks. According to the World Economic Forum (WEF 2018), cyber breaches recorded by businesses have almost doubled in five years from 68 per business in 2012 to 130 per business in 2017.[xviii] Furthermore, the flourishing cloud-based services market and the number of devices connected via the Internet of Things (IoT) is expected to expand from an estimated 8.4 billion devices in 2017 to a projected 20.4 billion in 2020, providing cybercriminals with an exponentially increasing number of potential targets.[xix]

The interdependence of technology and the critical infrastructure required to support communities during disasters has led to a fusion of virtual risk with real world cascading impacts. The failure of a critical software system, program, or network during a natural hazard event adds another layer of risk complexity to planning efforts. Consideration must be given to understanding the latent risk that exists borne out of an overreliance on these technologies and developing easily accessed workarounds to mitigate that risk. Virtual disasters are also very costly. Some analysts have outlined how the loss of a single cloud services provider could result in $50 billion to $120 billion in economic losses.[xx] This roughly equates to an event somewhere between Hurricane Sandy and Hurricane Katrina but without predefined risk boundaries, established populations-at-risk, geographic extent limitations, seasonality, or other attributes that are utilized when planning for natural hazards.

These events could happen anywhere and at any time. They're capable of having a truly global scope, causing cascading impacts to seemingly unaffiliated industries and communities in far-off locations. The annualized economic cost of cybercrime globally is estimated to be $1 trillion, which is a multiple of 2017's record year for natural disasters which cost approximately $300 billion.[xxi] While investment in cyber-risk management is increasing, it is still under-resourced when measured against the level of risk and the amount allocated to natural disasters. As the world becomes increasingly digitized, greater urgency must be directed towards understanding the risks inherent in use of these emergent technologies and developing proper safeguards to protect against catastrophic failures of the systems, processes, and infrastructures that rely on them.

Fourth Industrial Revolution (4IR)

The fourth industrial revolution is the term used to describe the magnitude of changes that are currently being experienced through the development of a range of new technologies that are fusing the physical, digital, and biological worlds. We are currently undergoing a fundamental change to the way we live, work, and relate to one another. These technologies are impacting all disciplines, economies, governments, and industries. Society is constructing the rules, norms, standards, incentives, institutions, and other mechanisms needed to shape these technologies while struggling to keep pace with the speed of their deployment.

While there are tremendous benefits to this change, the convergence of these technologies is creating new systemic risks and amplifying existing risks. There are serious repercussions if society doesn't navigate its way through this revolution safely. The very notion of the welfare state and the institutions designed to protect the social and economic well-being of citizens are being questioned. These systems are severely underfunded and are at a breaking point. The employers in this new economy are rethinking traditional employment models and social protection contributions, forcing individuals to assume a larger share of societal risks, such as unemployment, exclusion, sickness, disability, and old age. If risk continues to be transferred to individuals, governments must ensure that there are protections in place to support the most marginalized citizens in our society as they will become increasingly vulnerable to a singular disaster event.

The automation of jobs and replacement of humans with machines has the potential to further segment society. Some studies (Oxford 2013) suggest that up to 47% of US employment could be automated over the next two decades.[xxii] The areas of the workforce first to be impacted by this automation will likely be those currently occupied by lower-skilled workers. This could result in increased vulnerability of these groups and further exacerbate societal inequality. New employment models could also hinder the collection of taxes, thereby reducing the amount governments have available to fund social protections (i.e. “safety nets”) as well as disaster mitigation, response, and recovery. The cumulative effect of these forecast changes being decreased societal resilience.

Household Indebtedness and Rising Income/Wealth Disparity

In its November 2017 Economic Outlook report, the Organization for Economic Cooperation and Development (OECD) identified the level of household indebtedness in Canada as a major risk to the economy. The OECD assesses Canada's household debt as the highest among the 35 developed and developing countries the organization monitors. Canada is also the only country identified by the OECD as having household debt above 100 percent of GDP.[xxiii] Data from Statistics Canada shows that Canadian household debt hit a record high in the third quarter of 2017. Debt as a share of disposable income rose to 171.1 percent, meaning Canadians on average owe almost $1.71 for every dollar of disposable income.[xxiv]

This data suggest that Canadians are becoming increasingly vulnerable to shocks. The intersection of social, economic, cultural, built, and environmental systems directly contribute to the resilience of a specific location and people. If a flood of the same magnitude as 2013 were to occur today, it would likely have a far greater impact, given the current economic conditions in our city and inability of citizens to absorb the financial impact of another major event.

A recent report by the Broadbent Institute (2014) noted that the richest 10 per cent of Canadians own almost 50 per cent of the wealth and the bottom 50 per cent only own 6 per cent.[xxv] When broken down further, the bottom 20 percent don’t own any wealth and are actually in debt. This vulnerability has a negative influence on overall societal resilience to shocks and can amplify otherwise low-impact events into disasters.

This problem is also getting worse. An OECD report (2014) found that Canada is second only to the U.S. in its growing inequality.[xxvi] About 37 per cent of total growth in Canada went to the wealthiest one per cent between 1975 and 2007. Statistics Canada data (2017) reveal that Alberta and B.C. have the highest income inequality with the share of income going to the top 10 percent being 10 times higher than the share going to the bottom 10 percent.[xxvii] This trend is also exclusively seen in major urban centres. The Chartered Professional Accountants of Canada (2017) reported that Calgary’s inequality is four times the national average.[xxviii] Disasters aggrandize underlying cultural, economic, and social inequities. This inequity poses significant challenges to the enculturation of a resilient society in Calgary.

World Economic Forum (WEF) Global Risks Report 2018

The World Economic Forum undertakes an annual survey that asks global leaders what they perceive to be the most important risks and trends that will shape development in the next 10 years. The *Global Risks Report 2018* identifies the top risks by both likelihood and impact. The lists (below) clearly indicate that environmental risks are of primary concern for global leaders and risk managers. This is not surprising given the fact that 2017 was marked by hurricanes, extreme temperatures, and an overall rise in CO_2 emissions. Survey respondents were also asked to select the risks that are most strongly driven by the identified trends. Figure 7 (next page) articulates the strength of the relationships between risks and trends.

Top 5 Risks in Terms of Likelihood

- Extreme Weather Events
- Natural Disasters
- Cyber-attacks
- Data Fraud or Theft
- Failure of Climate Change Mitigation and Adaptation

Top 5 Risks in Terms of Impact

1. Weapons of Mass Destruction
2. Extreme Weather Events
3. Natural Disasters
4. Failure of Climate Change Mitigation and Adaptation
5. Water Crises

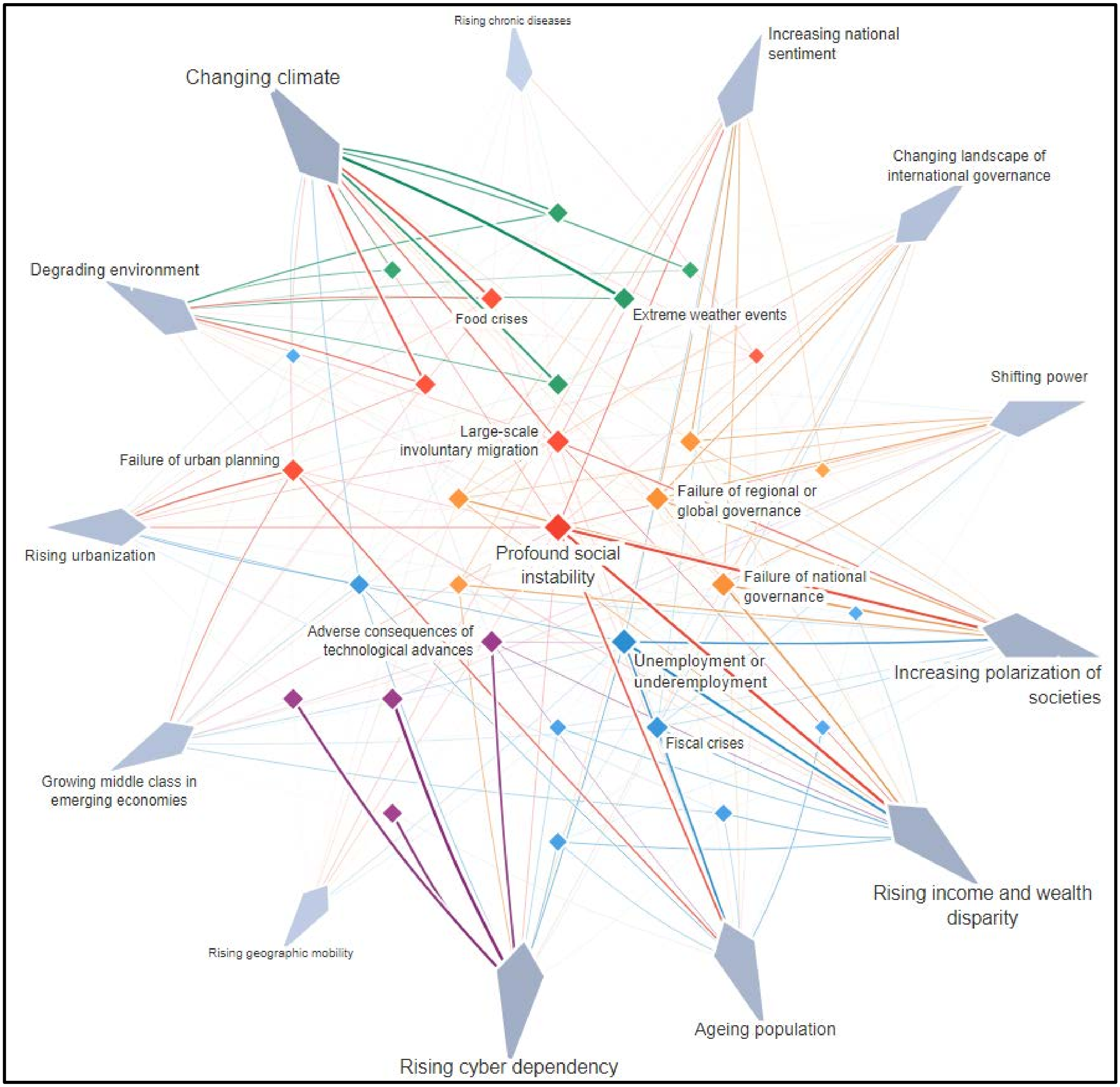
Global Trends

The WEF 2018 report also highlighted a number of global trends that survey respondents felt will be the most important in shaping global development in the next 10 years

- Ageing population
- Changing landscape of international governance
- Changing climate
- Degrading environment
- Growing middle class in emerging economies
- Increasing national sentiment
- Increasing polarization of societies
- Rising chronic diseases
- Rising cyber dependency
- Rising geographic mobility
- Rising income and wealth disparity
- Shifting power
- Rising urbanization

Figure 7 Global Risk-Trends Interconnection Map 2018

This graphic represents the relationship between the trends that World Economic survey respondents felt are the most important in shaping global development in the next 10 years and the risks that are most strongly driven by those trends. Trends are represented by the grey shapes on the outside and risks by the coloured shapes on the inside of the graphic. The size of the shape indicates the number and strength of connections. Larger shapes represent more connections and stronger relationships.



(Source: World Economic Forum 2018)

Climate Change

The City of Calgary has undertaken a detailed climate risk assessment focused on identifying and understanding major climate, weather, and climate change impacts and trends to The City of Calgary. The City used an evidence-based scoring process to identify the 14 core climate risks that will require action in order to address their impacts. The risks were then grouped into four separate categories based on their likelihood and consequence. When cross-referenced, 8 of the 13 Top Disaster Risks for 2018 are directly impacted by a changing climate.

Figure 8 provides a summary of the expected climate changes in Calgary between 2041 and 2100. Climate change acts as a risk multiplier by increasing the frequency, variability, and intensity of hazards. Calgary is forecast to be impacted by more extreme weather events which will require more frequent and costlier responses and the long-term effects of climate change will also stress our critical infrastructure. Actions taken to adapt and manage these risks today will be critically important in the future.

While the time horizons and scope are different, there is close alignment between Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA). Climate change exacerbates weather-induced hazards, therefore, reducing disaster risk for those hazards is also a critical component of adaptation planning. Both fields are focused on assessing risk, reducing vulnerability, increasing capacity, mitigating potential damage, and enhancing resilience in order to achieve long-term sustainability goals. There is an opportunity to align DRR and CCA in order to ensure both activities are working towards the mutual goal of long-term societal resilience.

Climate Risks

The core climate change risks are broken into the following four categories:

High Risk (high likelihood / high consequence)

- Heat waves
- Winter storms
- Multi-year drought
- Short duration, high intensity storms

Elevated Risk (low likelihood / high consequence)

- Wildfires
- Major river flooding
- Tornadoes

Moderate Risk (high likelihood / low consequence)

- Warming of air temperature and changes in seasonality
- Pests, diseases, and invasive species
- Overall wetter seasons
- High wind events
- Cold spells

Low Risk (low likelihood / low consequence)

- Elevated air pollution
- Freeze-thaw weathering

Figure 8 Summary of expected climate changes for Calgary (2041-2100)

Climate variable	Season	1981 – 2010 normals	Change by 2050s (2041-2070)			Change by 2080s (2071-2100)		
			Low[1]	Mean	High[1]	Low[1]	Mean	High[1]
Temperature (°C)	Annual	4.4	+1.1	+3	+7.2	+1.7	+4.9	+11.5
	Winter	-6.4	+1.8	+3	+4	+3.4	+4.9	+6.1
	Spring	4.2	+1.7	+2.6	+3.8	+2.8	+4.3	+5.8
	Summer	15.3	+2	+3.3	+4.4	+3.6	+5.7	+7.8
	Fall	4.6	+1.9	+2.8	+3.8	+3.1	+4.7	+6.1
Precipitation	Annual	418 mm	-3%	+6%	+12%	+1%	+8%	+19%
	Winter	30 mm	-3%	+9%	+18%	+3%	+16%	+27%
	Spring	99 mm	+2%	+13%	+20%	+6%	+19%	+30%
	Summer	216 mm	-16%	-3%	+8%	-25%	-8%	+10%
	Fall	73 mm	-5%	+5%	+16%	-1%	+9%	+19%
Days ≥ 29°C[2]	Annual	8.5	+9	+18.2	+34	+21.6	+40.4	+67.5
Extreme Precipitation[3]	Annual 95th percentile	99-182 mm	-7.2%	+10.5%	+30%	+3.4%	+23.6%	+46.3%
	Annual 99th percentile	32-182 mm	-22.8%	+16.9%	+58.2%	-5.2%	+37.4%	+69.8%
Freeze-thaw cycles	Annual	133	-49	-27	-15	-73	-49	-30
	Winter	48	-5	0	+2	-14	-5	0

Notes:

[1] Low and High represent the 10th and 90th percentile values generated by a 40 global climate model ensemble. All values are for the RCP 8.5 emissions scenario using AR5 generation models (IOCC 2013).

[2] This 29°C threshold is based on the Environment and Climate Change Canada warning criteria for heat waves in southern Alberta.

[3] Estimates are from previous analysis and the baseline is the range from climate model projections as opposed to the Calgary airport station.

(Source: The City of Calgary)

Disaster Risk Profile

A total of 65 natural and anthropogenic hazards/threats were reviewed during the assessment. The underlying vulnerability ecosystem that contributes to disaster risk is constantly in flux. As a result, the DRA is a point-in-time snapshot of this dynamic disaster risk landscape. The following sections detail the 13 High risks (no Extreme risks this year) that currently represent the most significant risk to Calgary. As a reminder, risk is based on consequence, risk trend, and likelihood. This means that there is the potential for events of moderate consequence that occur often to be prioritized over those that are more consequential but occur less often.

** Refer to Police and Security section for considerations regarding risk evaluation*

Top Disaster Risks 2018

High Risk

- Catastrophic riverine flooding – Bow River (1:100)
- Catastrophic riverine flooding – Elbow River (1:100)
- Extreme cold
- Major critical infrastructure failure or disruption
- Major dam breach – Bow River
- Major drought
- Major hostage incident*
- Major mass casualty attack*
- Major rail incident
- Severe storm - blizzard
- Severe storm - heavy rainstorm
- Severe storm - winter storm
- Tornado

It must be emphasized that the DRA is a preliminary assessment to provide decision-makers with a general idea of the prioritization of risks in order to determine whether risks should be treated, analysed further, or monitored. Detailed engineered assessments and analysis will be required for some risks prior to making final treatment decisions. All risks have an active suite of controls to mitigate their impacts that are briefly outlined herein. These have also been factored into the risk scoring. Additional hazards and threats not discussed in detail within this document may currently represent less risk but this does not mean they pose zero risk.

Top Monitored Risks 2018

Medium level risks that are currently trending upwards are monitored as they have the potential to become more severe due to a number of contributing factors, including: increased frequency and severity due to climate change; changes to the specific hazard/threat (i.e. volume of hazardous goods shipped by rail); or increased vulnerability within the built, environmental, economic, human, and political systems exposed to the hazard/threat.

Medium Risk – Trending Upwards

- Extreme heat
- Major Active shooter incident*
- Major basement seepage flooding
- Major Civil Disobedience*
- Major Cyber Attack - Technology as Instrument*
- Major sanitary forcemain failure (lift station)
- Major stormwater backup flooding
- Major supply chain interruption
- Major water contamination (distribution system)
- Major water contamination (widespread forest fires)
- Major wildland urban interface fire
- Poor air quality
- Severe windstorm
- Solar storms

Hazard and Threat Correlation Matrix

The worst catastrophes are combinations of events where a primary trigger event causes secondary cascading effects, resulting in the consequences being worse than if they had happened independently. The potential for one hazard or threat to trigger or exacerbate the effects of another is captured in this matrix. The darker areas (4) are the most critical as they have the highest potential to induce cascading events. The event types are grouped into two categories: Human-induced & technological threats and Natural hazards. The scoring is based on historical events, expert feedback, and an analysis of plausible future scenarios.

Secondary Consequential Event

Primary Trigger Event		*Human-induced and technological threats*					*Natural hazards*							
		CI Failure	Major Rail Incident	Major Dam Breach Bow River	Major Hostage Incident	Major Mass Casualty Attack	Catastrophic Flooding Bow River	Catastrophic Flooding Elbow River	Extreme Cold	Major Drought	Severe Blizzard	Severe Heavy Rainstorm	Severe Winter Storm	Tornado
Human-induced and technological threats	CI Failure	4	2	1	1	1	1	1	1	0	0	0	0	1
	Major Rail Incident	3	4	2	1	1	1	1	0	0	0	0	0	1
	Major Dam Breach Bow River	4	4	4	1	1	3	3	0	1	0	1	0	1
	Major Hostage Incident	1	1	1	1	3	1	1	0	0	0	0	0	1
	Major Mass Casualty Attack	1	1	1	1	1	1	1	0	0	0	0	0	1
Natural hazards	Catastrophic Flooding Bow River	3	3	3	1	1	1	1	0	0	0	1	0	1
	Catastrophic Flooding Elbow River	3	3	1	1	1	1	1	0	0	0	1	0	1
	Extreme Cold	2	1	1	0	0	0	0	1	0	1	0	1	0
	Major Drought	2	0	0	0	0	0	0	0	1	0	1	0	0
	Severe Blizzard	0	2	0	0	0	0	0	1	0	1	0	1	0
	Severe Heavy Rainstorm	3	3	3	0	0	3	3	0	0	0	1	0	1
	Severe Winter Storm	3	3	1	0	0	0	0	1	0	1	0	1	0
	Tornado	3	3	2	0	1	1	1	0	0	0	1	0	1

Hazard and threat correlation scoring:

4	***Cascading potential:*** *an event of this type can potentially trigger other sub-category hazards/threats within the same category (i.e. human-induced or natural).*
3	***Strong potential:*** *an event of this type can potentially directly trigger an event of the second type.*
2	***Weak potential:*** *there is some potential for an event to contribute to the causal mechanisms that would trigger the occurrence of an event of the second type*
1	***Indirect potential:*** *no mechanism for this event type to directly cause an event of the second type but the consequences of a coincidental second event shortly afterwards would be made significantly worse due to resources already being committed and abilities to respond and contain being reduced*
0	***No potential:*** *the two event types are uncorrelated and if they occurred coincidentally their consequences would be broadly the same as if they occurred independently*

Catastrophic Riverine Flooding Bow & Elbow Rivers

Consequence	Major	**Risk Level**	High
Likelihood	Unlikely	**Risk Trend**	Increasing

A catastrophic riverine flood is defined as a 1:100 return period event (or greater) caused by a combination of heavy rainfall, moist antecedent soil conditions, and snowmelt. A 1:100 year return period means there is a 1% chance that the area will flood in any given year. Prior to 2013, Calgary had not experienced an event of this magnitude since the 1890's.

Lead Agency	Water Services
Expected Event Duration	1 week
High-risk Season(s)	May 15 – July 15
High-risk Areas	Flood plain, flood fringe, downtown
Annual Exceedance Probability	1%

Exposure and Consequences

Calgary is at the confluence of two rivers (Bow and Elbow Rivers) and several smaller creeks. Both river watersheds have steep relief and relatively short travel distances from the mountains to Calgary. The dynamics of these two river systems means that sudden changes to high flow rates can reach Calgary rapidly with little warning. Depending on the hydrometric conditions, this can leave a very short window for emergency response resources and flood protection measures to be deployed. This dynamic emphasizes the need to have effective early warning system, emergency response plans, and built mitigation structures in place prior to an event.

This represents the potential consequence of the hazard event within each assessed category. Highest consequence is furthest from centre.

Calgary has significant development in flood inundation areas. There are over 8,000 buildings (all types) in the 1:100 flood inundation area with an assessed value close to $55 billion. In the 1:200 flood inundation area there are over 10,000 buildings (all types) with an assessed value over $80 billion. The total population exposed within the 1:100 year flood inundation area is approximately 27,000 (2015), which increases to 42,000 (2015) within the 1:200 year flood inundation area. While there is a substantial amount of development and population at risk in the flood inundation area, current and planned flood mitigation projects significantly reduce exposure. In fact, once these projects are completed, the downtown core will be protected up to a 1:200 year flood event.

In Calgary, the most exposed areas in terms of total asset value, dwellings, and populations at-risk are: the Beltline, Sunnyside, Hillhurst, Mission, Inglewood, Downtown East Village, Bridgeland/Riverside, Chinatown, Bowness, Rideau-Roxboro, Erlton and Elbow Park. The downtown core of Calgary is a high-priority for disaster risk managers as it contains a high-density of people, vulnerable populations, critical infrastructure, livelihoods, critical services, and economic activity. Figure 9 outlines the type and amount of critical infrastructure exposed within the 1:100 year and 1:200 year flood inundation areas in Calgary. As indicated by the high number and variety of CI at risk, there are a number of expected challenges that first responders and emergency managers will need to address when planning for these types of scenarios. As flooding can be mapped with a reasonable degree of accuracy, it is possible to develop effective mitigation and response strategies for specific areas, populations at risk and infrastructure. Uncertainty around forecasting, the presence of localized flooding, the status of upstream reservoirs, and other variables beyond control means that there is some residual risk.

Figure 9 CI at-risk to 1:100 and 1:200 year flood inundation w/ 50 metre buffer (Source: The City of Calgary)

Critical infrastructure	100-year (1% AEP)	200-year (0.5% AEP)
After School Programs	8	13
Ambulance Stations	3	5
Clinics	5	7
Community Centres	7	9
Day Cares	26	38
ENMAX Substations	4	6
Fire Stations	1	3
LRT Stations	4	13
Municipal Halls	1	1
Nursing Homes	17	20
Police Stations	0	1
Rec Centres	13	15
Schools	16	24
Water Treatment Plants	1	2
Special Care Facilities	1	1

The recent availability of flood insurance in Calgary will likely result in homeowners no longer being eligible for Disaster Recovery Program (DRP) financial assistance, thereby increasing the financial exposure of many property owners to flooding. Flood insurance is very expensive as there is a smaller population living in high-risk flood areas across which the overall annual loss can be amortized. To date, the take-up rates for insurance coverage have been very low (less than 30% in most provinces). In addition, changes to insurance policies in Alberta following the 2013 floods stipulates that if both overland flooding and sewer backup occur at the same time, the homeowner must have overland flood insurance in order to be compensated. This was not the case in 2013 when private insurance industry compensation for sewage backups was much higher than it would be for an event today.

Many property owners are also unaware of their flood risk. A recent survey conducted by the University of Waterloo (2017) found that of the 2,300 surveyed individuals who live in federally designated high-risk flood areas, only 6% knew they lived in a designated high-risk area and less than 30% were taking action to protect their property.[xxix] The high cost of coverage coupled with low risk awareness and the expectation of financial assistance (from government and/or insurers) due to previous event experience may contribute to a significant number of homeowners remaining unprotected against floods with a subset of that group potentially unaware they are not protected.

Floods have a defined geographic area of risk that allows for an assessment of the potential range of impacts. Calgary's recent experience with a catastrophic flood in 2013 further informs an understanding of the possible consequences from future events. As was experienced during 2013, flooding can cause significant damage to the built and natural environments while also precipitating a measurable negative impact to the local economy and well-being of citizens.

For significant events, the range of expected flood impacts can include: widespread power outages; traffic re-routing; large-scale evacuations; backed-up storm/sanitary systems; prolonged service interruptions; closures to major road arteries and bridges; basement seepage; damage or destruction of critical infrastructure; temporary and permanent relocation of people; extensive debris buildup requiring removal; business closures; loss of life, injury, temporary isolation, and long-term emotional and psychosocial issues. Responding and recovering from flood events will likely overwhelm local emergency response resources and require a major intervention of financial and technical assistance.

Risk Treatment and Controls

Calgary's recent experience with a major flood event has confirmed the benefit of existing flood preparedness and mitigation activities while also leading to the development of a new suite of risk treatment options. In terms of preparedness, The City of Calgary has detailed flood emergency response plans, forecasting and monitoring systems, flood hazard maps and models, notification systems, trained emergency response teams, and targeted community awareness programming. The City of Calgary's Land Use Bylaw and other development regulations also contain certain restrictions and considerations related to development in the flood hazard area. The Government of Alberta also has an agreement in place with TransAlta regarding the flood operation of Ghost Reservoir prior to and during flood season.

Since the 2013 flood, The City of Calgary has committed over $150 million to various flood mitigation and resilience projects throughout Calgary. These flood mitigation projects include: Glenmore Dam infrastructure upgrades, flood mitigation barriers, stormwater system improvements, bridge enhancements, gravel bar and bank stabilization projects, sanitary system upgrades, and flood resilience work at the Calgary Zoo and Municipal Complex.

The City of Calgary is also working with upstream communities and the Government of Alberta on major mitigation projects on the Bow and Elbow Rivers, including off-stream reservoirs and dry dams that will significantly reduce the flood risk to Calgary. A Flood Mitigation Measures Assessment completed by The City of Calgary in 2016 along with Provincial Flood Mitigation Plans will guide future flood mitigation and resiliency projects.

In the absence of any flood mitigation being in place, the annual flood damage costs in Calgary would average $170 million per year. Flood mitigation projects implemented since 2013 have decreased the annual flood damage risk by approximately 30 per cent to $115 million per year. The Province of Alberta's Springbank Off-Stream Reservoir and The City's upgraded Glenmore Dam gates will protect Calgary from Elbow River flood waters to an event similar to the 2013 flood. A new upstream reservoir, in combination with ongoing TransAlta operations and complementary flood barriers in communities along the Bow River, will protect against a flood event similar to 2013.

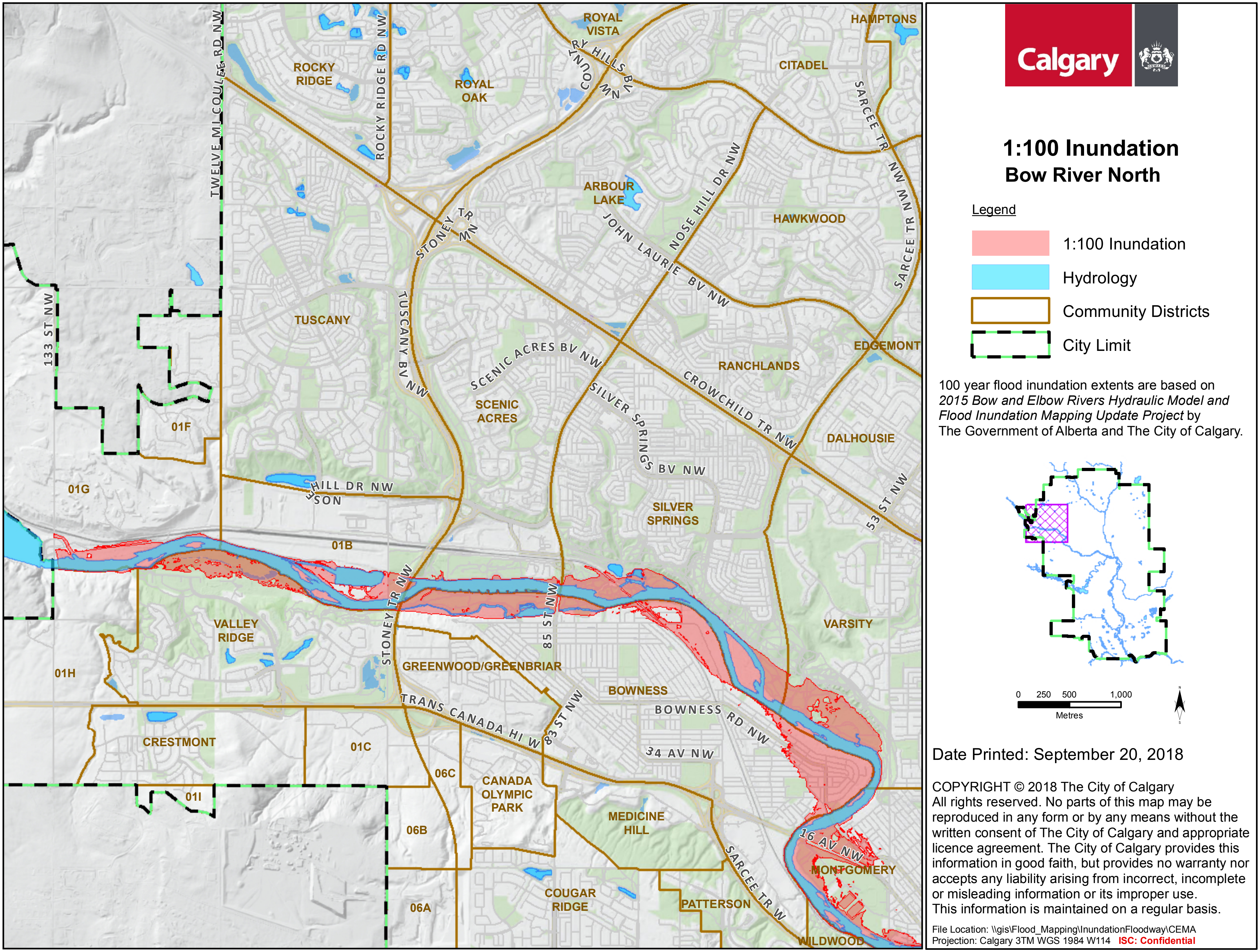
Previous Occurrences (source: The City of Calgary, IBC)

The 2013 (1:70 year event) flood resulted in $6 billion in damage to southern Alberta, including $1.7 billion in insured losses. Hundreds of thousands of people were evacuated, a significant number of people lost their homes, critical infrastructure was compromised, and emotional recovery will be ongoing for many more years.

Other notable events

- 1879 and 1897 Calgary AB: > 1:200 year (0.5% AEP) events.

Figure 10



1:100 Inundation

Bow River North

Legend

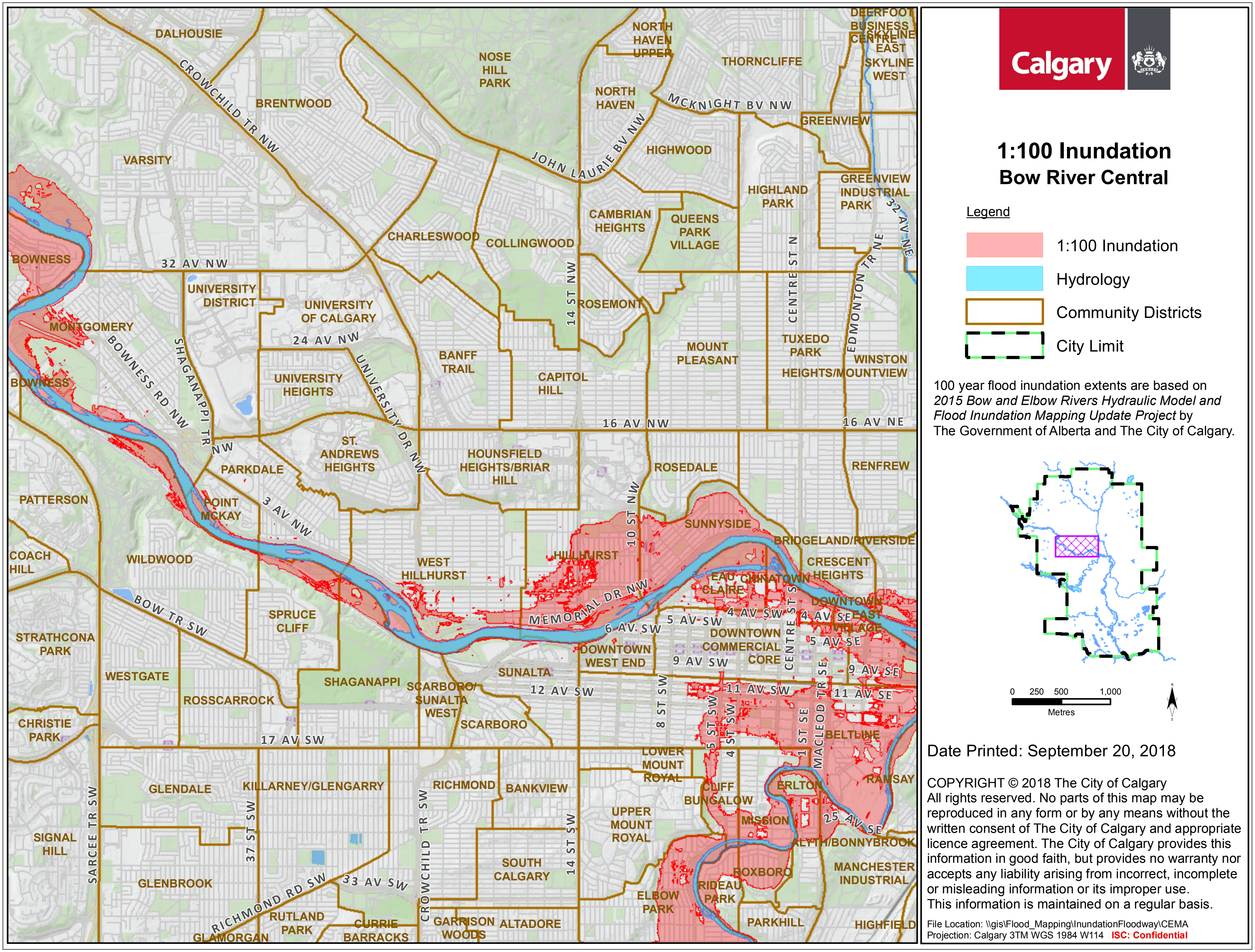
🟥 1:100 Inundation
🟦 Hydrology
☐ Community Districts
☐ City Limit

100 year flood inundation extents are based on *2015 Bow and Elbow Rivers Hydraulic Model and Flood Inundation Mapping Update Project* by The Government of Alberta and The City of Calgary.

Date Printed: September 20, 2018

File Location: \\gis\Flood_Mapping\InundationFloodway\CEMA
Projection: Calgary 3TM WGS 1984 W114 **ISC: Confidential**

Figure 11



1:100 Inundation
Bow River Central

Legend

- 🟥 1:100 Inundation
- 🟦 Hydrology
- ☐ Community Districts
- ⬚ City Limit

100 year flood inundation extents are based on *2015 Bow and Elbow Rivers Hydraulic Model and Flood Inundation Mapping Update Project* by The Government of Alberta and The City of Calgary.

Date Printed: September 20, 2018

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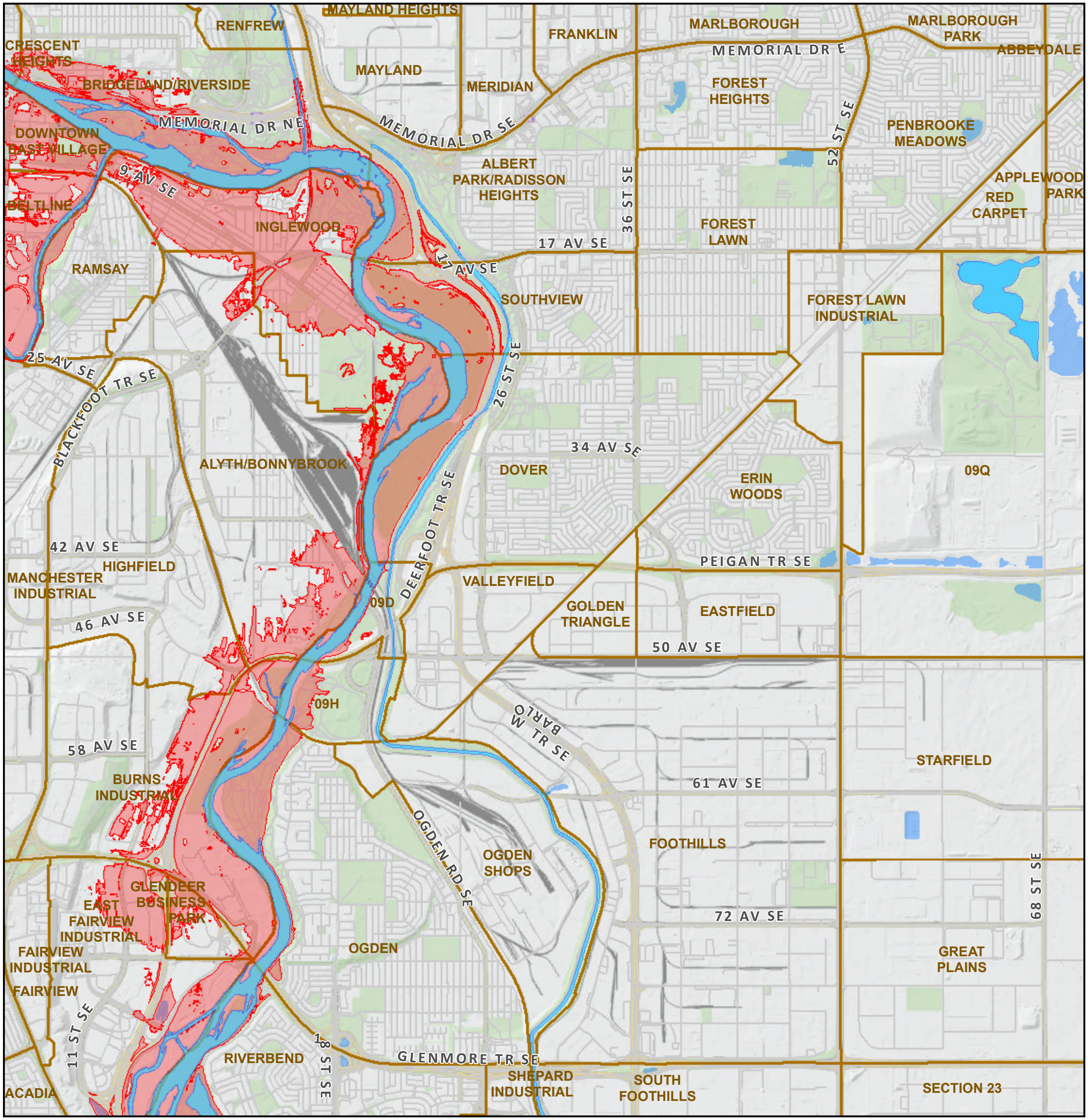
Projection: Calgary 3TM WGS 1984 W114 **ISC: Confidential**

Figure 12



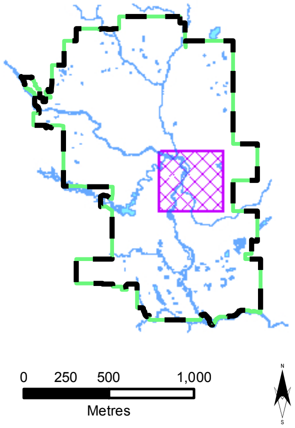
Calgary

1:100 Inundation
Bow River East

Legend

🟥	1:100 Inundation
🟦	Hydrology
▭	Community Districts
⬚	City Limit

100 year flood inundation extents are based on *2015 Bow and Elbow Rivers Hydraulic Model and Flood Inundation Mapping Update Project* by The Government of Alberta and The City of Calgary.



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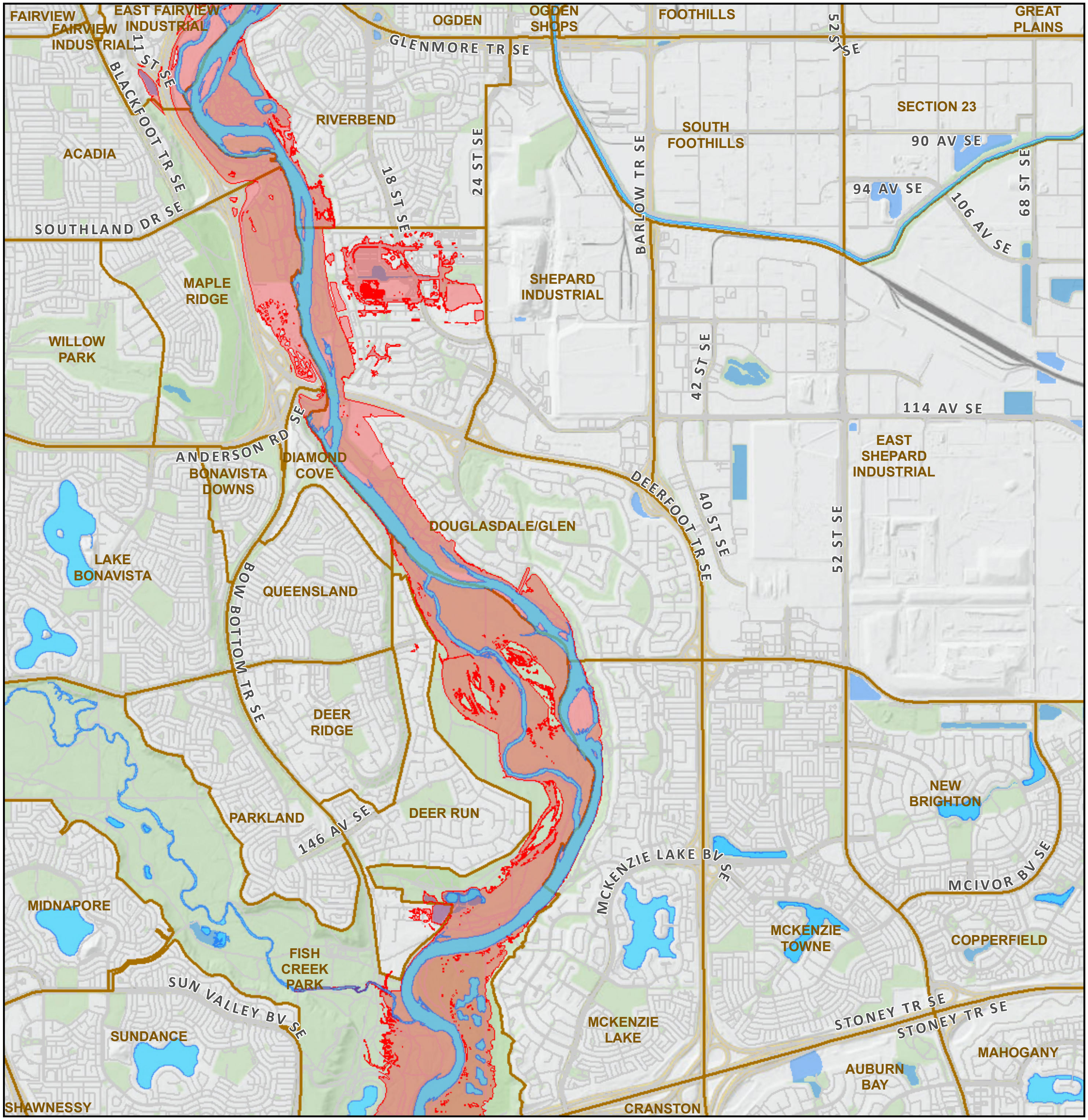
Projection: Calgary 3TM WGS 1984 W114 ISC: Confidential

Figure 13



Calgary

1:100 Inundation
Bow River South

Legend

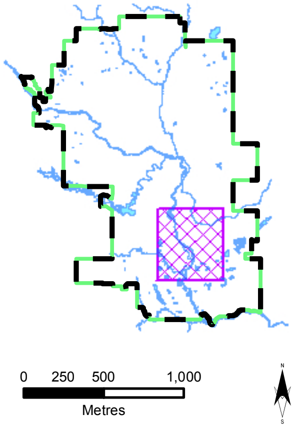
🟥 1:100 Inundation

🟦 Hydrology

☐ Community Districts

☐ City Limit

100 year flood inundation extents are based on *2015 Bow and Elbow Rivers Hydraulic Model and Flood Inundation Mapping Update Project* by The Government of Alberta and The City of Calgary.



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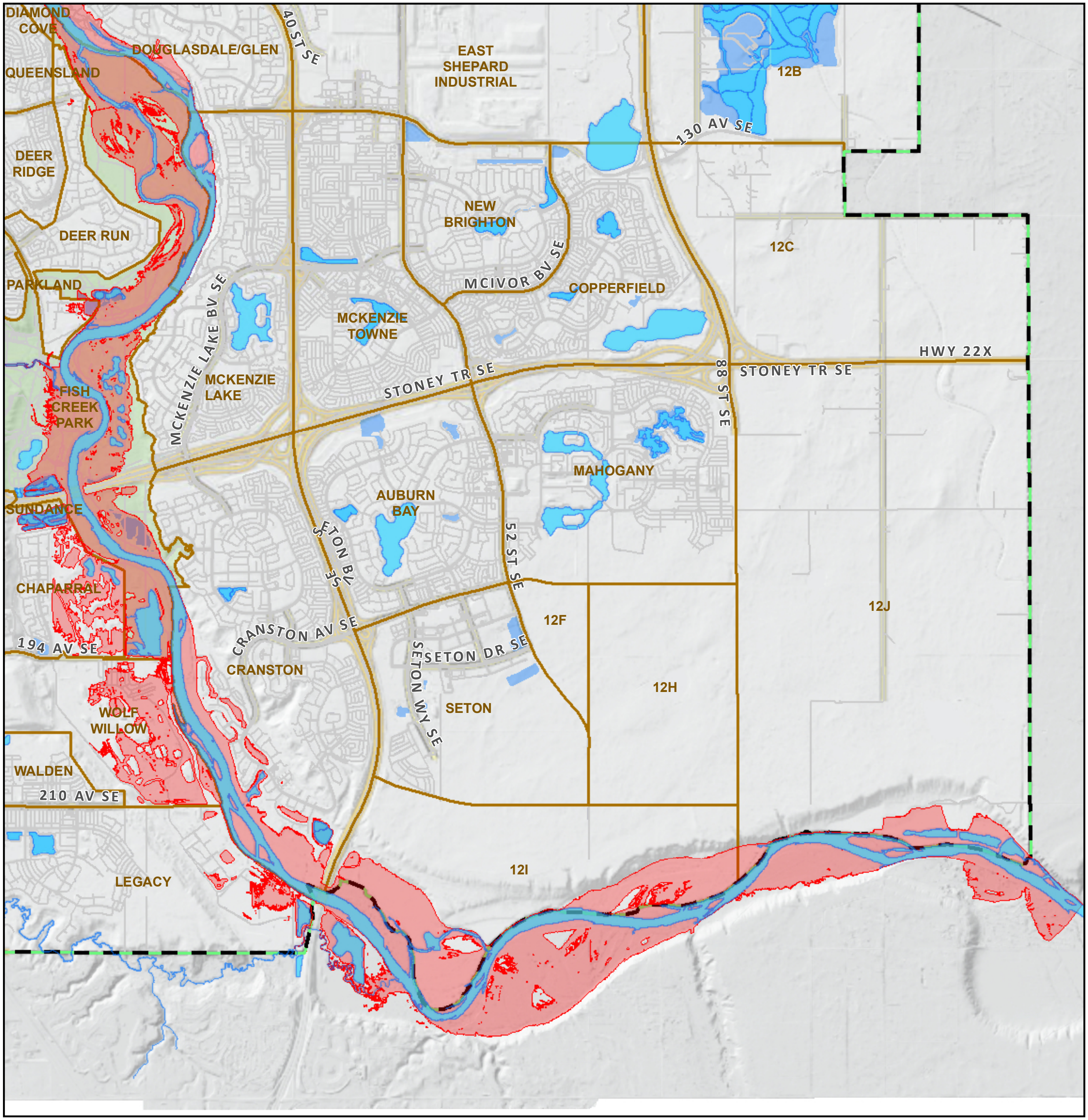
Projection: Calgary 3TM WGS 1984 W114 **ISC: Confidential**

Figure 14



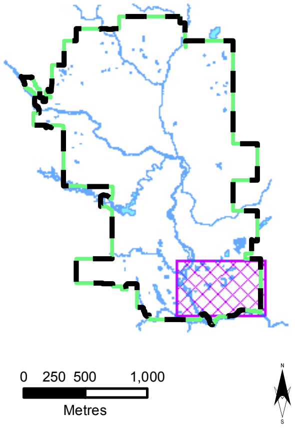
1:100 Inundation

Bow River South East

Legend

🟥	1:100 Inundation
🟦	Hydrology
☐	Community Districts
▭	City Limit

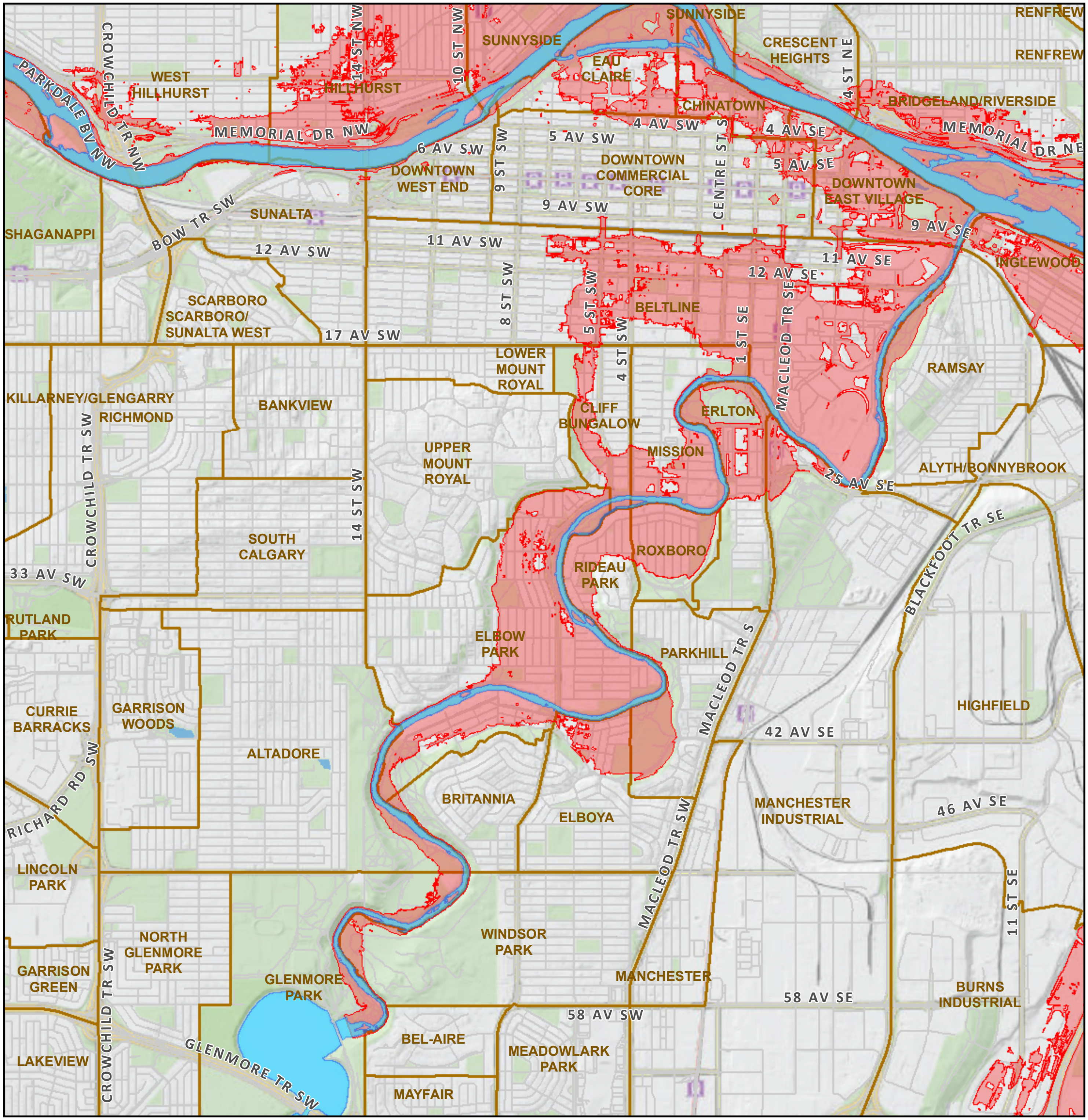
100 year flood inundation extents are based on *2015 Bow and Elbow Rivers Hydraulic Model and Flood Inundation Mapping Update Project* by The Government of Alberta and The City of Calgary.



Date Printed: September 20, 2018

File Location: \\gis\Flood_Mapping\InundationFloodway\CEMA
Projection: Calgary 3TM WGS 1984 W114 **ISC: Confidential**

Figure 15



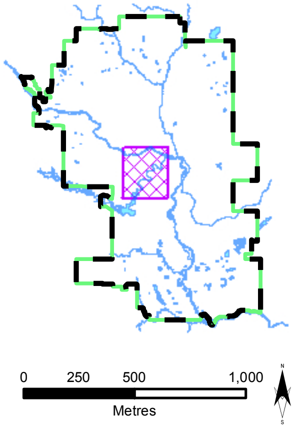
Calgary

1:100 Inundation
Elbow River

Legend

🟥	1:100 Inundation
🟦	Hydrology
▭	Community Districts
▭	City Limit

100 year flood inundation extents are based on *2015 Bow and Elbow Rivers Hydraulic Model and Flood Inundation Mapping Update Project* by The Government of Alberta and The City of Calgary.



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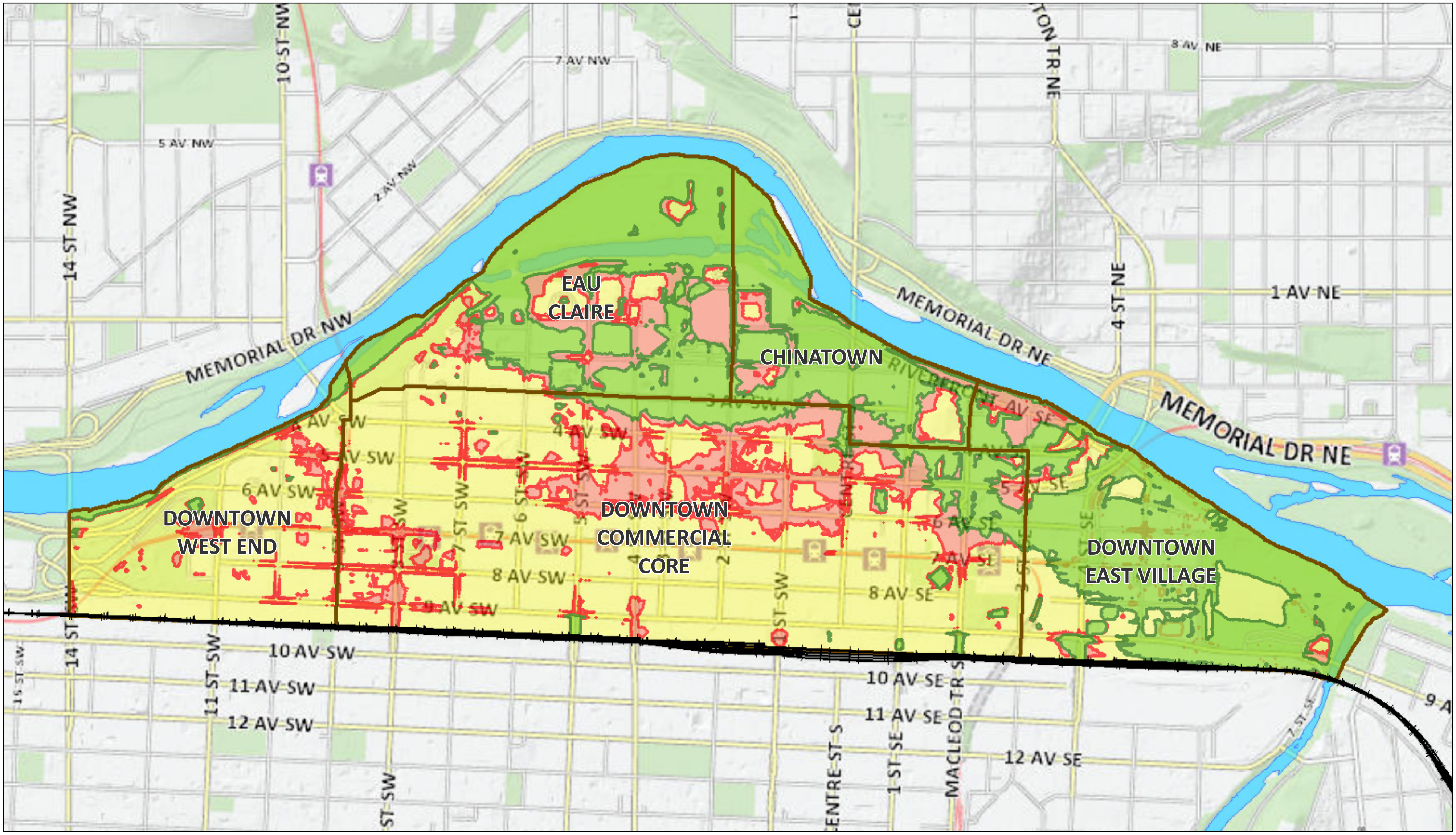
Projection: Calgary 3TM WGS 1984 W114 ISC: Confidential

Figure 16



1:100 & 1:200 Inundation in the Downtown Core

Community Name	Community (Ha)	Inundation 1:100 (Ha)	Inundation 1:100 (%)	Inundation 1:200 (Ha)	Inundation 1:200 (%)
CHINATOWN	24.76	18.20	73.52	23.06	93.17
DOWNTOWN COMMERCIAL CORE	132.87	9.48	7.14	33.40	25.14
DOWNTOWN EAST VILLAGE	52.08	36.25	69.60	39.94	76.68
DOWNTOWN WEST END	36.45	1.36	3.72	3.81	10.46
EAU CLAIRE	51.61	31.15	60.37	41.93	81.25
Total	**297.76**	**96.44**	**32.39**	**142.14**	**47.74**

Legend

🟩 Inundation 1:100

🟥 Inundation 1:200

🟨 Downtown Communities

0 125 250 500
Metres

Calgary

Date Printed: September 20, 2018

File Location: \gis\Flood_Mapping\InundationFloodway
Projection: Calgary 3TM WGS 1984 W114

ISC: Confidential

Extreme Cold

Consequence	**Moderate**	**Risk Level**	**High**
Likelihood	**Likely**	**Risk Trend**	**Increasing**

Persistent extreme cold is typically the result of cold winter air trapped under a persistent ridge of high pressure that has moved south from the Arctic (possibly after a significant winter storm) or a moderately cold air mass combined with light to moderate winds. Environment and Climate Change Canada issues "Extreme Cold" warnings when the temperature is expected to reach minus 40°C (or the "Wind Chill Index", which is not an actual temperature, is expected to reach minus 40) for at least two hours.

Lead Agency	Environment and Climate Change Canada
Expected Event Duration	Days to weeks
High-risk Season(s)	Nov-Feb (With Dec/Jan most likely)
High-risk Areas	Anywhere
Annual Exceedance Probability	10% to less than 63%

This represents the potential consequence of the hazard event within each assessed category. Highest consequence is furthest from centre.

Exposure and Consequences

As outlined in Figures 17 and 18, Calgary is located in a region that frequently experiences extreme cold events where temperatures can reach close to -40°C. On average, Calgary has 3 days per year with temperatures below -40°C. While extreme cold events can impact the entire city population, the most vulnerable to these events are the homeless, seniors, young children, people with chronic illnesses, and people working or exercising outdoors. Water system infrastructure is particularly vulnerable to extreme cold conditions. Extreme cold is rated as a high risk due to its potential to cause significant negative impacts to people's health (including fatalities) and the high frequency of its occurrence. During winter months, this type of event could result in elevated numbers of frostbite and hypothermia victims. If winds are light, as when under a cold arctic high pressure system, air pollution levels can rise significantly. A prolonged event could also result in increased demand on health care and high electricity demands/brown outs. Burst pipes and localized flooding due to freeze-thaw processes could lead to an increased demand for emergency services. Icy conditions may cause major road closures and postpone non-essential travel. Air traffic could be interrupted and flights cancelled. During summer months, freezing damage to crops is possible.

Risk Treatment and Controls

Robust early warning systems are in place to notify the public, emergency response personnel, and health providers in advance of extreme cold events. Warming centres, community awareness programming, and emergency response plans are also in place.

Previous Occurrences (source: Environment and Climate Change Canada)

- 1989/01/29-31 Alberta: temperatures dropped from +3°C to -26°C, leaving 8 dead and 100 people with frostbite in Calgary.
- 2016/12/07 Alberta: temperatures reached -35°C leading to school closures, travel restrictions and record electricity use. One death was attributed to the event.

Figure 17 Extreme Minimum Temperature in Alberta, 1901 to 2000 (Source: Alberta Agriculture and Forestry)

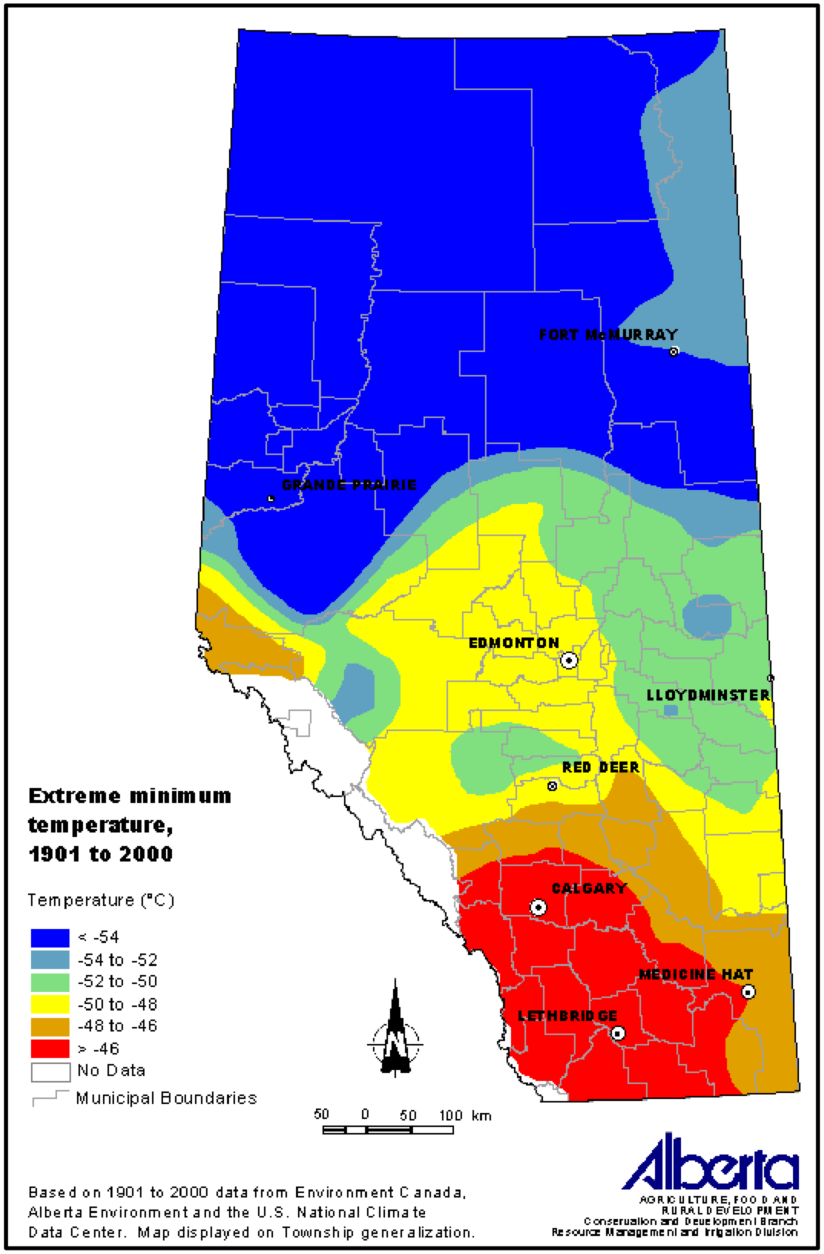
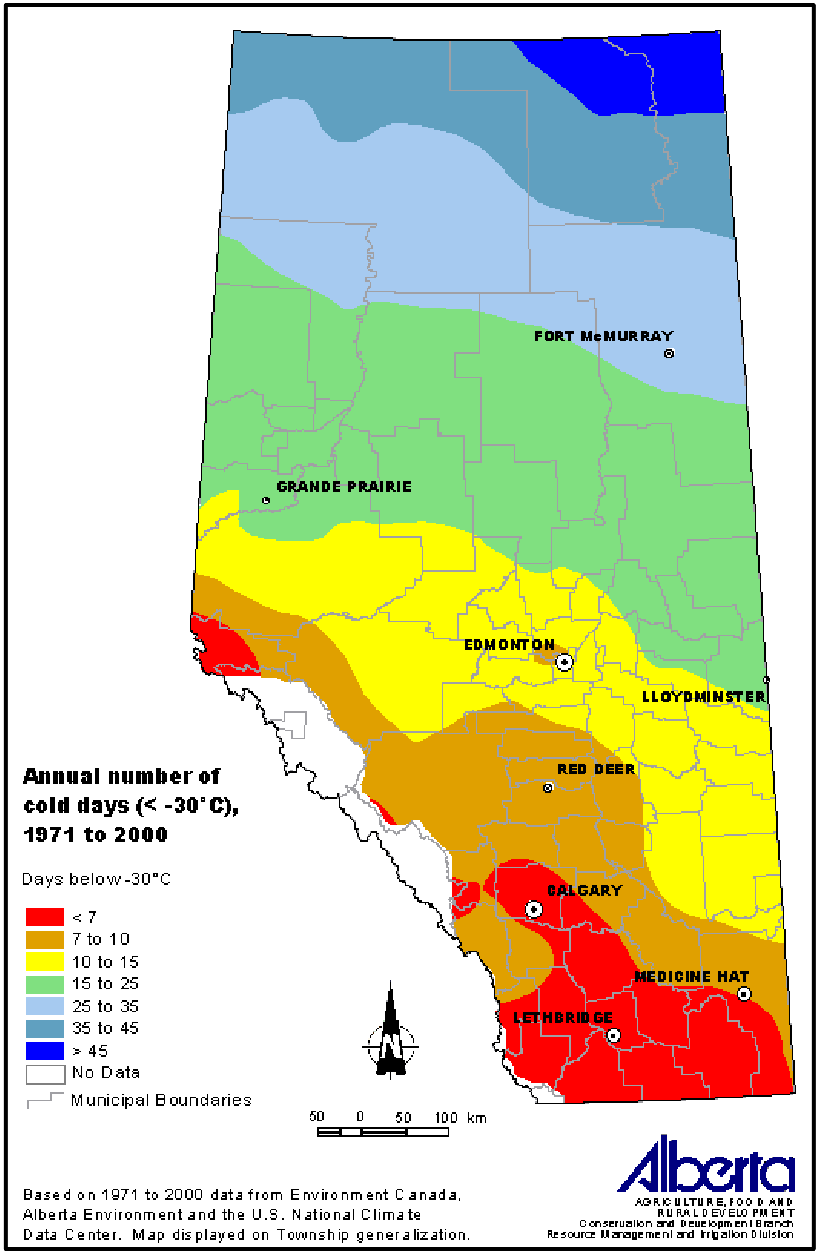


Figure 18 Annual number of cold days (<-30C), 1971 to 2000 (Source: Alberta Agriculture and Forestry)



Major CI Failure or Disruption

Consequence	Moderate	**Risk Level**	High
Likelihood	Likely	**Risk Trend**	Increasing

Critical infrastructure (CI) is defined as the interdependent and interconnected networks of facilities, institutions, services, systems, and processes that sustain and protect vital human needs, economies, public health, safety, security, and the continuity of government. Damage, disruption, or destruction of critical infrastructure can have a negative impact to the safety, security, and well-being of citizens. A Major Critical Infrastructure Failure or Disruption can be triggered by environmental (ex. weather-related hazards), human-induced (ex. terrorism, human error), or technological (ex. cyber-attacks, systems failures) causal events. Figure 19 provides examples within the 10 identified CI sectors in Canada.

Lead Agency	CEMA
Expected Event Duration	Variable
High-risk Season(s)	Flood and summer/winter storm seasons
High-risk Areas	Flood plain, downtown, rail corridor
Annual Exceedance Probability	10% to less than 63%

Exposure and Consequences

Critical Infrastructure failures are high-frequency events that can impact any community in Calgary. While possible at any point during the year, they most commonly occur during the high-risk seasons of the other hazard and threat events that trigger them. As outlined in the Hazard and Threat Correlation Matrix, 12 of the 13 identified risks have the potential to contribute to the causal mechanisms that would trigger the occurrence of a CI failure and the cascading impacts to the interdependent systems and services they support.

This represents the potential consequence of the hazard event within each assessed category. Highest consequence is furthest from centre.

The total exposure of people and assets to CI failures can only be discussed in the most general terms as there are a multitude of factors that contribute to the potential geographic boundaries and consequences of an event. The most exposed locations are those with a high-density of people, infrastructure, housing, production capacities, livelihoods, critical services, economic activity, and other tangible human assets situated in hazard-prone areas. In Calgary, the downtown core represents the area with the highest total exposure to a CI failure. A significant proportion of local employment and GDP is based in the downtown core while this area is also exposed to numerous high-risk hazards, including flooding and rail.

The time of year, locality, causal event, and number of interdependencies are significant factors that determine the severity of a failure or interruption to a specific piece of critical infrastructure. CI is vulnerable to the original trigger event while also being critical to supporting response and community recovery efforts. A key piece of CI that has been compromised during an event will increase the burden on first response resources and the demand on organizations who service vulnerable populations. A major CI failure event could last from several hours to weeks before backup systems or workarounds are implemented. There is the potential for significant knock-on damage to physical infrastructure, extended power outages, transportation delays, business interruption, prolonged evacuations, access/egress restrictions, and other secondary impacts.

Risk Treatment and Controls

The majority of risk treatment is focused on having effective business continuity strategies and workarounds in place in order to limit the impact of localized or widespread critical infrastructure failures. As these failures frequently occur as a result of other hazard events (ex. extreme weather), the procedures and treatment options in place to mitigate those hazards serve to mitigate the risk to critical infrastructure. For example, major flood mitigation projects are often focused on protecting specific pieces of critical infrastructure.

Previous Occurrences (source: The City of Calgary)

- 2012/07/09 Calgary AB: a fire at Shaw Court cut power and telephone services to 30,000 customers including Alberta Health Services, Service Alberta, The City of Calgary, and numerous major banks.
- 2014/09/09 Calgary AB: early snowfall damages the tree canopy in 148 of 227 Calgary communities resulting in 74,000 ENMAX customers without power (2,000 lasting several days) and significant interruptions to the cities road network.
- 2014/10/12 Calgary AB: a power outage in the downtown forces the evacuation of 5,000 impacted ENMAX commercial/residential customers, interrupts internet/telephone services to over 6,000 people, and closes 4 roads.

Figure 19 Critical infrastructure sectors in Canada (Source: Public Safety Canada)

Critical infrastructure Sector	Examples
Energy and utilities	Electrical power grids, natural gas pipelines, oil production facilitties, power substations, and power lines
Finance	Banks, securites, financial services, and payment systems
Food	Food safety, production facilities, distribution systems, and storage
Government	Government facilities, government services (ex. elections), government information networks, government assets, and cultural institutions/monuments
Health	Hospitals, healthcare facilities, blood-supply facilities, laboratories, and pharmaceuticals
Information and communication technology	Telecommunications (phone, fax, cable, satellites), broadcasting systems, software, hardware, and networks (internet)
Manufacturing	Chemical and strategic manufacturers
Safety	Hazardous substances, explosives, nuclear waste, and emergency services
Transportation	Roads, air, rail, and marine
Water	Drinking water and wastewater management systems

Major Dam Breach – Bow River

Consequence	Catastrophic	**Risk Level**	High
Likelihood	Very Rare	**Risk Trend**	Stable

A major dam breach is a catastrophic type of dam failure characterized by the sudden, rapid, and uncontrolled release of impounded water. Dam failures can usually be categorized as structural failures, mechanical failures, or hydraulic failures. A number of conditions and causal factors can contribute to dam failures. These can include any combination of the following: prolonged periods of significant rainfall and flooding; inadequate spillway capacity; internal erosion; improper maintenance; improper design; improper construction materials; failure of an upstream dam; landslides into reservoirs; high winds; human-caused; or earthquakes.

Lead Agency	Transalta
Expected Event Duration	Hours to days
High-risk Season(s)	May 15 – July 15 (flood season)
High-risk Areas	Flood plain, flood fringe, downtown
Annual Exceedance Probability	0.01% to less than 0.1%

Exposure and Consequences

A major breach of any of the 11 dams upstream of Calgary along the Bow River and its tributaries has the potential to cause varying degrees of flooding within the city with a large range in the speed of onset and expected consequences depending on which dam fails.

This represents the potential consequence of the hazard event within each assessed category. Highest consequence is furthest from centre.

Risk Treatment and Controls

Risk treatment focuses on preventing failures and mitigating potential consequences by using built infrastructure, policy, and planning measures. Dams are designed to meet provincial and federal legislation as well as the regulations established in the Canadian Dam Association Guidelines. Dam owners undertake regular risk assessments, inspections, and maintenance of dam facilities while also having prescribed operating procedures in place to limit the potential of an event occurring. Routine auditing of dam safety performance is undertaken by independent consultants. Internal measures include emergency response plans, mapping, training, and exercises. External controls emergency preparedness plans and public alerting systems.

Previous Occurrences (source: Dam Incident Database - Stanford University)

- 1972/02/26 Buffalo Creek WV: a coal-waste dam collapsed, releasing approximately 17.6 million cubic feet of water. The flood killed 125 people, destroyed 500 homes, left 4,000 homeless, and caused over $50 million in damage.
- 1976/06/05 Idaho: the Teton Dam failed during initial impoundment. The reservoir was almost full and 300,000 acre-feet of flood water was released downstream. There were 11 fatalities and approximately $400 million in damages.

Major Drought

Consequence	Major	**Risk Level**	High
Likelihood	Rare	**Risk Trend**	Increasing

Environment and Climate Change Canada defines drought as a sustained and regionally extensive occurrence of appreciably below-average natural water availability in the form of precipitation, streamflow, or groundwater. It can be further classified into four general typologies: meteorological drought (less precipitation than normal over a prolonged period), agricultural drought (insufficient soil moisture to meet the needs of crops), hydrological drought (lake, river, reservoir or groundwater supplies fall below average levels due to a lack of precipitation), and socioeconomic drought (people and the economy are impacted due to a prolonged absence of water in a region).

Lead Agency	Water Services
Expected Event Duration	Months to years
High-risk Season(s)	August to the end of April
High-risk Areas	Bow and Elbow River watersheds
Annual Exceedance Probability	0.1% to less than 1%

Exposure and Consequences

Calgary is located in a prairie region historically prone to drought. Although Calgary has not experienced a major drought in recent urban history, this region did experienced prolonged and severe droughts in the 18th and 19th century. Drought risk is expected to become significantly more likely in the future as the climate warms. Although drought is a natural occurrence that is part of the climate cycle, multi-year drought can have serious consequences to human activity and can be intensified by population growth and high water consumption leading to water shortages. In this region, past droughts have lasted for varying lengths of time: from seasonal to decades in the 18th and 19th centuries.

This represents the potential consequence of the hazard event within each assessed category. Highest consequence is furthest from centre.

Drought can also be uniquely challenging since the recognition of onset can be slow and duration unknown. This can lead to inaction by decision-makers and delayed risk treatment and controls. Droughts can have major impacts on the environment, health, society, and economy. Drought impacts may include: stressed vegetation, wetlands, wildlife and urban forests; desiccated terrestrial landscapes in parks and open spaces; and low rivers flows resulting in damage to aquatic ecosystems. The impact to wastewater discharges from the City of Calgary can further degrade water quality.

The issuance of water use restrictions across the city to all citizens in multiple years and seasons can lead to: mental health impacts; closure of facilities; interruption of community services and businesses; and reduced housing and business development. In the extreme, compromised water treatment plants could impact fire suppression, operation of critical facilities, and jeopardize overall well-being due to reduced assess to potable water and compromised food sources. Heat stress and increased wildfire danger are secondary risks that can be associated with drought.

A severe drought event lasting several years in Calgary could have a major impact in the hundreds of millions to local GDP, cause significant damage to ecosystems, and significantly compromise The City's ability to deliver services. These potential damages can be long-lasting and take decades to recover. Droughts have historically been one of the most costly disaster event types in Canada with multiple events having financial impacts exceeding $500 million. This risk is also expected to increase with the effects of climate change (i.e. shifting spring runoff periods and longer and drier summers). As outlined in the Climate Risks section of this report, droughts represent a high-risk climate scenario in terms of likelihood and impact. They are expected to have a nearly threefold increase in frequency by the 2080s which could have cascading downstream effects on the community and macro economy.

Risk Treatment and Controls

The City of Calgary uses a combination of built infrastructure, strategic supply and demand management, and policy to mitigate the risk of drought. The challenge with preventing this type of phenomenon is that a number of the causal factors that contribute to drought conditions are not solely within the control of The City of Calgary. To manage this risk, regional levels of cooperation and management of water supply are addressed through collaboration of the major water licence holders on the Bow River – both operationally during weekly water users meetings and strategically through the Bow River Working Group.

The City of Calgary has also identified tools and strategies to mitigate the impact of drought. The City's efforts in reducing water demand through the Water Efficiency Plan have already increased drought resiliency. Others actions include: upgrades to strategic water and wastewater infrastructure; the ability to initiate water restrictions under the Water Utility Bylaw; early warning drought forecasting and river water quality monitoring; accessing additional water through temporary water assignments; trained emergency response teams and resources; climate change adaption planning and support for long-term regional water storage and security plans.

Two current flood mitigation projects have added drought resiliency benefits. The Glenmore Dam infrastructure upgrades will allow for increased water storage during the winter season. The Alberta government has a five-year agreement with TransAlta to modify operations at several TransAlta facilities to help protect communities along the Bow River against the impacts of both floods and drought. A future upstream reservoir on the Bow River to protect against a flood event similar to 2013 would also have additional drought resiliency benefits for the region.

Previous Occurrences (source: Public Safety Canada)

There have not been any major droughts in Canada within an urban context in recent history. The following were widespread events mainly impacting agriculture.

- 1987/1988 Southern Prairies: the hottest summer on record (at the time), combined with half the normal growing season rainfall and a virtually snow-free previous winter, produced a drought that rivaled the 1930s. Over $4 billion economic impact.
- 2001/2002 Canada: the first coast-to-coast drought on record in Canada. The event impacted multuiple sectors, including: agricultural production and processing, water supplies, recreation, tourism, health, hydro-electric production, transportation, and forestry. GDP fell $5.8 billion and employment losses exceeded 41,000 jobs.

Major Rail Incident

Consequence	Catastrophic	**Risk Level**	High
Likelihood	Rare	**Risk Trend**	Increasing

A major rail incident can occur when the rolling stock is involved in a collision or derailment; the rolling stock causes or sustains a fire or explosion; the rolling stock accidentally releases dangerous goods or an emission of hazardous materials resulting from damage to the containment system; or there is a rail security incident. A probable worst-case scenario event in Calgary would likely involve a significant derailment in a high-density urban area that leads to a major spill and fire within multiple cars carrying dangerous goods/hazardous materials.

Lead Agency	Multiple
Expected Event Duration	Variable
High-risk Season(s)	Flood season, summer event season (ex. Stampede), daytime hours, rush hours
High-risk Areas	Flood plain, downtown, rail corridor, rail yards, rail bridges, rail crossings
Annual Exceedance Probability	0.1% to less than 1%

Exposure and Consequences

Although these types of events are rare, if a major rail incident involving a dangerous goods/hazardous materials release, fire, explosion, or all of the above were to occur in a high-risk area of Calgary, there could be catastrophic impacts.

This represents the potential consequence of the hazard event within each assessed category. Highest consequence is furthest from centre.

Risk Treatment and Controls

There have been serious issues identified within the rail Safety Management System (SMS) and regulations in Canada that require attention. Following the Lac-Mégantic QC incident, the Transportation Safety Board of Canada (TSB) made five key recommendations (Railway Investigation R13D0054) aimed at addressing systemic safety issues that posed a significant risk. In addition, the TSB currently has an additional 15 active rail transportation safety recommendations in place. To be included as an active recommendation, the TSB has assessed the residual risk associated with the deficiency to be sufficient enough to warrant continued TSB involvement. Of these, 7 have been placed on an elevated watch list that represent the highest priority safety issues.

The most common types of risk treatment activities in the rail sector are: emergency notification systems; adoption of rail safety standards and adherence to SOPs; rail emergency response assistance plans (ERAPs); railway tank-car safety standards; transport Canada Safety Management System (SMS); ASKRAIL app; rail safety education and awareness programming; rail emergency responders and resources; transportation of Dangerous Goods Act 1992; CANUTEC; Alberta Railway Safety Management System; public alerting and warning; and the Calgary EM system, personnel, and resources.

Previous Occurrences (source: Public Safety Canada)

- 1979/11/10 Mississauga ON: derailment, chemical release, explosion, and 225,000 people evacuated.
- 2012/02/26 Burlington ON: derailment, chemical release, and environmental contamination left 3 dead, 45 injured, and 4,300L of diesel released.
- 2013/07/06 Lac-Mégantic QC: derailment, chemical release, and explosion. Cost to rebuild >$2 billion, 47 dead, 115 buildings destroyed or damaged, 6 million litres of crude oil released, and 2,000 people evacuated.

Severe Storm - Blizzard

Consequence	Moderate	**Risk Level**	High
Likelihood	Likely	**Risk Trend**	Increasing

Environment and Climate Change Canada issues Blizzard Warnings when wind speeds of 40 km/hr. or greater are expected to cause widespread reductions in visibility (400 metres or less) due to blowing snow or blowing snow in combination with falling snow, for at least 4 hours. A blizzard by meteorological definition is based on wind and visibility, not on snowfall.

Lead Agency	Environment and Climate Change Canada
Expected Event Duration	Up to one day
High-risk Season(s)	December to February
High-risk Areas	Anywhere
Annual Exceedance Probability	10% to less than 63%

Exposure and Consequences

Blizzard conditions causing reduced visibility can develop behind a cold front with rapidly dropping temperatures or ahead of an advancing warm front with slowly rising temperatures. They're very dependent on snow pack conditions (i.e. fluffy/dry, hard, compact, or wet/sticky), terrain (highly variable in urban environments), and wind. Approximately 85% are caused by migrating low pressure centres (ex. gusty NW winds following an Alberta Clipper) and 15% are called "pressure gradient" blizzards that can occur with clear skies in combination with strong winds and fresh snow/loose snowpack.

Blizzard conditions can have a significant impact on individuals and livestock. Homeless populations and outside workers are particularly vulnerable as high-winds combined with cold temperatures speeds the rate of heat loss to the body, increasing the risk of serious health issues, such as frostbite and hypothermia. Blizzards are one of the most serious winter weather events due the reduced visibility associated with them. They can result in hazardous travel conditions, leading to an increased number of accidents and traffic delays. Travelers may also end up temporarily stranded due to blowing snow and whiteouts.

This represents the potential consequence of the hazard event within each assessed category. Highest consequence is furthest from centre.

While they are near impossible in dense urban areas with numerous local landmarks and infrastructure for spatial reference, they are likely in suburbs and rural areas of the city. As people travel from cities into the suburbs and rural areas, especially on major highways, they can instantly become totally disoriented or be involved in collisions that responders will have difficulty accessing safely. Although the expected impacts of blizzards are not as severe as other hazards, the frequency with which they occur necessitates them being prioritized as high-risk events.

Risk Treatment and Controls

The majority of controls focus on early warning systems to notify the public, emergency response personnel, and health providers in advance of blizzard events. Agencies responsible for traffic safety have emergency plans and resources in place to mitigate this hazard and respond when these events occur.

Previous Occurrences (source: Environment and Climate Change Canada)

- 1964/12/15 Southern Prairies: heavy snow, strong winds, and cold temperatures killed 3 people and thousands of animals.
- 1941/03/14 Prairies Canada: a severe blizzard producing a storm called an "Alberta Low" lasted 7 hours and produced winds exceeding 100 km/h and causing 76 deaths.

Severe Storm - Heavy Rain

Consequence	Moderate	**Risk Level**	High
Likelihood	Likely	**Risk Trend**	Increasing

A rainfall related warning will be issued by the Meteorological Service of Canada (MSC) - Environment and Climate Change Canada when there is an imminent weather system capable of causing significant rainfall. These rainfall events and warnings in Alberta are grouped into two general categories. The first category is large-scale weather systems that can affect extensive areas of the province over hours to days and would be tied to Rainfall Warnings. There are different rainfall thresholds for events in the warm season vs. the cold (frozen ground) season. The second category is for short-duration thunderstorms with intense localized downpours capable of producing flash flooding which would normally be tied to Severe Thunderstorm Warnings in the warm season.

Lead Agency	Environment and Climate Change Canada
Expected Event Duration	Minutes to several days
High-risk Season(s)	May-Sept. w/ late May-July being likeliest
High-risk Areas	Anywhere
Annual Exceedance Probability	10% to less than 63%

Exposure and Consequences

Calgary receives approx. 326.4 mm of rainfall each year with almost half of this in July and August (period 1981-2010). On average, Calgary experiences 2 days per year with rainfall greater than 25 mm (period 1981-2010). The single-day rainfall record for the city of Calgary is 64.2 mm (set on August 1, 1988). Heavy rainstorms may be a major contributing factor to disaster events such as floods, flash floods, and landslides. As outlined in the Hazard and Threat Correlation Matrix, almost half of the High risks in Calgary can be triggered or escalated by a severe rainstorm event. These storms are capable of causing major infrastructure damage, power disruptions, traffic re-routing, flooded properties, backed-up storm/sanitary systems, evacuations, stranded motorists, debris removal, and prolonged service interruptions. Figure 20 outlines the short duration rainfall, intensity, and frequency graph for the Calgary International Airport station.

This represents the potential consequence of the hazard event within each assessed category. Highest consequence is furthest from centre.

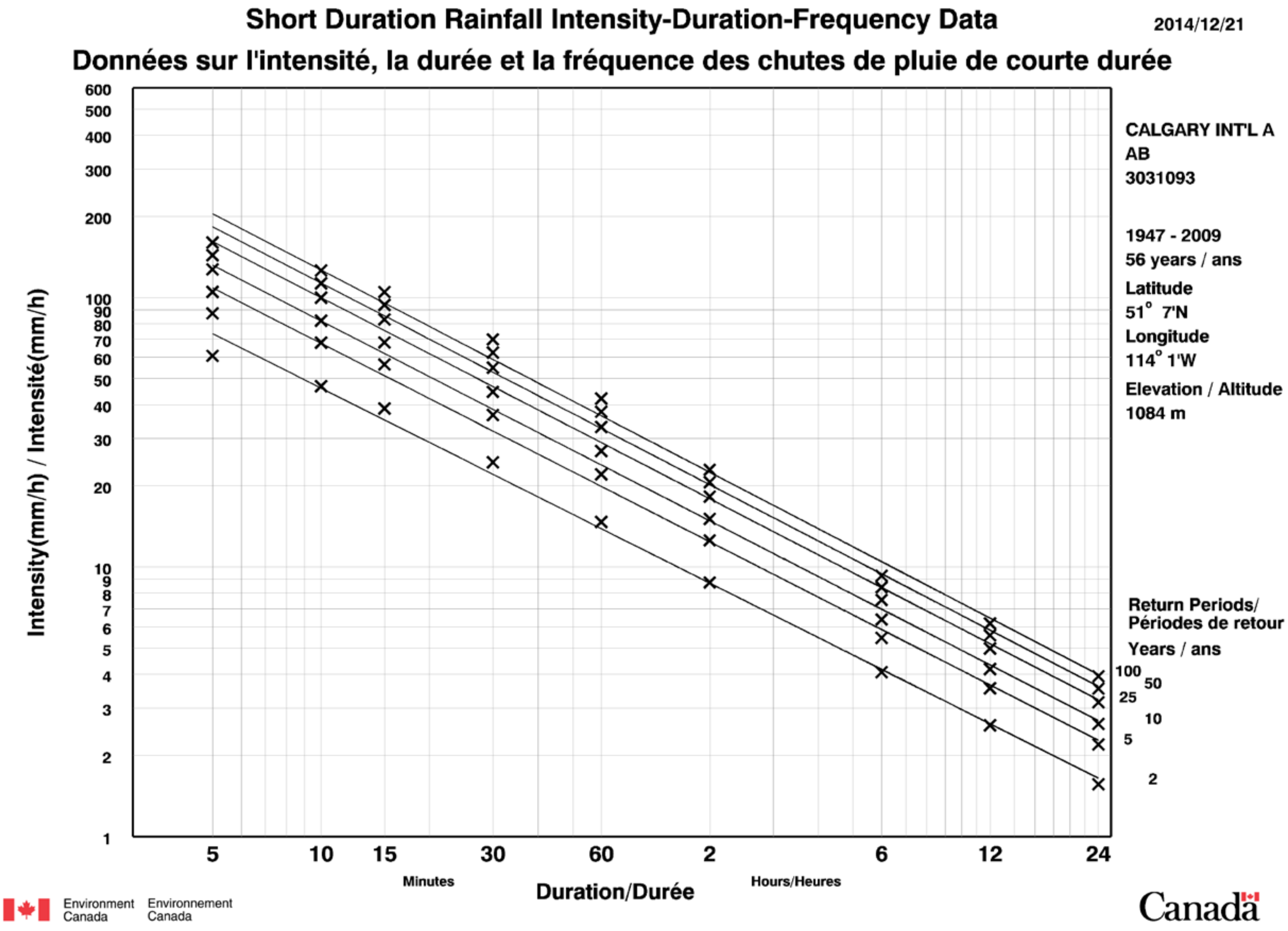
Risk Treatment and Controls

The risk of heavy rainstorms is treated with a combination of built infrastructure, emergency response systems, and policy measures. These include: land-use planning, development regulations, urban design standards, storm-system design and maintenance, drainage upgrades, physical infrastructure protection, trained emergency response personnel, emergency response plans, early warning systems, public alerting, event forecasting and modelling, and community awareness campaigns.

Previous Occurrences (source: Environment and Climate Change Canada)

- 2005/06 S. AB Floods: 40 municipalities with significant infrastructure damage, 14 states of local emergency, and 4 Fatalities.
- 2007/06/05 Calgary AB: Calgary airport recorded 42.6 mm of rain in a 30-minute period and 59.8 mm of rain in a 60-minute period. There was extensive flooding in the city including submerged vehicles on Deerfoot Trail.

Figure 20 Short Duration Rainfall Intensity Frequency at Calgary International Airport



Severe Storm - Winter Storms

Consequence	**Major**	**Risk Level**	**High**
Likelihood	**Unlikely**	**Risk Trend**	**Increasing**

Winter storms are large-scale weather systems that produce a combination of significant winter weather conditions. Environment and Climate Change Canada releases Winter Storm warnings for major snowfall (≥25 cm in a 24-hour period) or significant snowfall (≥10 cm in a 12-hour period) combined with freezing rain, strong winds, blowing snow, and/or extreme cold.

Lead Agency	Environment and Climate Change Canada
Expected Event Duration	Hours to days
High-risk Season(s)	October to May
High-risk Areas	Anywhere
Annual Exceedance Probability	1% to less than 10%

Exposure and Consequences

The mix of these winter weather conditions poses a threat to public safety and property. Winter storm conditions are not necessarily restricted to the winter season and may occur in the late autumn and early spring as well. Winter storms can cause power outages that last for days and roads and walkways can become extremely dangerous or impassable. This can lead to the closure or interruption of critical community services such as public transportation, child care, health programs and schools. Injuries and deaths may occur from exposure, dangerous road conditions, heart attacks related to snow clearing, and carbon monoxide poisoning. Snowfall of greater than 20 cm per day has occurred in Calgary every month from September through June. The one day snowfall record for the city of Calgary was May 6, 1981 at 48.4 cm. On average, Calgary experiences a snowfall greater than 20 cm once every three years (for the period 1881-2012).

This represents the potential consequence of the hazard event within each assessed category. Highest consequence is furthest from centre.

Risk Treatment and Controls

Similar to extreme cold and blizzard events with a few additional treatment options, which include: designated snow routes, early warning systems, event forecasting, public alerting, and building codes.

Previous Occurrences (source: Environment and Climate Change Canada)

- 2013/03/21 Leduc AB: over 100 vehicle accidents closed portions of Alberta's busiest highway for 12 hours.
- 1967/04 Southern Alberta: a series of snowstorms dropped 175 cm of snow, blocking roads, closing schools, and cutting off power. Army units were deployed to assist and thousands of cattle died.

Tornado

Consequence	Major	**Risk Level**	High
Likelihood	Unlikely	**Risk Trend**	Stable

A tornado is a violently rotating column of air extending between a “convective” (vertically developing) cloud base and the surface. The convective cloud may be a thunderstorm or a weaker convective cloud that is not producing lightning. Winds speeds in most tornadoes are under 140 km/h though on rare occasion can exceed 300 km/h. Tornadoes exhibit a high degree of variability in appearance, strength, speed, direction of travel, and duration. The tornadic wind column is often visible as a funnel shaped cloud, though may appear to be only part way to the ground - the key is to look for airborne dust or debris under any such funnel like cloud to confirm ground contact. The strongest and longest lasting tornadoes occur from supercells (rotating thunderstorms) but not all thunderstorms are supercells nor does every supercell produce a tornado.

Lead Agency	Environment and Climate Change Canada
Expected Event Duration	Less than 1 hour (seconds to minutes likely)
High-risk Season(s)	June to August (afternoon and evening)
High-risk Areas	Anywhere
Annual Exceedance Probability	1% to less than 10%

Wind speeds within tornadoes (or strong straight line wind events) are implied after the fact using what is called the Enhanced Fujita (EF) damage intensity scale. The EF scale does not directly use units of wind speed (such as km/h) but rather assesses wind damage. Wind speed is not measured as the tornado (or other wind) is occurring but is estimated and numerically categorized post-event based on the scale of wind damage caused. Actual wind speeds are implied based on historical engineering and other studies. The EF scale numerical damage categories range from EF0 damage (implied winds of 90-130 km/h) to EF5 damage (implied winds 315 km/h or higher).

This represents the potential consequence of the hazard event within each assessed category. Highest consequence is furthest from centre.

Exposure and Consequences

As Figures 21 and 22 indicate, Calgary is located within an area of high-risk for tornadic activity in Canada in terms of both frequency and severity. Alberta as a whole averages 8 reported tornadoes per year (from 2005 through 2017). Many tornadoes likely go unreported. The region is susceptible to tornadoes that are capable of causing severe to catastrophic damage (EF2-EF5). Recent examples of devastating tornadoes in Alberta include the 1987 Edmonton tornado (F4, the strongest documented in Alberta) that killed 27 people and the 2000 Pine Lake tornado (F3) that killed 12 people.

Despite the severe impact of the Edmonton and Pine Lake events, they could have been much worse. In Edmonton, the tornado tracked through two lower-density areas (an industrial zone and trailer park) and would have been far more deadly had it veered towards higher-density communities. The Pine Lake tornado tracked through a relatively sparsely populated area. It would have been far more significant if it had impacted Red Deer, which is only 40 km away. If an F3 or F4 tornado were to touch-down in Calgary in a high-density area during summer outdoor event season, the consequences could be catastrophic.

Tornadoes are one of nature’s most destructive and hazardous phenomena. They are capable of destroying well-built structures, flattening forests, and throwing heavy objects long distances. A tornado occurring in a densely populated area of Calgary could result in significant loss of life and critical injuries, hundreds of millions of dollars in economic damage, severe transportation disruptions, major debris build-up, large-scale evacuations, damaged and destroyed critical infrastructure, permanent environmental destruction, and a severe reduction in the delivery of essential city services.

Risk Treatment and Controls

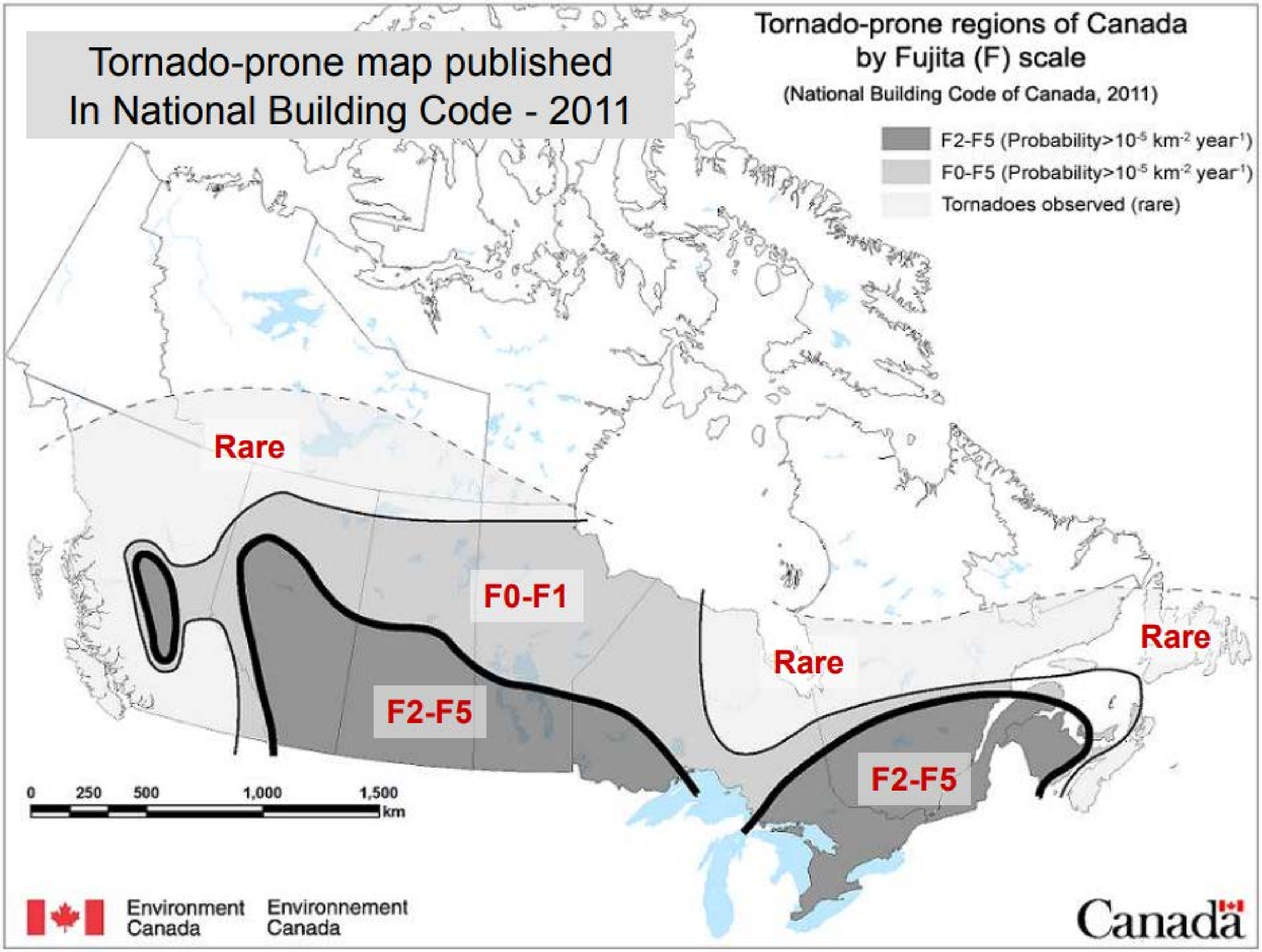
As with other fast-moving meteorological hazards, the most effective controls are focused on having early warning systems in place to warn the public and emergency response personnel with as much advance notice as possible. Environment Canada releases tornado watches when conditions are favourable for the development of severe thunderstorms that can produce one or more tornadoes. Tornado warnings are released when a tornado has been reported or there is evidence to suggest that a tornado is imminent.

Other risk controls include: trained emergency response personnel and resources, emergency response plans, public alerting, event forecasting, community awareness and education campaigns, building codes, heavy urban search and rescue teams, wind-resistant construction materials, and business continuity plans.

Previous Occurrences (source: Environment and Climate Change Canada)

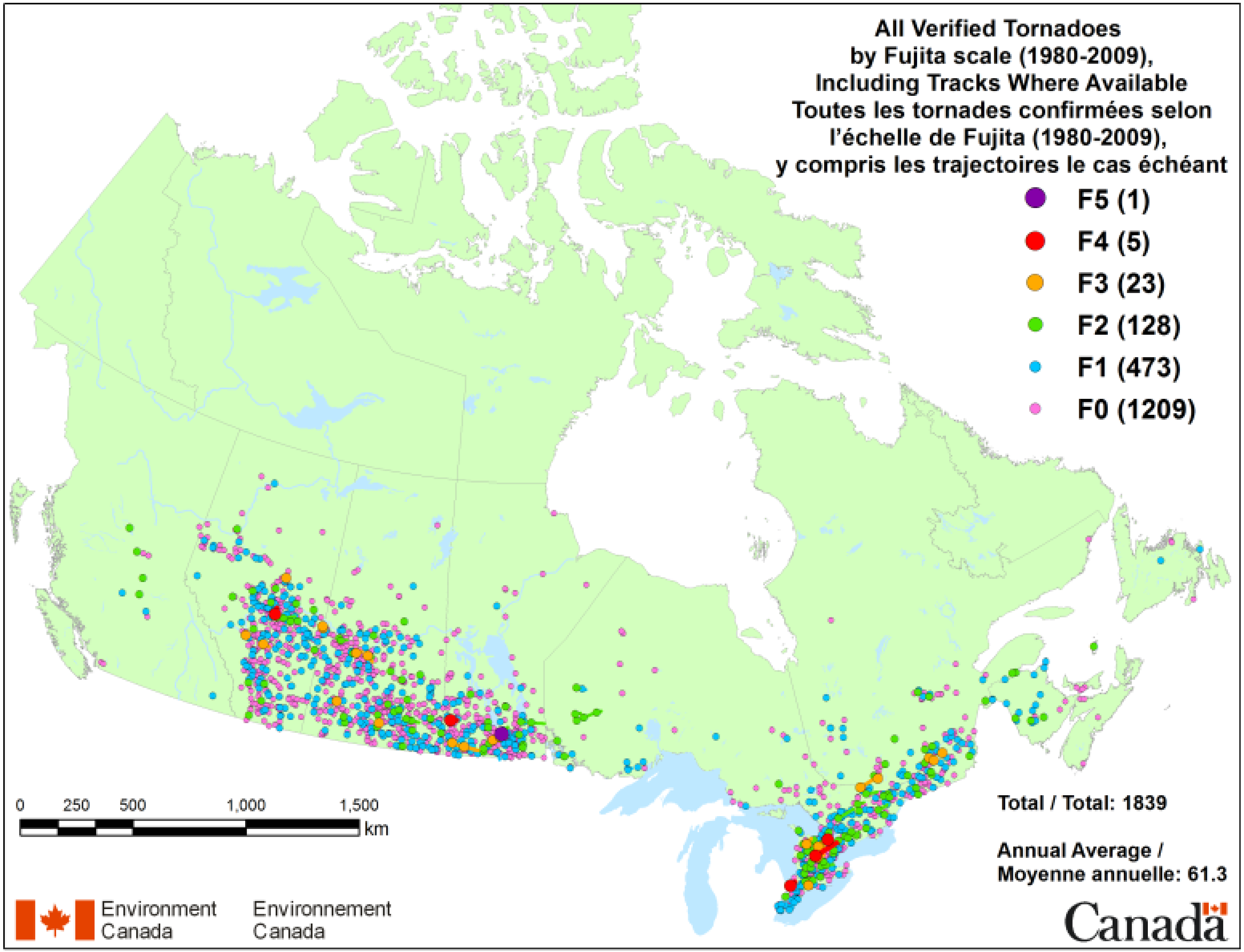
- 1987/07/31 Edmonton: 27 dead, 300 injured, and $181 million estimated cost.
- 2000/07/14 Pine Lake: 12 dead, 130 injured, and $3.4 million estimated cost.

Figure 21 Risk map of Tornado-prone regions of Canada



(Source: Environment & Climate Change Canada)

Figure 22 Map of all verified tornadoes in Canada



(Source: Environment & Climate Change Canada)

Police and Security Threats

Determining the likelihood of major disaster scenarios involving human actor(s) with malicious intent is very different from other threats/hazards (i.e. weather events). When quantitative data is not available (i.e. historical data, statistical studies), likelihood can instead be determined by qualitative judgments by SMEs, while considering the overall capability (technical feasibility) of the malicious actor(s) carrying out the threat. In this type of likelihood analysis, aspects of risk are considered using descriptive scales (i.e. level of knowledge and access to target).

For many of the scenarios assessed in the DRA, a disaster of city-wide magnitude has not yet occurred in Calgary. This qualitative assessment of likelihood was drawn from the Federal All-Hazards Risk-Assessment approach to disaster risk assessment. The threats developed for the DRA are realistic, worst-case scenarios with city-wide impact. **They are hypothetical and are not based on any specific intelligence.**

Likelihood scoring for Police and Security Threats

Estimating the likelihood of malicious scenarios is considerably different than for other hazards or threats as these estimates must take into account the determined and adaptive nature of an intelligent adversary. Such an adversary will make a choice to carry out an attack based on considerations such as whether mounting an attack is technically feasible, an individual's or organization's intent to carry out an attack, or whether they have the means to carry it out.

The current approach developed by Public Safety Canada (*All Hazards Risk Assessment Methodology Guidelines 2012*, 2013) and utilized for this assessment relies on judgment from domain experts to assess various components of the *technical feasibility* of a malicious attack scenario. In this approach, **an assessment of the technical feasibility of mounting an attack is used as a proxy for an assessment of likelihood.**

While it may be relatively easy for subject matter experts to estimate an expected recurrence interval, frequency, and probability of certain natural hazard events for a specific location based on the historical record and other observable data; for malicious scenarios, this can be quite challenging as likelihood is relative to potential. As recommended by Public Safety Canada, the overall feasibility score for a scenario is based on the principle of the *weakest link*, meaning that the final rating is determined by selecting the lowest component rating, across all components. A successful adversarial attack cannot occur if one of the elements is absent, lacking, or unobtainable; in other words, an attack is assessed as unlikely if the level for one element of the overall capability of the malicious actor(s) is below a necessary level.

Figure 23 Likelihood Scoring Matrix for Police and Security Threats

Likelihood	**Material**	**Equipment**	**Access to Target or System**	**Technical Expertise**	**Knowledge**
Extremely rare	Extremely difficult to produce or acquire	Custom designed	Almost impossible	Requires controlled advanced specialized technical training	Almost impossible to access required information (e.g., highly classified government information)
Very Rare	Material very difficult to produce or acquire	Manufactured equipment	Extremely difficult	Requires advanced specialized technical training	Extremely difficult to access required information (e.g., closely held military information)
Rare	Material difficult to produce (e.g., synthesis of 9 or more steps or tissue culture)	Some specialized equipment	Very difficult	Requires advanced technical training	Very difficult to access required information (e.g., protected or restricted access to information)
Unlikely	Material easily produced	Standard laboratory and dissemination equipment	Difficult	Requires some advanced technical training	Difficult to access required information (e.g., specialized scientific literature or declassified military documents)
Likely	Material readily available (e.g., commercially available product or frequently occurring in nature)	No specialized equipment need, purchased outside the household (i.e., Home Depot)	Accessible	Requires minimal technical training	Required information easily accessible (e.g., standard published literature)
Almost Certain	Material uncontrolled, commercially available	Derived from household products or no equipment needed	Very accessible	Requires no technical training	Required information readily available

Police and Security Threats – Risk Profiles

Major Mass Casualty Attack

The planning scenario utilized to assess the risk of a mass casualty event included large gatherings at events and threats to critical infrastructure.

Lead Agency: Calgary Police Service
Expected Duration: hours to days
High-risk Time: weekday during business hours or during major events
High-risk Areas: highly-populated areas or facilities

Expected consequences: a large number of deaths and serious injuries; significant property damage and cascading downstream impacts to critical infrastructure; building collapse; business closures and a disruption to services; and lasting psychosocial and emotional trauma.

Control measures: emergency response plans, security contingencies, security equipment (x-rays, alarms, etc.), tactical resources, security protocols, automatic lockdown procedures, SOPs, mutual aid agreements, operational protocols, intelligence gathering techniques, established partnerships (provincially, federally, and internationally), mutual aid agreements, community partnerships/programs, internal/external operational planning, table top exercises, and extensive training programs.

Major Hostage Incident

The planning scenario utilized to assess the risk of a major hostage incident was an assailant entering a building and holding multiple people hostage.

Lead Agency: Calgary Police Service
Expected Duration: hours to days
High-risk Time: weekdays during business hours
High-risk Areas: highly-populated areas or facilities

Expected consequences: multiple deaths and serious injuries (including psychosocial harm); property damage and business interruptions; road closures and traffic rerouting; security lockdowns; and localized evacuations.

Control measures: emergency response plans, security contingencies, tactical resources, exercises, mutual aid agreements, extensive training programs, and planning with external partner agencies.

Appendix 1 Summary of all assessed risks in Calgary

Risk Level	Hazard or Threat
High	Catastrophic Riverine Flooding Bow River (> =1:100)
High	Catastrophic Riverine Flooding Elbow River (> =1:100)
High	Extreme Cold
High	Major Critical Infrastructure Failure or Disruption
High	Major Dam Breach - Bow River
High	Major Hostage Incident
High	Major Hydrological Drought
High	Major Mass Casualty Attack
High	Major Rail Incident
High	Severe Storm – Blizzard
High	Severe Storm - Heavy Rain
High	Severe Storm - Winter Storms
High	Tornado
Medium	Extreme Heat
Medium	Extreme Solar Storm (Carrington-level event)
Medium	Loss of major transportation corridor
Medium	Major Active shooter incident
Medium	Major Basement Seepage Flooding
Medium	Major Bomb Threat incident
Medium	Major Bridge Failure/Interruption
Medium	Major Civil Disobedience
Medium	Major Cyber Attack - Technology as Instrument
Medium	Major Electric Power Blackout
Medium	Major Hazmat Incident
Medium	Major Incident of Data Fraud/Theft
Medium	Major Industrial Accident
Medium	Major Mass Gathering Incident
Medium	Major Riot
Medium	Major Road Accident
Medium	Major Sanitary Forcemain Failure (Lift Station)
Medium	Major Security Incident at City Facility
Medium	Major Solar Storm (Quebec-level event)
Medium	Major Stormwater Backup Flooding
Medium	Major Structure Fire
Medium	Major Supply Chain Interruption
Medium	Major Telecommunications failure
Medium	Major Transit Rail Incident
Medium	Major Water Contamination - Distribution system
Medium	Major Water Contamination - Widespread Forest Fires
Medium	Major Wildland / Urban Interface Fire
Medium	Poor Air Quality
Medium	Severe Storm – Hail
Medium	Severe Storm – Lightning
Medium	Severe Storm - Thunderstorms
Medium	Severe Storms – Wind
Medium	Water Distribution Infrastructure Failure
Medium	Severe Pandemic (CPIP scenario)
Low	Flooding Ice Jam
Low	Major Aircraft Incident
Low	Major Cyber Attack - Technology as Target
Low	Major Dam Breach - Elbow River
Low	Major Forcemain Failure (purple pipe)
Low	Major Forcemain Failure (sludge)
Low	Major Freezing Precipitation
Low	Major Gas Main Break
Low	Major Labour Action
Low	Major Pipeline Incident along AER regulated lines
Low	Major Pipeline incident along the TNPL to Calgary Airport
Low	Major Sanitary Failure Next to a Water Body
Low	Major Water Contamination - Watershed Spills
Low	Major Water Shortage
Low	Moderate Earthquake (Magnitude 4.0+)
Low	Moderate Pandemic (CPIP scenario)
Low	Severe Fog
Very Low	Treated Effluent Pump station Failure (purple pipe)

Appendix 2 World Economic Forum Trends 2018

Trend	Description
Ageing population	Ageing populations in developed and developing countries driven by declining fertility and decrease of middle- and old-age mortality
Changing landscape of international governance	Changing landscape of global or regional institutions (e.g. UN, IMF, NATO, etc.), agreements or networks
Changing climate	Change of climate, which is attributed directly or indirectly to human activity, that alters the composition of the global atmosphere, in addition to natural climate variability
Degrading environment	Deterioration in the quality of air, soil and water from ambient concentrations of pollutants and other activities and processes
Growing middle class in emerging economies	Growing share of population reaching middle-class income levels in emerging economies
Increasing national sentiment	Increasing national sentiment among populations and political leaders affecting Countries' national and international political and economic positions
Increasing polarization of societies	Inability to reach agreement on key issues within countries because of diverging or extreme values, political or religious views
Rising chronic stresses	Increasing rates of non-communicable diseases, also known as "chronic diseases", leading to rising costs of long-term treatment and threatening recent societal gains in life expectancy and quality
Rising cyber dependency	Rise of cyber dependency due to increasing digital interconnection of people, things and organizations
Rising geographic mobility	Increasing mobility of people and things due to quicker and better-performing means of transport and lowered regulatory barriers
Rising income and wealth disparity	Increasing socioeconomic gap between rich and poor in major countries or regions
Shifting power	Shifting power from state to non-state actors and individuals, from global to regional levels, and from developed to emerging market and developing economies
Rising urbanization	Rising number of people living in urban areas resulting in physical growth of cities

Notes

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[i] Making Development Sustainable: The Future of Disaster Risk Management. Global Assessment Report on Disaster Risk Reduction. United Nations Office for Disaster Risk Reduction (UNISDR), 2015.
[ii] Natural Catastrophes: A Canadian Economic Perspective. TD Bank, 2014.
[iii] Natural catastrophes and man-made disasters in 2017: a year of record-breaking losses. Sigma Report. Swiss Re Institute, 2018.
[iv] Ibid.
[v] Estimate of the Average Annual Cost for Disaster Financial Assistance Arrangements due to Weather Events. Government of Canada. Office of the Parliamentary Budget Officer, 2016.
[vi] Ibid.
[vii] 2018 Facts of the Property and Casualty Insurance Industry in Canada. Insurance Bureau of Canada, 2018.
[viii] These numbers are an estimate of the aggregated total disaster losses over this period. They reference data provided by the City of Calgary, Government of Alberta, and Insurance Bureau of Canada (IBC).
[ix] Ibid.
[x] The City of Calgary internal financial records, 2018.
[xi] Making Development Sustainable: The Future of Disaster Risk Management. Global Assessment Report on Disaster Risk Reduction. United Nations Office for Disaster Risk Reduction (UNISDR), 2015.
[xii] World Urbanization Prospects: The 2018 Revision. United Nations, 2018.
[xiii] Statistics Canada, 2016.
[xiv] Lloyd's City Risk Index 2015-2025. Lloyd's, 2015.
[xv] The City of Calgary, Corporate Economics, 2014.
[xvi] Disaster Risk and Age Index. HelpAge International, 2015.
[xvii] Ibid.
[xviii] Global Risks Report 2018. World Economic Forum, 2018.
[xix] Ibid.
[xx] Ibid.
[xxi] Ibid.
[xxii] The Future of Employment: How Susceptible are Jobs to Computerisation. The Oxford Martin School, University of Oxford, 2013.
[xxiii] November 2017 Economic Outlook Report. OECD, 2017.
[xxiv] Statistics Canada, 2017.
[xxv] Haves and Have-Nots: Deep and Persistent Wealth Inequality in Canada. Broadbent Institute, 2014.
[xxvi] Focus on Top Incomes and Taxation in OECD Countries: Was the crisis a game changer? OECD, 2014.
[xxvii] Statistics Canada, 2017.
[xxviii] Income Inequality in Canada: The Urban Gap. CPA Canada, 2017.
[xxix] Canadian Voices on Changing Flood Risk: Findings from a National Survey. The University of Waterloo, 2017.

2019 Citizen Flood Risk Research

Telephone Survey Key Findings Report

Prepared for The City of Calgary by:

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Background, Objectives, and Methodology

Background & Objectives

Background

Since the 2013 flood, it has been a priority for The City of Calgary (The City) to build resilience to flooding. A cornerstone of resilience is citizen awareness and action. To this end, The City has been conducting an annual campaign to raise awareness of flood risk every spring.

To continue to improve the effectiveness of its citizen awareness and preparedness activities, The City is seeking to understand citizens' levels of awareness, action and knowledge gaps related to flood risk and preparedness.

The research program included 21 in-depth interviews with key stakeholders (reported on separately) and a random citizen telephone survey (this report).

The results of the research program will inform the development of future citizen education activities intended to inspire action and increase flood resilience within our communities.

Objectives

The objectives of the phone survey are to:

- Measure citizens' level of understanding of their personal risk of river flooding;
- Identify what, if any, actions citizens have taken to reduce their risk of damages and increase their safety during a flood;
- Identify perceived barriers to action among citizens who have not taken any action to reduce their flood risk;
- Understand citizens' level of knowledge about how to reduce flood risk;
- Identify citizens' information needs as they relate to understanding their risk of river flooding, actions to reduce risk and how to prepare for the potential impacts of a major flood; and
- Understand how citizens would prefer to learn about flood risk and actions they can take to reduce their risk of damages and increase their safety during a flood.

Research Methodology

- Advanis conducted a telephone survey between November 25th, 2019 and December 12th, 2019 with 803 Calgarians aged 18 years or older. Both landline and cell phone sample was used.
- Average interview length was 16.5 minutes
- The sample included 401 Calgarians inside the flood zone and 402 Calgarians outside the flood zone
- The final data was weighted to ensure the overall sample's quadrant, age, and gender composition reflects that of the actual population of Calgary.
- The margin for error for Calgarians living inside the flood zone, as well as for those outside of the flood zone, is ±4.9%, 19 times out of 20.

Summary of Findings and Recommendations

Risk Perceptions

Although Calgarians who live inside the flood zone are significantly more concerned about flooding, are more likely to perceive to their flood risk to moderate or high, and feel a greater need to prepare for river flooding than those who live outside of the flood zone:

- About one-third (30%) of those living in the flood zone are not (very) concerned about flooding; and
- 22% perceive their flood risk to be low (15% in 1:100 flood zone and 45% in the 1:200 flood zone)

Mitigative Measures Taken and Barriers to Action

Each of the main flood preparedness measures are reported by less than half of Calgarians who live inside the flood zone, with those outside of the flood zone reporting several measures even less frequently.

- The exception is storing important items in a safe place, which two-thirds of those inside the flood zone reported doing.
- Even within the 1:100 flood zone, Calgarians could be more prepared to evacuate. Only about half have an evacuation plan and only about one-quarter have a grab-and-go evacuation kit.
- The main reason for not having flood preparedness measures in place is due to low perceived risk from flooding, especially outside of the flood zone and for more expensive measures. Additionally:
  - 38% of Calgarians inside the flood zone do not perceive a grab-and-go kit to be useful and 35% never thought of it.
  - One-quarter of Calgarians inside the flood zone haven’t purchased overland flood insurance because it is not available to them or because they were denied coverage.
- Among Calgarians who currently do not have an evacuation plan, a majority would be at least somewhat likely to create one if The City provided a template.
- Just over half of Calgarians who live inside the flood zone and who currently do not have a sump pump indicate that they would be likely to install one if The City provided simple instructions. Of those not at all likely, very few would install a sump pump even if The City subsidized the cost.

Flood Support

The City of Calgary website is the best-known flood preparedness resource and the most preferred channel of communication for additional flood information.

- The City of Calgary is also the most trusted source of reliable information about the risks of potential river flooding and how to prepare for potential river flooding, followed closely by not-for-profit organizations.
  - Of note, citizens in the 1:100 flood zone have a substantially lower level of trust in The City, not-for-profit organizations, and the provincial government compared to those outside the 1:100 flood zone.
- Most Calgarians who lived in Calgary in 2013 could not think of any information that would have helped them before, during, or after the Flood.
- Although The City of Calgary website is the most preferred channel of communication for additional flood information, Calgarians prefer a wide range of communication channels that also include online videos or tutorials, regular mail, and email newsletters.

Social Resiliency and Mental Health Support

Calgarians report high levels of community support, both inside and outside the flood zone.

- The vast majority of Calgarians have people to support them in case of an emergency and would be willing to offer help to others.
- For those inside the flood zone, family doctors have the highest level of awareness as a mental health resource, followed by helplines and a psychologist or therapist. For those outside the flood zone, family doctors, helplines, and hospitals have similar levels of awareness.

Recommendations

1. Continue to raise awareness of potential flood risk, especially in the 1:200 flood zone, where the perceived flood risk is substantially lower compared to the 1:100 flood zone.
2. Provide templates and simple instructions to residents for developing an evacuation plan, putting together a grab-and-go kit, and installing a sump pump. Making these measures easy to implement will overcome a major barrier for many Calgarians.
3. Continue to provide information, including online videos and tutorials, on the City of Calgary website and use a wide variety of communication methods to direct people to those materials.
4. In light of high levels of community support, combined with relatively lower levels of trust in The City of Calgary, the provincial government, not-for-profits, and academic institutions in the 1:100 flood zone, engage with residents at a community-level, including working with local businesses and community organizations, to increase flood preparedness.

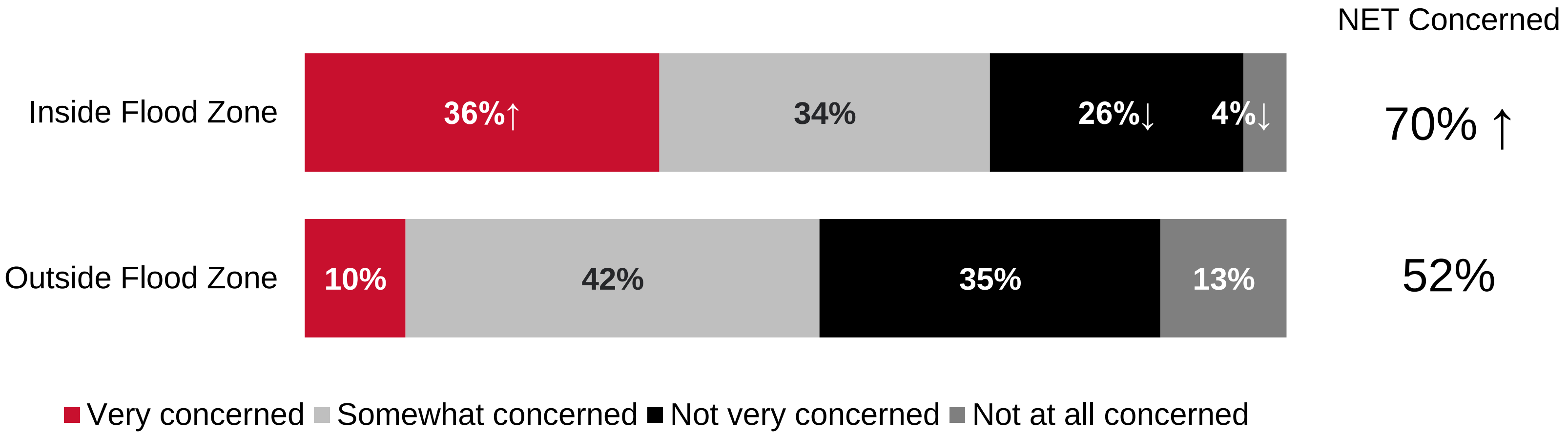
Detailed Findings:

Risk Perceptions

Concern about River Flooding

Unsurprisingly, Calgarians who live inside the flood zone are significantly more concerned about flooding than those who live outside of the flood zone.

- That said, about one-third (30%) of those living in the flood zone are not (very) concerned about flooding.



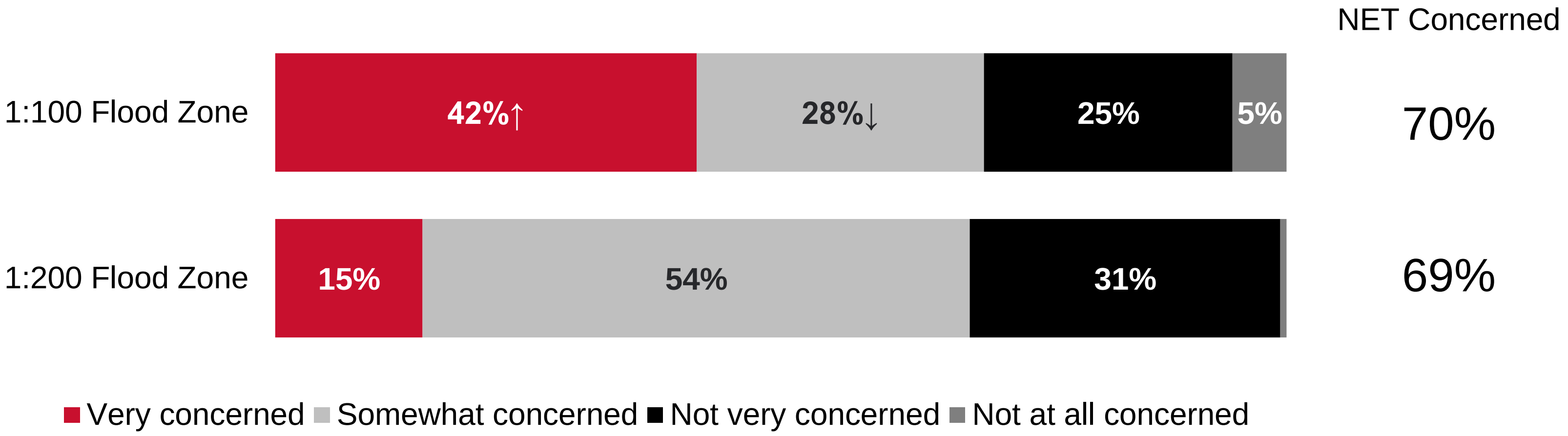
Base: All respondents (excluding Don’t know) (Inside Flood Zone n=398; Outside Flood Zone n=402)
A1. Overall, how concerned are you about river flooding in Calgary? Would you say you are …

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Concern about River Flooding

A higher proportion of those who live in the 1:100 flood zone are *very concerned* about river flooding in Calgary.

- Though again, even among those in the 1:100 flood zone, about one-third (30%) are not (very) concerned about flooding.

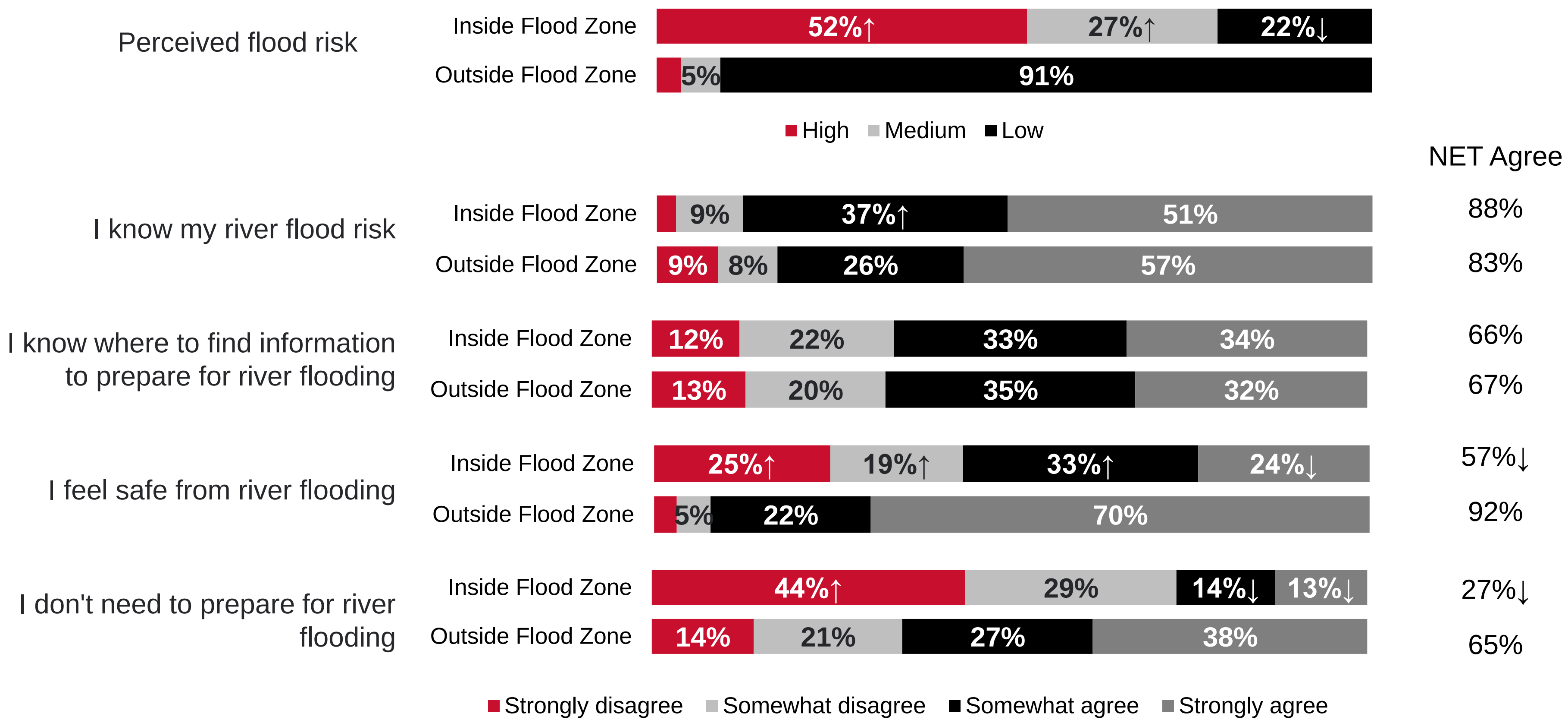


Base: All respondents (excluding Don't know) (1:100 n=297; 1:200 n=101)
A1. Overall, how concerned are you about river flooding in Calgary? Would you say you are …

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Perceptions Regarding Flood Risk and Preparedness

The vast majority (91%) of those living outside of the flood zone perceive their flood risk to be low while those living inside the flood zone feel more at risk and are less likely to agree that they don't need to prepare for river flooding.



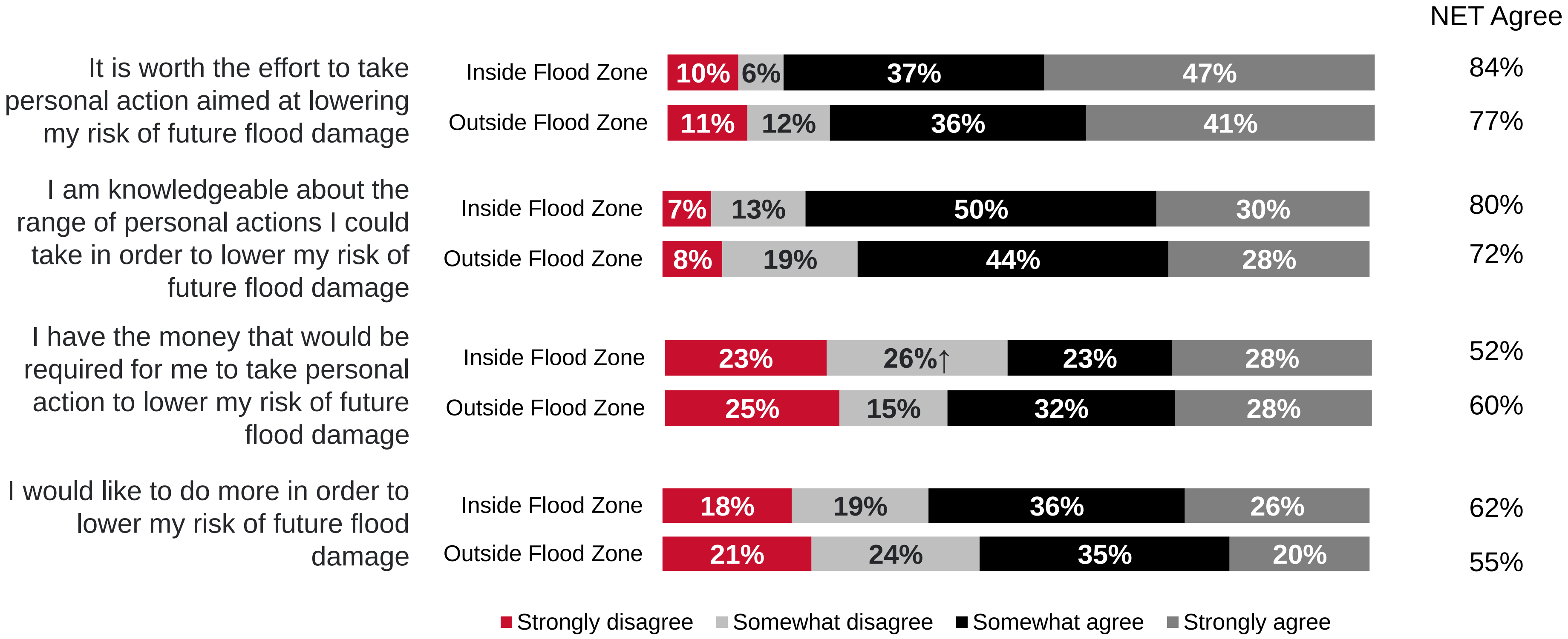
Base: All respondents (excluding None/Don't know) (Inside Flood Zone n=399; Outside Flood Zone n=401)
A2. Thinking about where you live today, would you say your risk for potential river flooding is high, medium, or low?
Base: All respondents (excluding Don't know) (Inside Flood Zone n=394-399; Outside Flood Zone n=396-401)
A3. For each of the following statements, please let me know if you strongly agree, somewhat agree, somewhat disagree, or strongly disagree.

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Perceptions Regarding Flood Risk and Preparedness

Most Calgarians, both inside and outside of the flood zone, agree that efforts to lower their risk of future flood damage are worthwhile and that they have the knowledge to do so.

Just over half would like to do more to lower their risk, though financial supports may be needed; just less than half feel they do not have the money to do so.



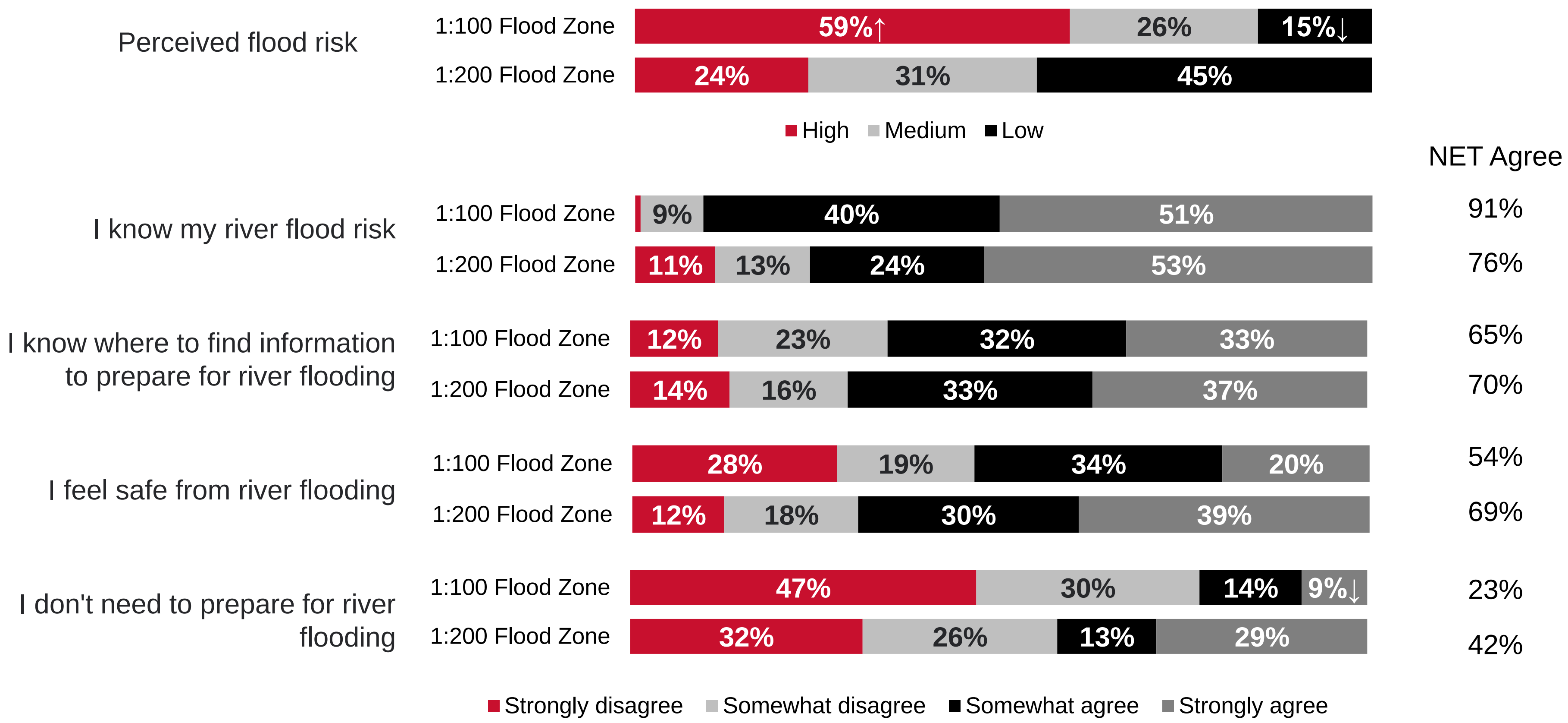
Base: All respondents (excluding Don't know) (Inside Flood Zone n=351-385; Outside Flood Zone n=377-389)
B6. For each of the following statements, please let me know if you strongly agree, somewhat agree, somewhat disagree, or strongly disagree.

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

1:100 vs. 1:200 (Inside Flood Zone)

Perceptions Regarding Flood Risk and Preparedness

Awareness-raising is particularly needed in the 1:200 flood zone, where the perceived flood risk is substantially lower compared to the 1:100 flood zone.



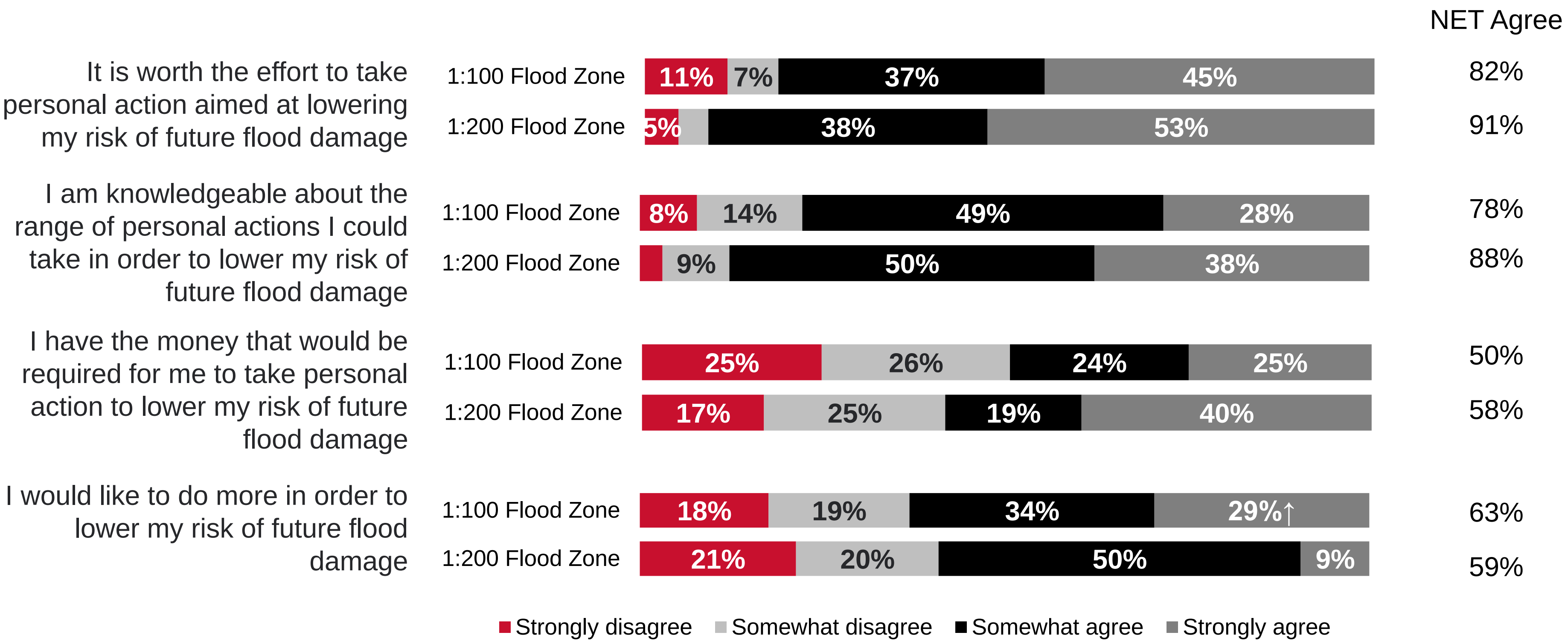
Base: All respondents (excluding None/Don't know) (1:100 n=299; 1:200 n=100)
A2. Thinking about where you live today, would you say your risk for potential river flooding is high, medium, or low?
Base: All respondents (excluding Don't know) (1:100 n=296-299; 1:200 n=98-100)
A3. For each of the following statements, please let me know if you strongly agree, somewhat agree, somewhat disagree, or strongly disagree.

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Perceptions Regarding Flood Risk and Preparedness

1:100 vs. 1:200 (Inside Flood Zone)

Perceptions of flood risk preparedness are very similar for those living in the 1:100 and 1:200 flood zones.



Base: All respondents (excluding Don't know) (1:100 n=259-289; 1:200 n=89-96)
B6. For each of the following statements, please let me know if you strongly agree, somewhat agree, somewhat disagree, or strongly disagree.

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

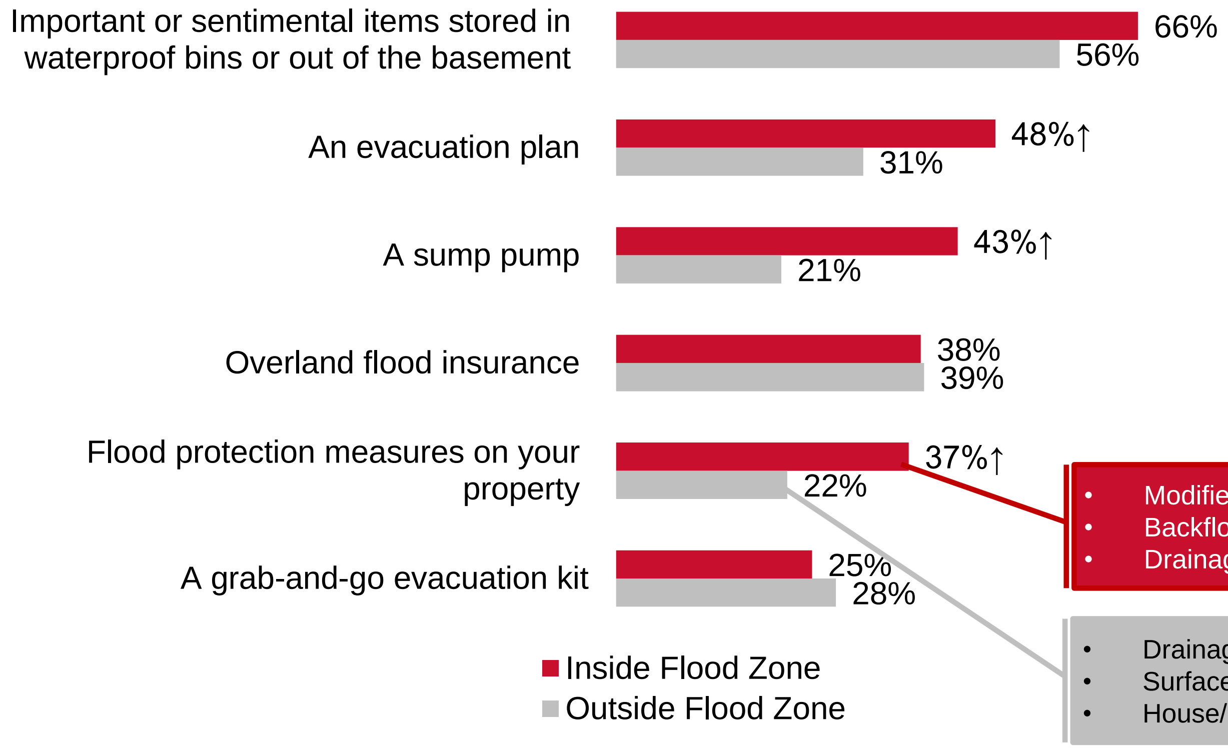
Detailed Findings:

Mitigative Measures Taken and Barriers to Action

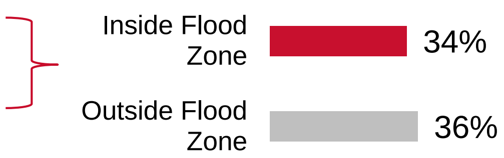
Flood Preparedness

With the exception of storing important items in a safe place, each of the main flood preparedness measures are reported by less than half of Calgarians who live inside the flood zone, with those outside of the flood zone reporting several measures even less frequently.

Have … (% Yes)



Have battery backup



Top 3 measures

- Modified/rebuilt house to withstand flooding: 33%
- Backflow valve/backflow preventer/one-way valve: 23%
- Drainage system installed on property: 21%

- Drainage system installed on property: 30%
- Surface grading/sloping/landscaping: 20%
- House/property is constructed above flood level: 17%

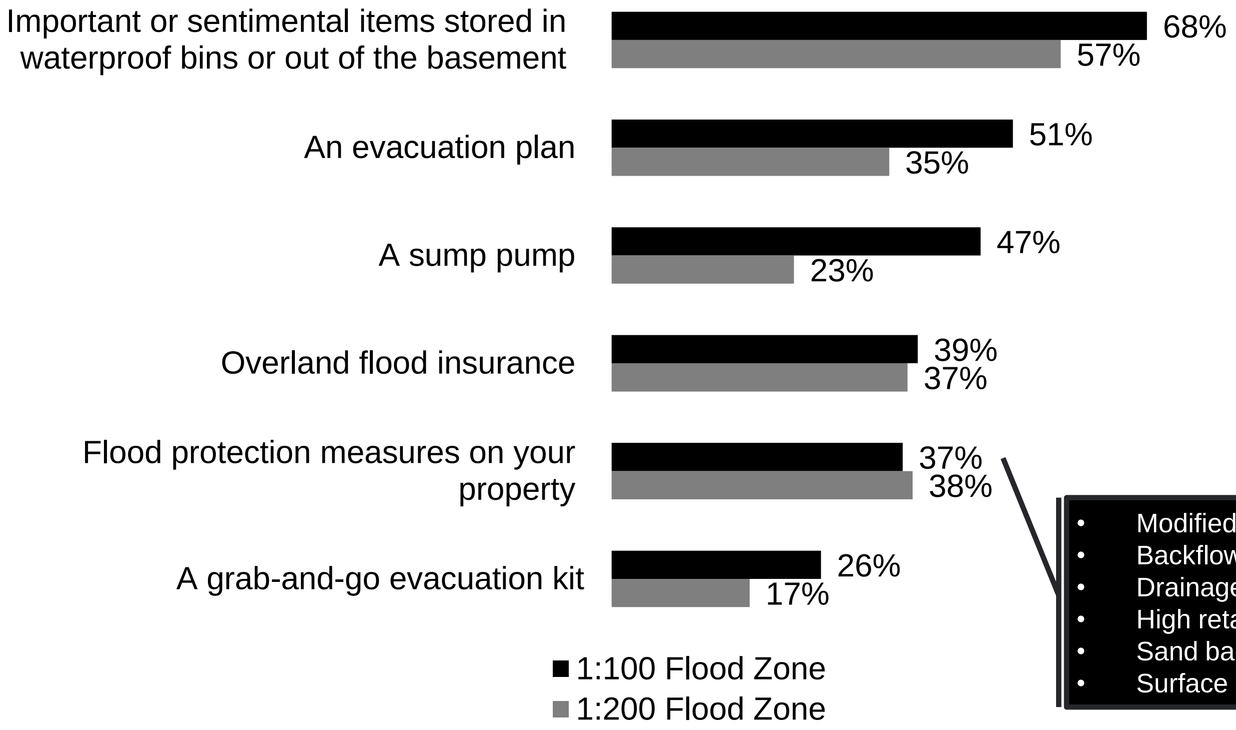
Base: All respondents (excluding Don't know/Not Applicable) (Inside Flood Zone n=307-389; Outside Flood Zone n=306-400)
B1. In preparation for river or basement flooding, do you have …
Base: Have a sump pump (excluding Don't know) (Inside Flood Zone n=138; Outside Flood Zone n=66)
B1b. Do you have a battery backup power source for your sump pump?
B1a. What flood protection measures on your property do you have? (Inside Flood Zone n=135; Outside Flood Zone n=61)

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

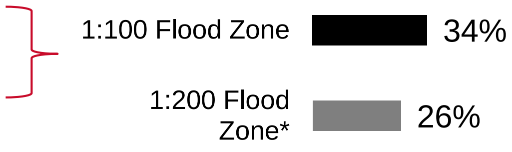
Flood Preparedness

Even within the 1:100 flood zone, Calgarians could be more prepared to evacuate. Only about half have an evacuation plan and only about one-quarter have a grab-and-go evacuation kit.

Have … (% Yes)



Have battery backup



Top measures

- Modified/rebuilt house to withstand flooding: 33%
- Backflow valve/backflow preventer/one-way valve: 23%
- Drainage system installed on property: 21%
- High retaining wall: 13%
- Sand bags/flood sacks: 13%
- Surface grading/sloping/landscaping: 13%

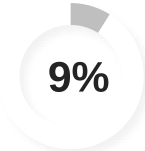
Base: All respondents (excluding Don’t know/Not Applicable (1:100 n=240-293; 1:200 n=67-96)
B1. In preparation for river or basement flooding, do you have …
Base: Have a sump pump (excluding Don’t know) (1:100 n=117; 1:200 n=21*)
B1b. Do you have a battery backup power source for your sump pump?
B1a. What flood protection measures on your property do you have? (Inside Flood Zone n=135)

* Base <30, interpret with caution
↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Other Actions Taken to Prepare for Flooding

The most common other actions taken by those inside the flood zone are no longer storing items in the basement and having modified or renovated the basement.

Took other actions



Took other actions

Top 10 Actions Taken – Inside Flood Zone	
No longer store items in basement	22%
Modified/renovated basement (e.g., changed pipes in basement, etc.)	17%
Generator	13%
Training/awareness of what to do/plan of action	12%
Free-standing pump/sump pump	12%
Backup valve/backflow preventer/one-way valve	9%
Moved to another location / planning to move	9%
Items in basement are stored in plastic tubs/raised on stilts/better organization of basement	7%
Appliances, furnace raised off the floor	6%
Attend city/community meetings about flood preparedness	4%

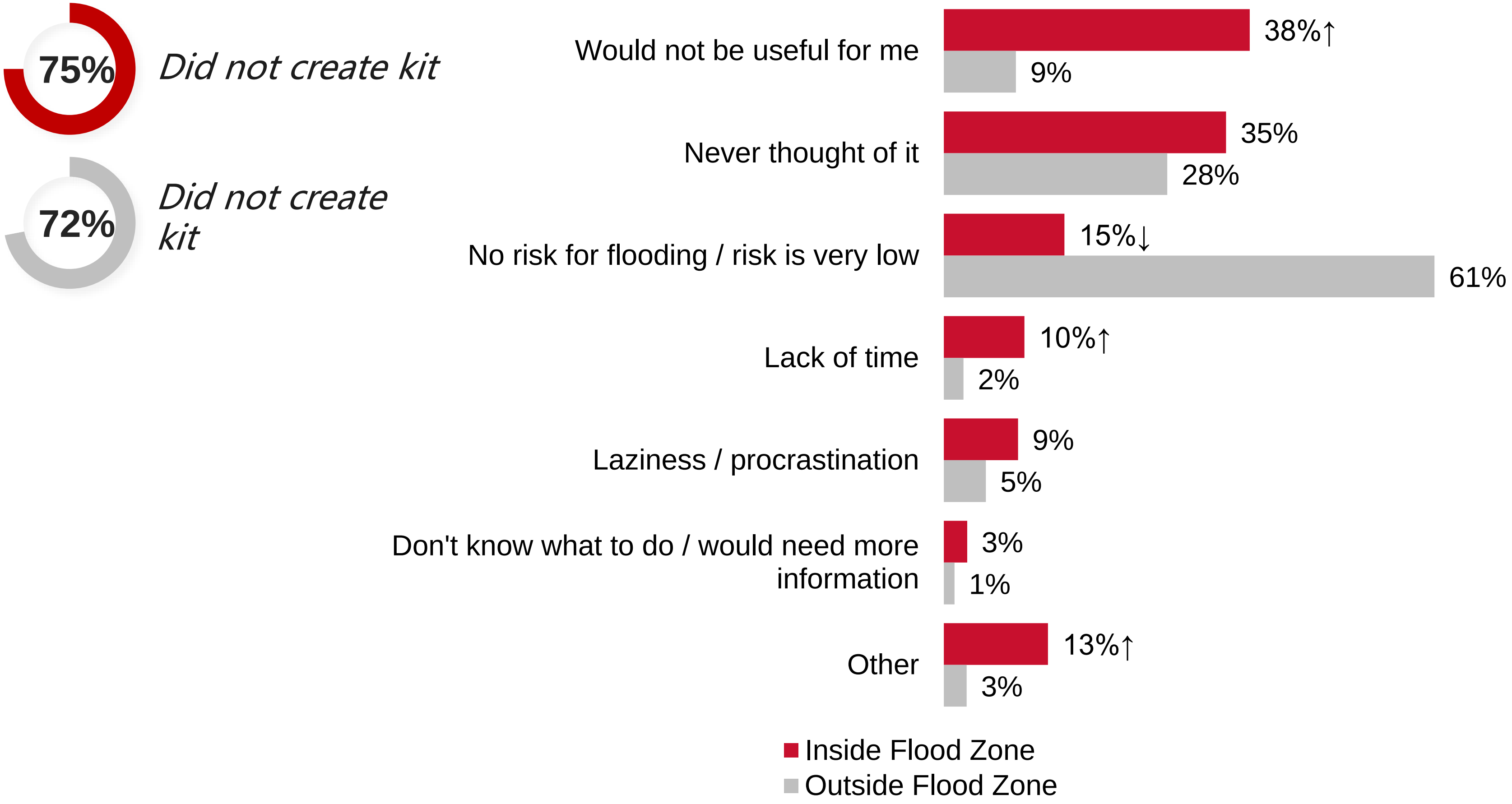
Top 10 Actions Taken – Outside Flood Zone	
Items in basement are stored in plastic tubs/raised on stilts/better organization of basement	18%
Modified/renovated basement (e.g., changed pipes in basement, etc.)	16%
Monitors/alarms (for water leakage, presence of water in basement, etc.)	14%
Backup valve/backflow preventer/one-way valve	11%
Training/awareness of what to do/plan of action	9%
Have a boat	6%
No longer store items in basement	5%
Moved to another location / planning to move	5%
Did waterproofing outside	5%
Free-standing pump/sump pump	5%

Base: All respondents (excluding Don't know) (Inside Flood Zone n=398; Outside Flood Zone n=399)
B2. Have you taken any other actions to prepare for potential river or basement flooding?
Base: Took action (excluding Don't know) (Inside Flood Zone n=108; Outside Flood Zone n=40)

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Reasons for Not Creating a Grab-and-Go Kit

Most Calgarians inside the flood zone have not created a grab-and-go kit because they don’t feel it would be useful or they hadn’t thought of it while most of those outside of the flood zone haven’t created one because they perceive their flood risk is low.

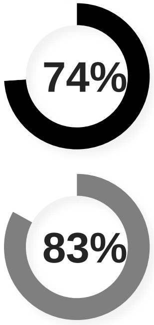


↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Base: Do not have a grab and go kit (excluding Don’t know/Not Applicable) (Inside Flood Zone n=262; Outside Flood Zone n=282)
B4a. Would you be able to tell me your reasons for not creating a grab-and-go evacuation kit?

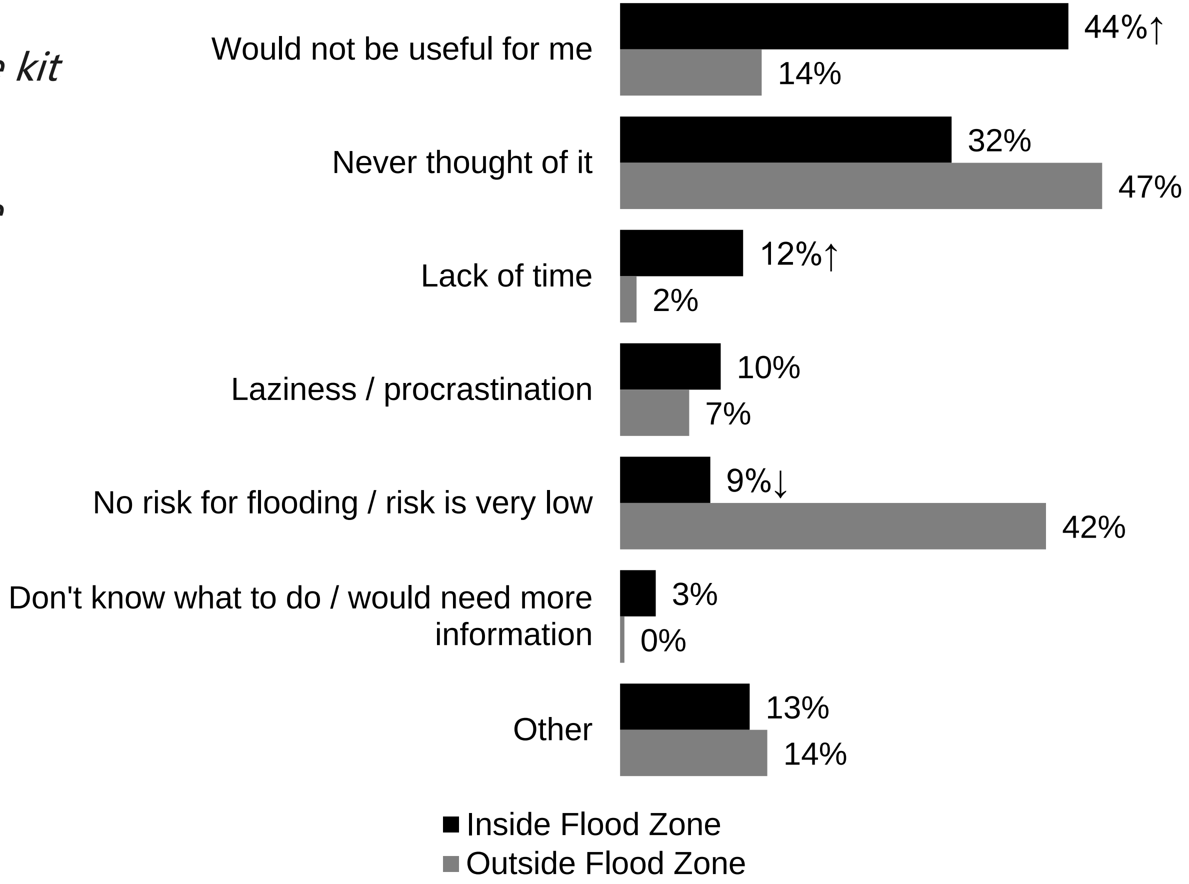
Reasons for Not Creating a Grab-and-Go Kit

In particular in the 1:100 zone, Calgarians indicate that a grab-and-go kit would not be useful for them or that they hadn't thought of it. In the 1:200 flood zone, never having thought of it or perceived flood risk being low are the main reasons for not having created a grab-and-go kit.



Did not create kit

Did not create kit



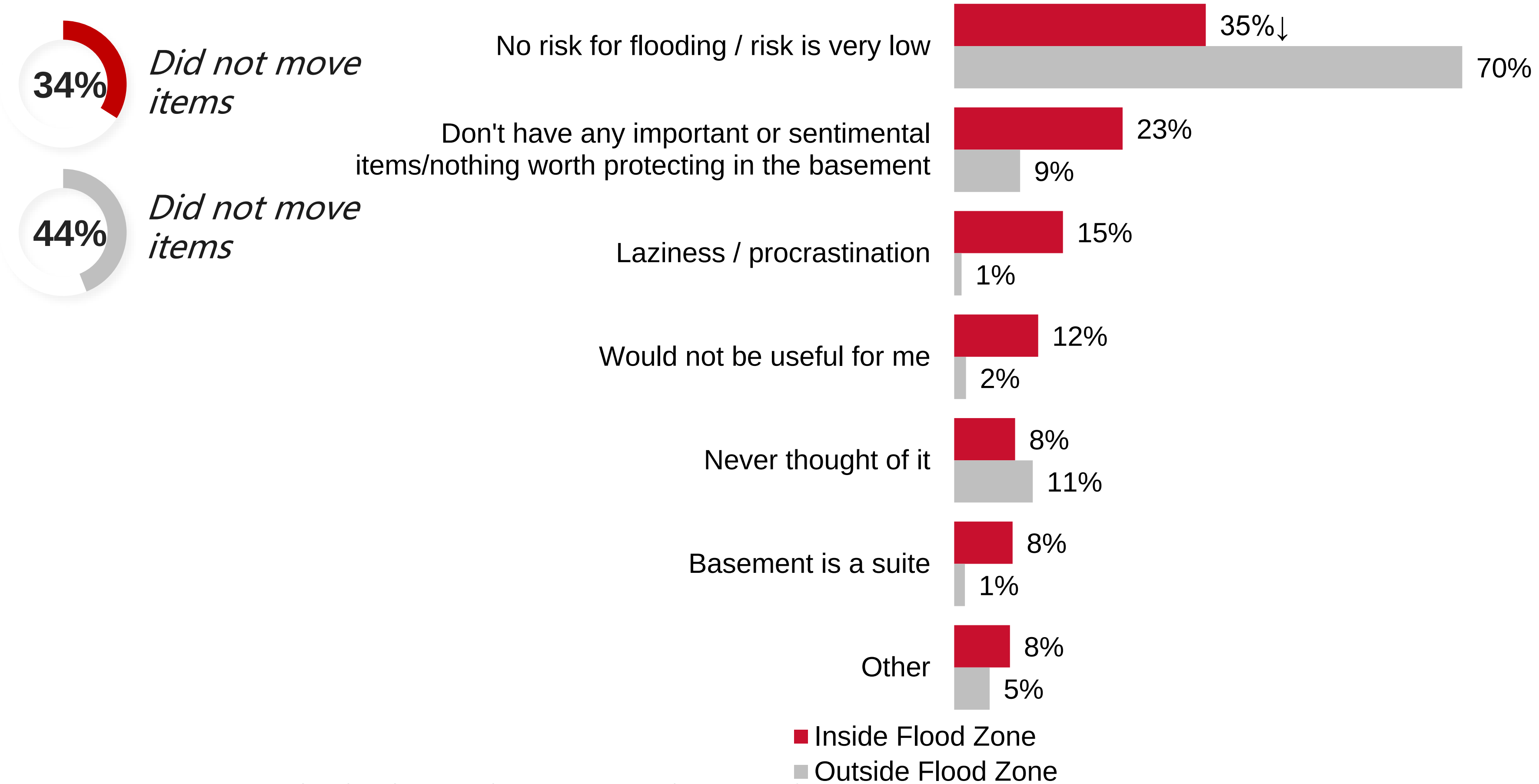
↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Base: Do not have a grab and go kit (excluding Don't know/Not Applicable) (1:100 n=191; 1:200 n=71)
B4a. Would you be able to tell me your reasons for not creating a grab-and-go evacuation kit?

Inside vs. Outside Flood Zone

Reasons for Not Moving Items into Waterproof Bins / out of the Basement

Having a low risk of flooding is the most common reason for not having moved items into waterproof bins or out of the basement, more so for those outside the flood zone. Almost one-quarter of those inside the flood zone feel they don't have items in the basements that are worth protecting.

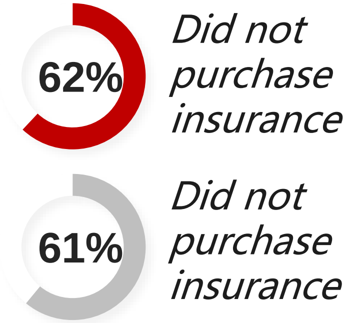


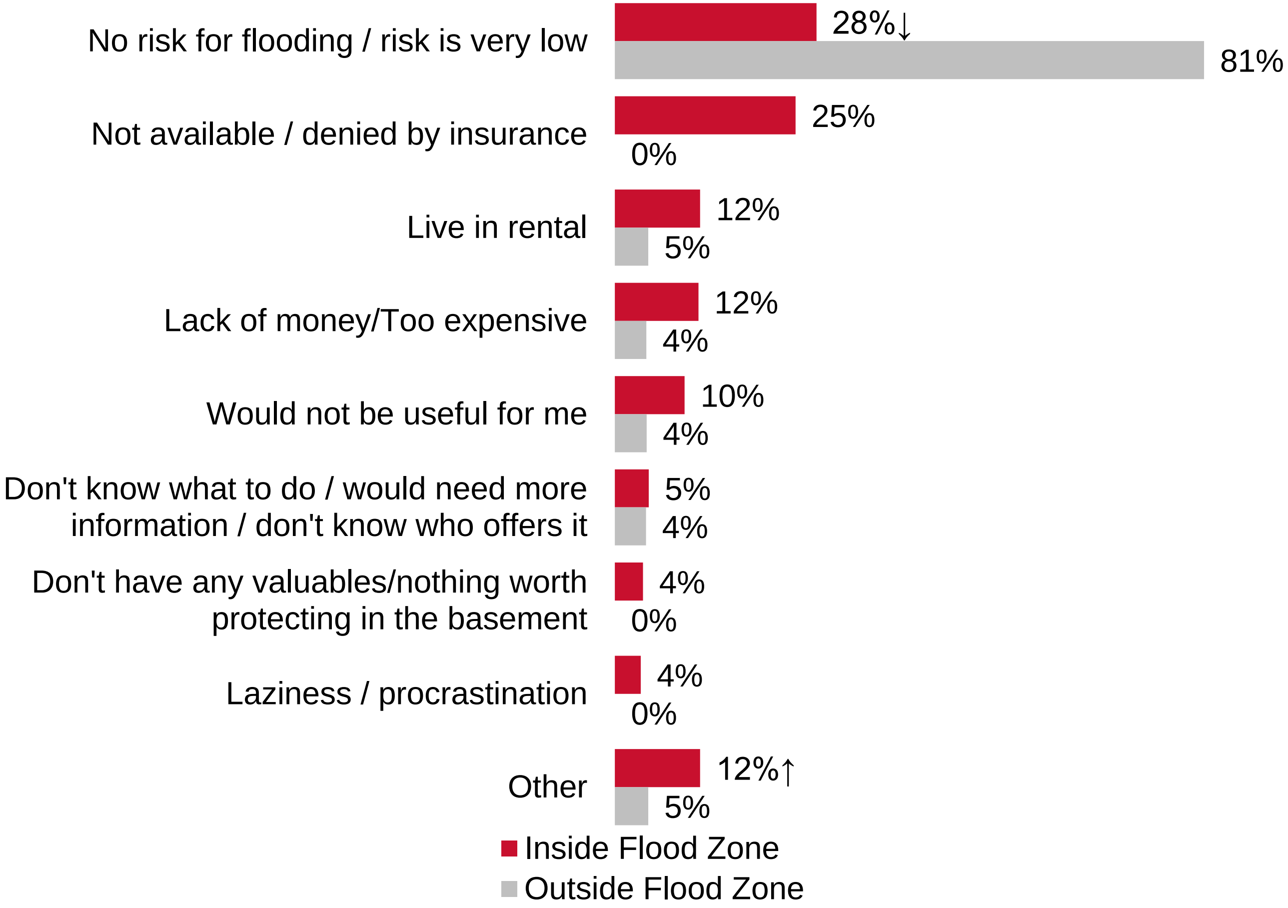
Base: Did not move items into waterproof bins/out of basement (excluding Don't know/Not Applicable) (Inside Flood Zone n=97; Outside Flood Zone n=174)
B4b. And would you be able to tell me your reasons for not moving important or sentimental items into waterproof bins or out of the basement?

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Reasons for Not Purchasing Overland Flood Insurance

About one-quarter of Calgarians inside the flood zone haven't purchased overland flood insurance because they perceive their flood risk to be low, while another quarter indicate that it is not available to them / that they were denied coverage.



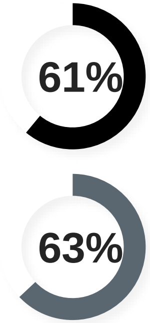


Base: Do not have overland flood insurance (excluding Don't know/Not Applicable) (Inside Flood Zone n=159; Outside Flood Zone n=185)
B4c. And would you be able to tell me your reasons for not purchasing overland flood insurance?

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

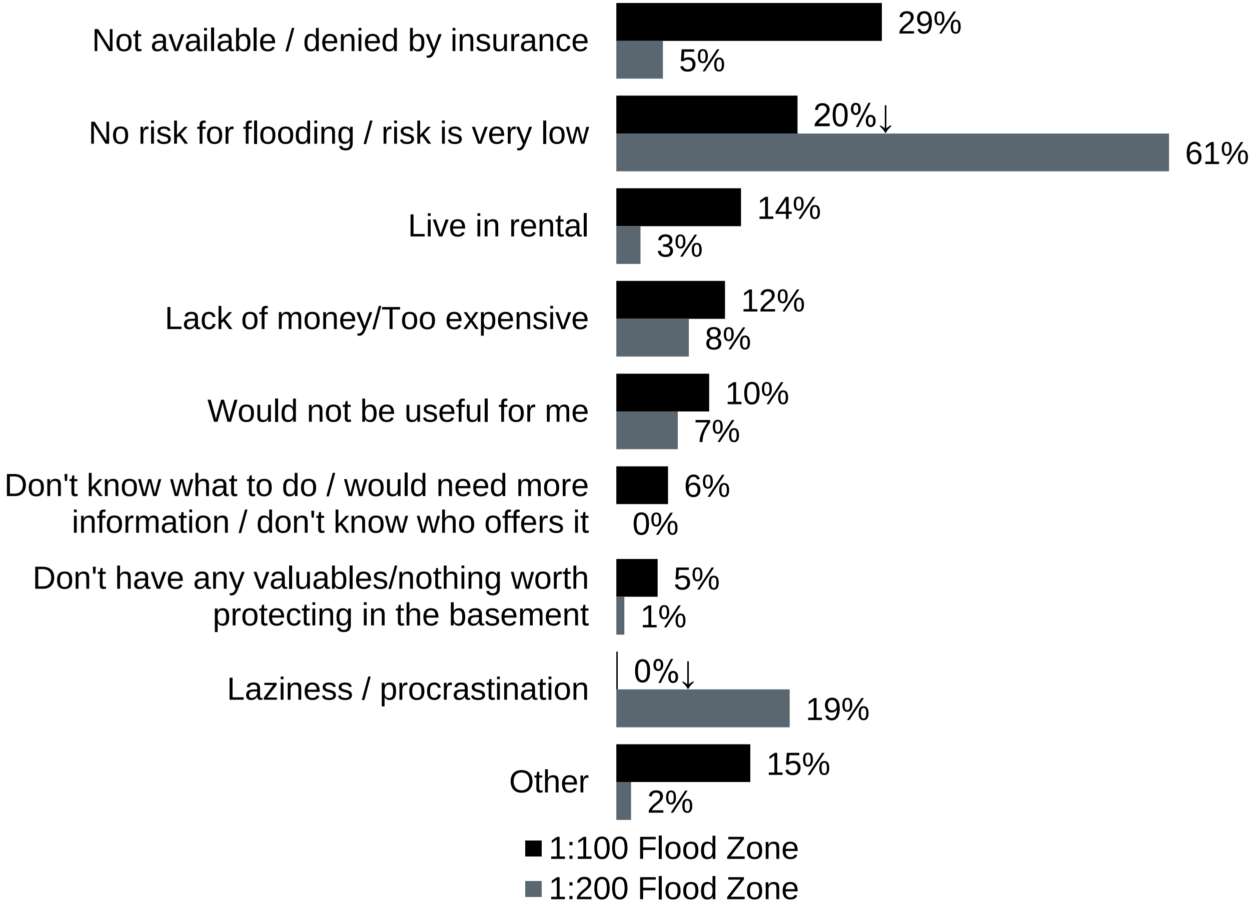
Reasons for Not Purchasing Overland Flood Insurance

In the 1:100 flood zone, 29% of residents indicate that overland flood insurance isn't available for them or that they were denied coverage. In the 1:200 flood zone, the majority haven't purchased insurance because they perceive their flood risk to be low.



Did not purchase insurance

Did not purchase insurance

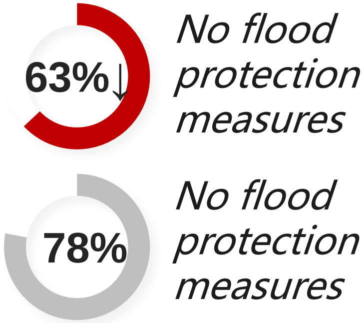


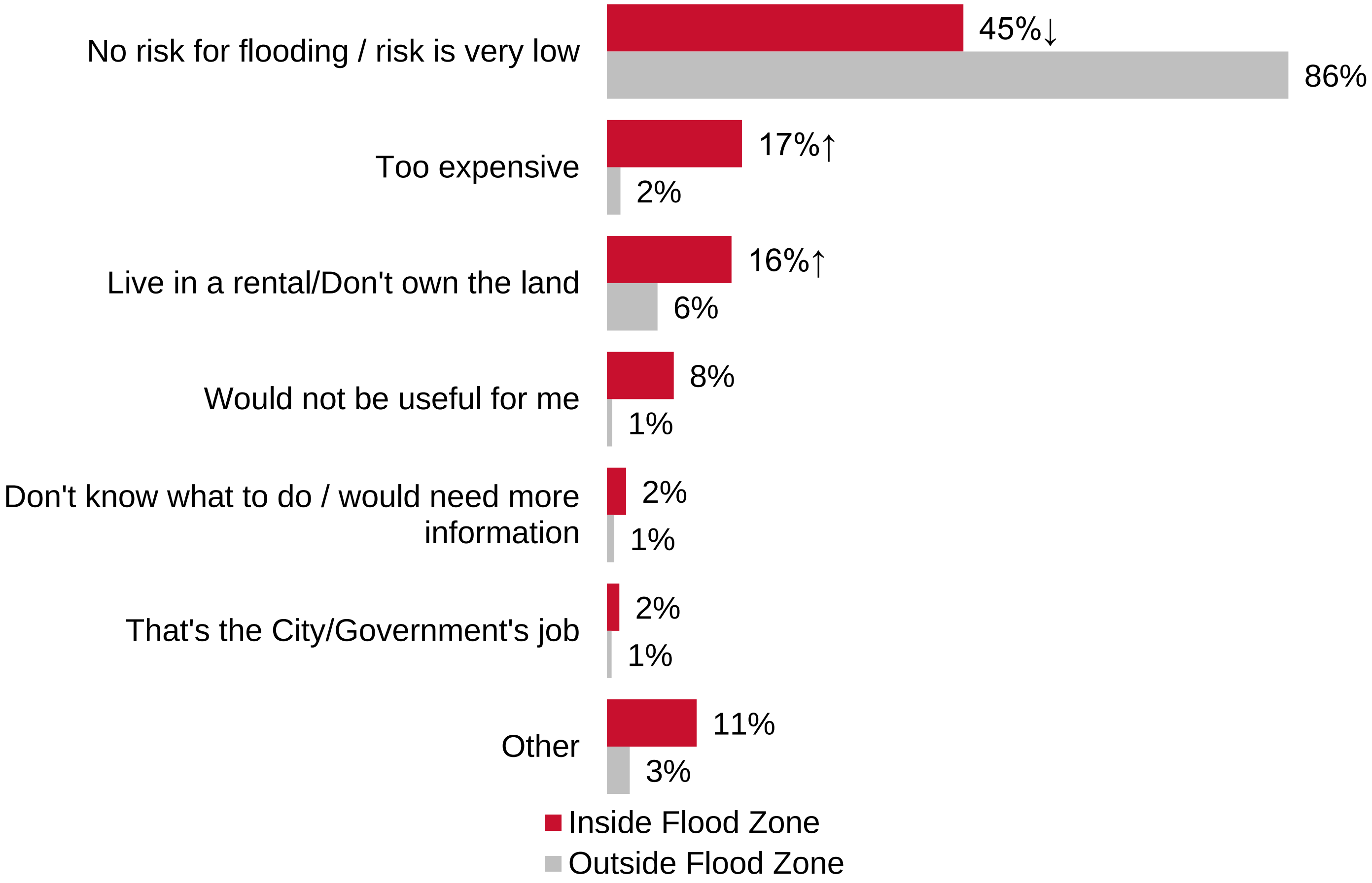
↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Base: Do not have overland flood insurance (excluding Don't know/Not Applicable) (1:100 n=124; 1:200 n=35)
B4c. And would you be able to tell me your reasons for not purchasing overland flood insurance?

Reasons for Not Making Alterations to Property or Purchasing Equipment

The most common reason for not having made alterations or purchased equipment, bit inside and outside of the flood zone, is a perceived low risk of flooding. 1 in 6 residents inside the flood zone mention these measures being too expensive.





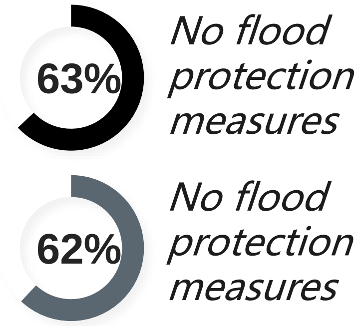
Base: Did not make alterations to property (excluding Don't know/Not Applicable) (Inside Flood Zone n=-191; Outside Flood Zone n=285)
B4d. And would you be able to tell me your reasons for not making alterations to your property or purchasing equipment that you can set up to protect your property from flooding?

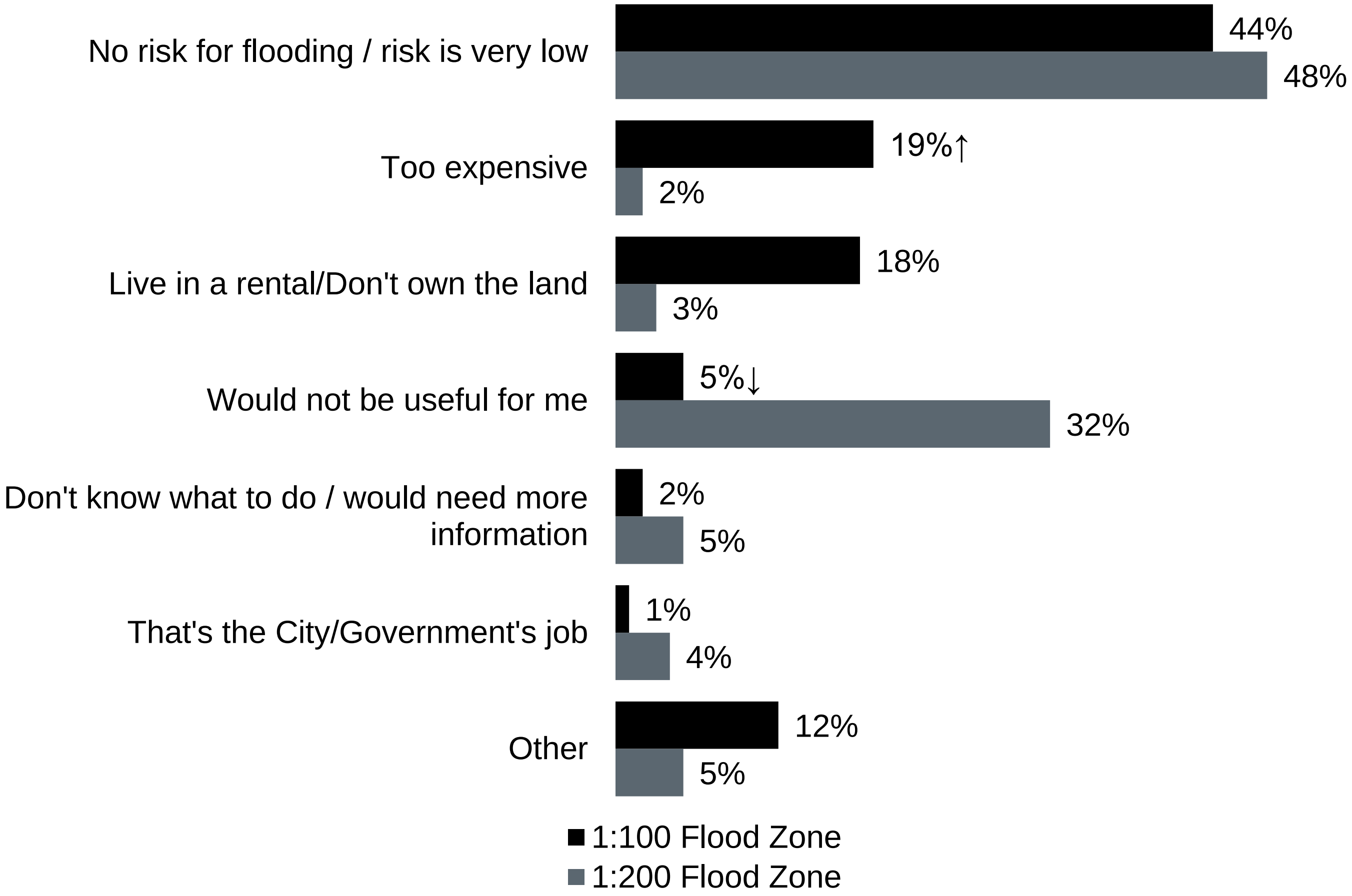
↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

1:100 vs. 1:200 (Inside Flood Zone)

Reasons for Not Making Alterations to Property or Purchasing Equipment

Those in the 1:100 flood zone are more likely to feel that property alterations or equipment are too expensive while those in the 1:200 flood zone are more likely to think property alterations or equipment are not useful for them.



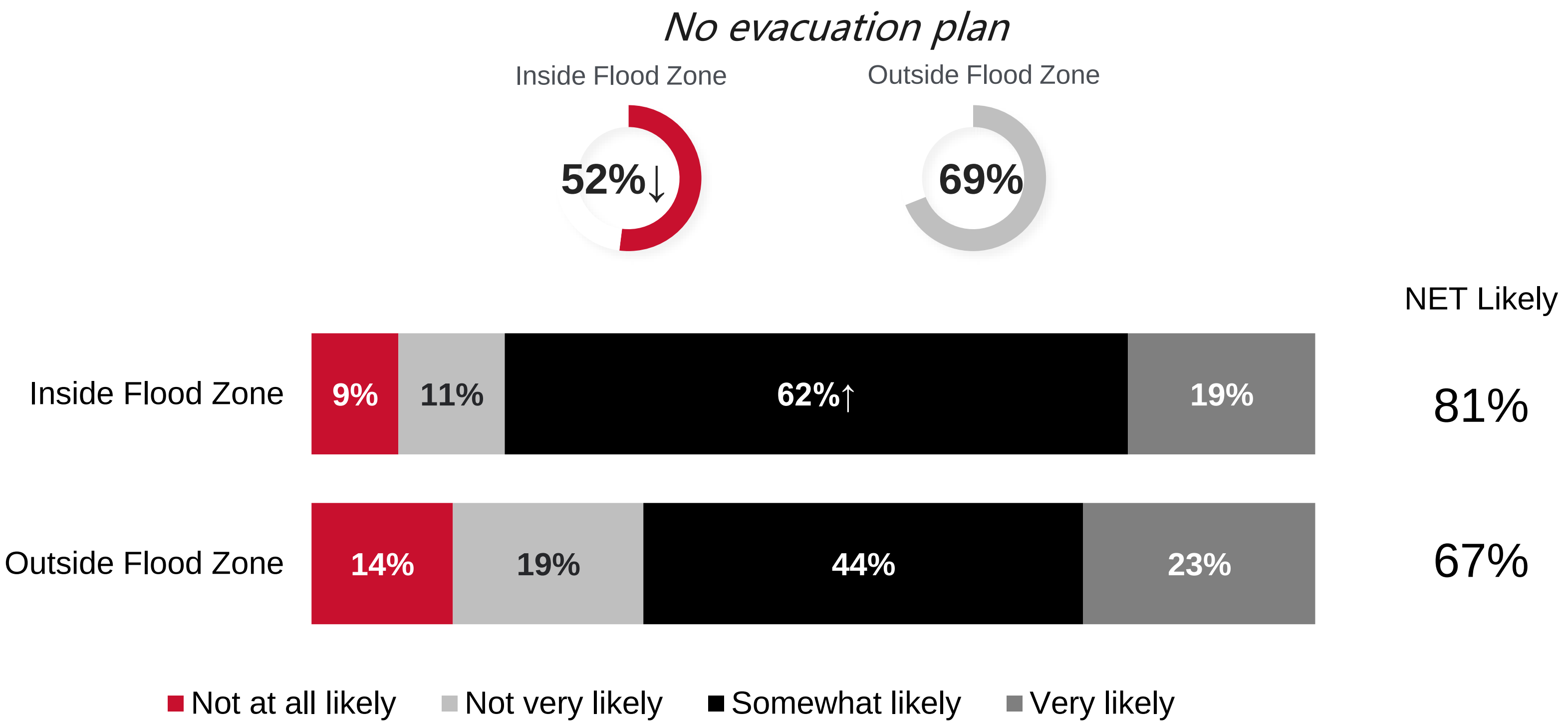


Base: Did not make alterations to property (excluding Don't know/Not Applicable) (1:100 n=141; 1:200 n=50)
B4d. And would you be able to tell me your reasons for not making alterations to your property or purchasing equipment that you can set up to protect your property from flooding?

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Likelihood to Create an Evacuation Plan if The City were to Provide Template

Among Calgarians who currently do not have an evacuation plan, a majority would be at least somewhat likely to create one if The City provided a template.

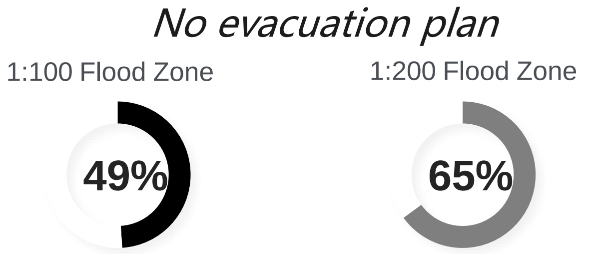


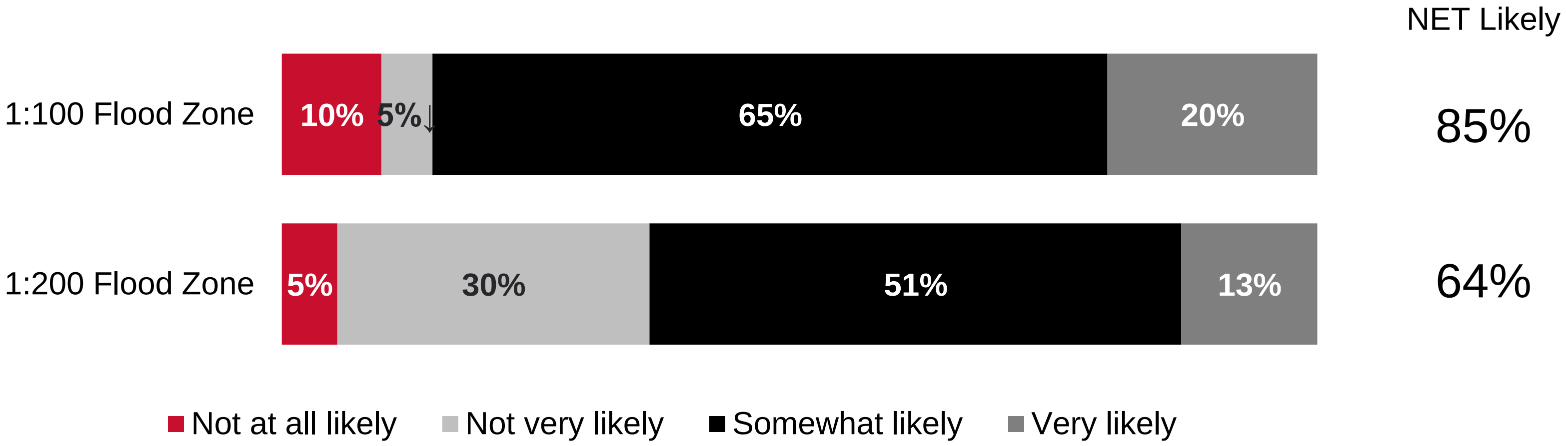
Base: Don't have an evacuation plan (excluding Don't know) (Inside Flood Zone n=167; Outside Flood Zone n=275)
B4e1. If The City were to provide a templated evacuation plan that would walk you through the steps to develop an evacuation plan for your household, would you be very likely, somewhat likely, not very likely, or not at all likely to develop an evacuation plan?

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Likelihood to Create an Evacuation Plan if The City were to Provide Template

Among residents in the 1:100 flood zone and who currently do not have an evacuation plan, 1 out of 5 would be very likely to create an evacuation plan if The City provided a template.





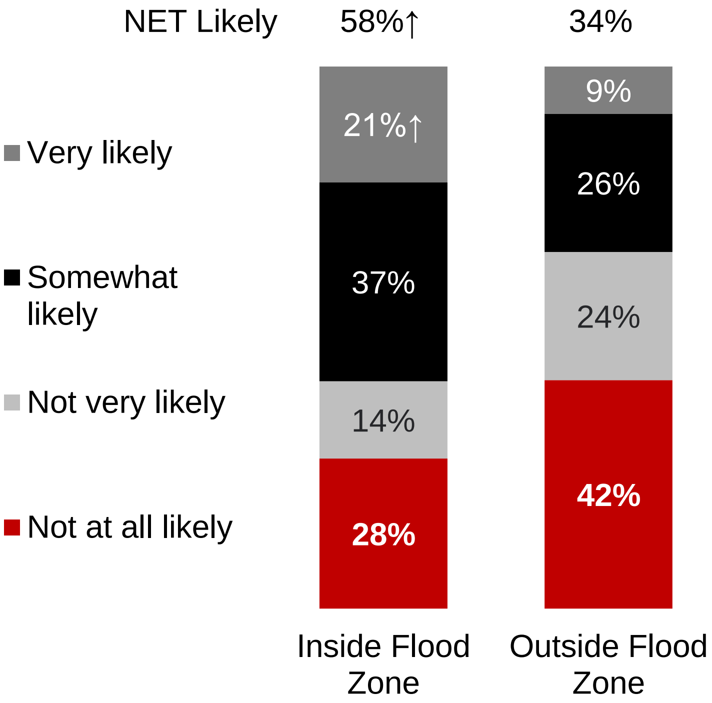
Base: Don't have an evacuation plan (excluding Don't know) (1:100 n=119; 1:200 n=48)
B4e1. If The City were to provide a templated evacuation plan that would walk you through the steps to develop an evacuation plan for your household, would you be very likely, somewhat likely, not very likely, or not at all likely to develop an evacuation plan?

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

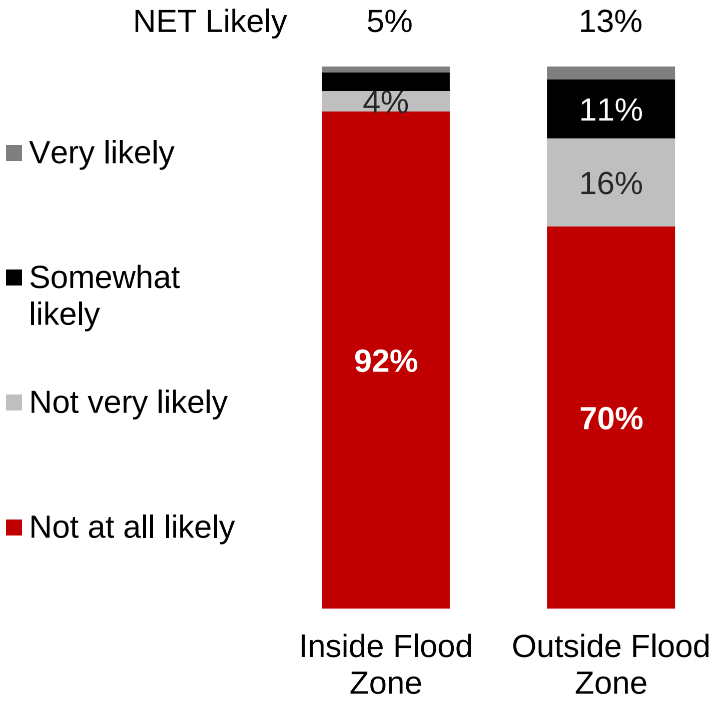
Likelihood to Install a Sump Pump …

If The City provided simple instructions, just over half inside the flood zone who currently do not have a sump pump indicate that they would be likely to install one. Of those not at all likely, very few would install a sump pump even if The City subsidized the cost.

… if The City Were to Provide Simple Instructions



… if The City Were to Subsidize Half of the Cost



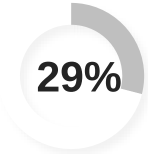
Base: Don't have a sump pump (excluding Don't know) (Inside Flood Zone n=163; Outside Flood Zone n=292)
B4f1. If The City were to provide simple instructions showing you how to have a sump pump installed, would you be very likely, somewhat likely, not very likely, or not at all likely to install a sump pump?
Base: Not at all likely to install sump pump (excluding Don't know) (Inside Flood Zone n=64; Outside Flood Zone n=126)
B4f2. And if The City were to provide a subsidy to cover half of the cost of installing a sump pump, would you be very likely, somewhat likely, not very likely, or not at all likely to install a sump pump?

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

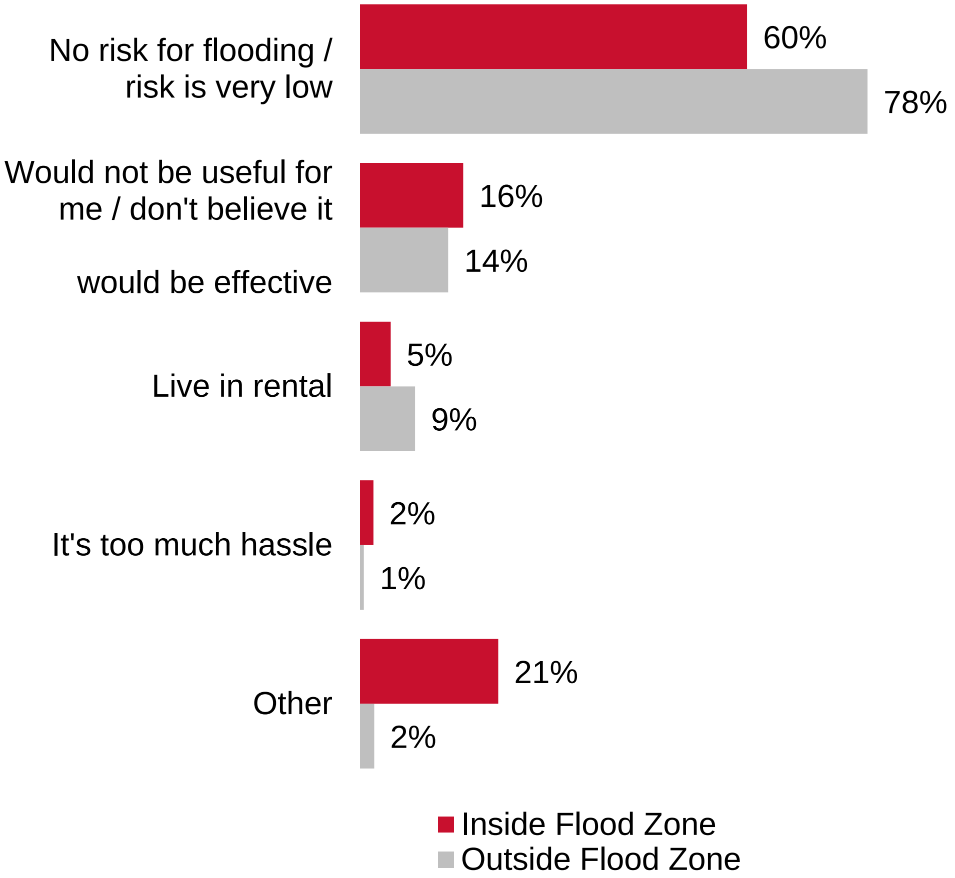
Reasons for Not Installing a Sump Pump

The majority of those who would not install a sump pump even if The City subsidized the cost, would not do so because of their low perceived flood risk.

Not at all likely even if The City covers ½ cost



Not at all likely even if the City covers ½ cost



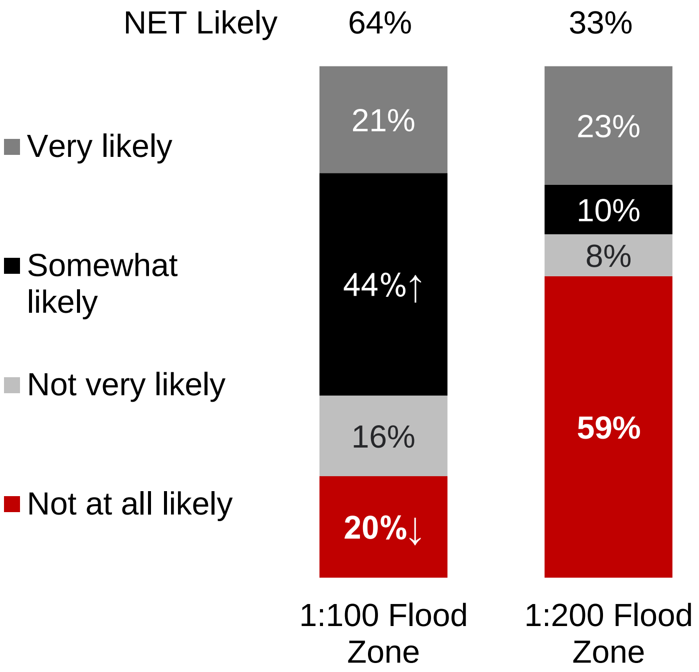
↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Base: Not at all likely to install a sump pump (excluding Don't know/Not Applicable) (Inside Flood Zone n=53; Outside Flood Zone n=92)
B4f3. What makes you unlikely to install a sump pump?

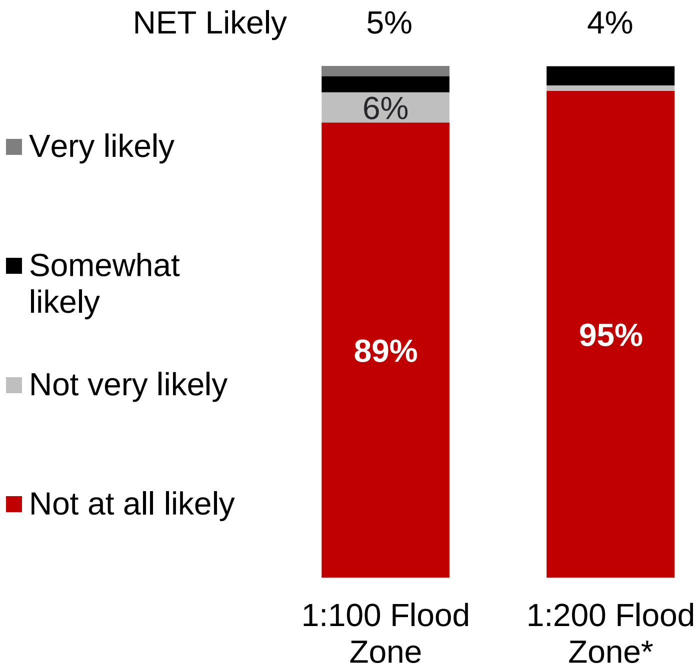
Likelihood to Install a Sump Pump

Almost two-thirds of those in the 1:100 flood zone who currently do not have a sump pump would be likely to install one if The City provided simple instructions, compared to just one-third of those in the 1:200 flood zone.

… if The City Were to Provide Simple Instructions



… if The City Were to Subsidize Half of the Cost

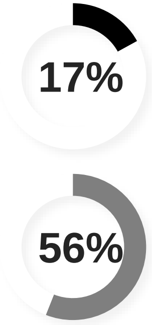


Base: Don't have a sump pump (excluding Don't know) (1:100 n=117; 1:200 n=46)
B4f1. If The City were to provide simple instructions showing you how to have a sump pump installed, would you be very likely, somewhat likely, not very likely, or not at all likely to install a sump pump?
Base: Not at all likely to install sump pump (excluding Don't know) (1:100 n=39; 1:200 n=25)
B4f2. And if The City were to provide a subsidy to cover half of the cost of installing a sump pump, would you be very likely, somewhat likely, not very likely, or not at all likely to install a sump pump?

* Base <30, interpret with caution
↑ Significantly higher than 1:200
↓Significantly lower than 1:200

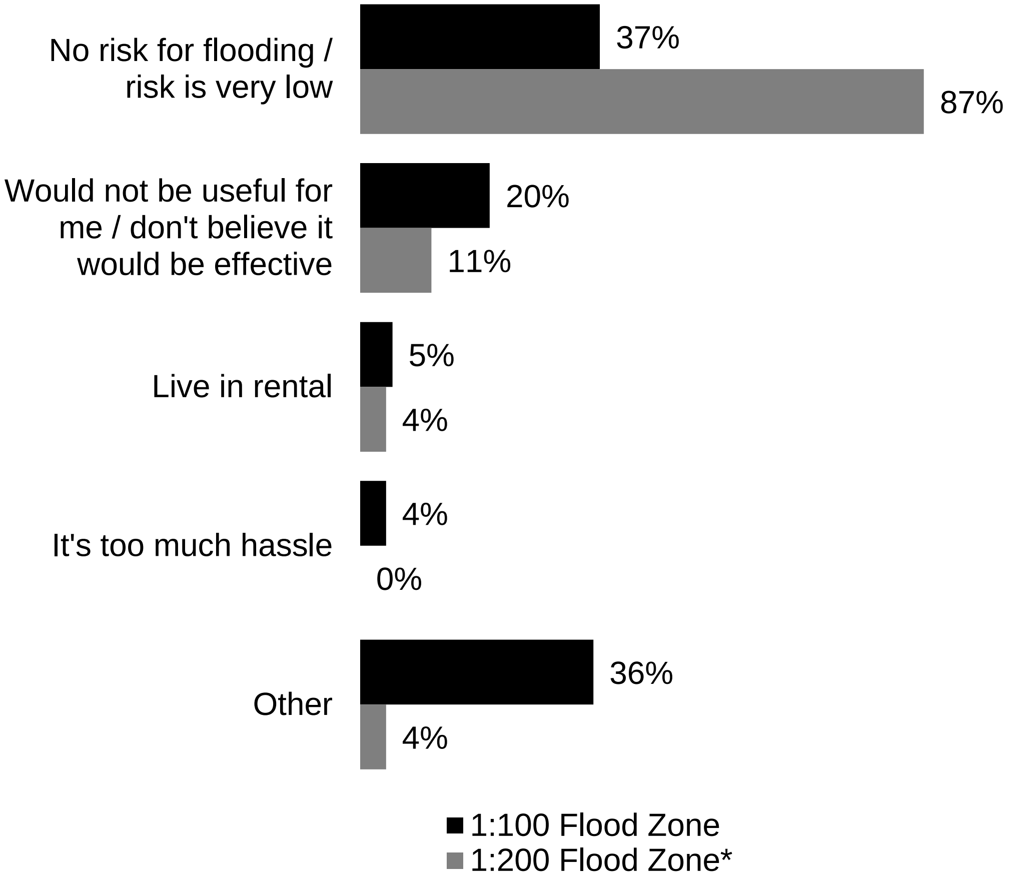
Reasons for Not Installing a Sump Pump

The majority of those in the 1:200 flood zone who would not install a sump pump even if The City subsidized the cost, would not do so because of their low perceived flood risk. In the 1:100 flood zone, the reasons for not doing so are varied.



Not at all likely even if The City covers ½ cost

Not at all likely even if The City covers ½ cost



* Base <30, inter[ret with caution
↑ Significantly higher than 1:200
↓Significantly lower than 1:200

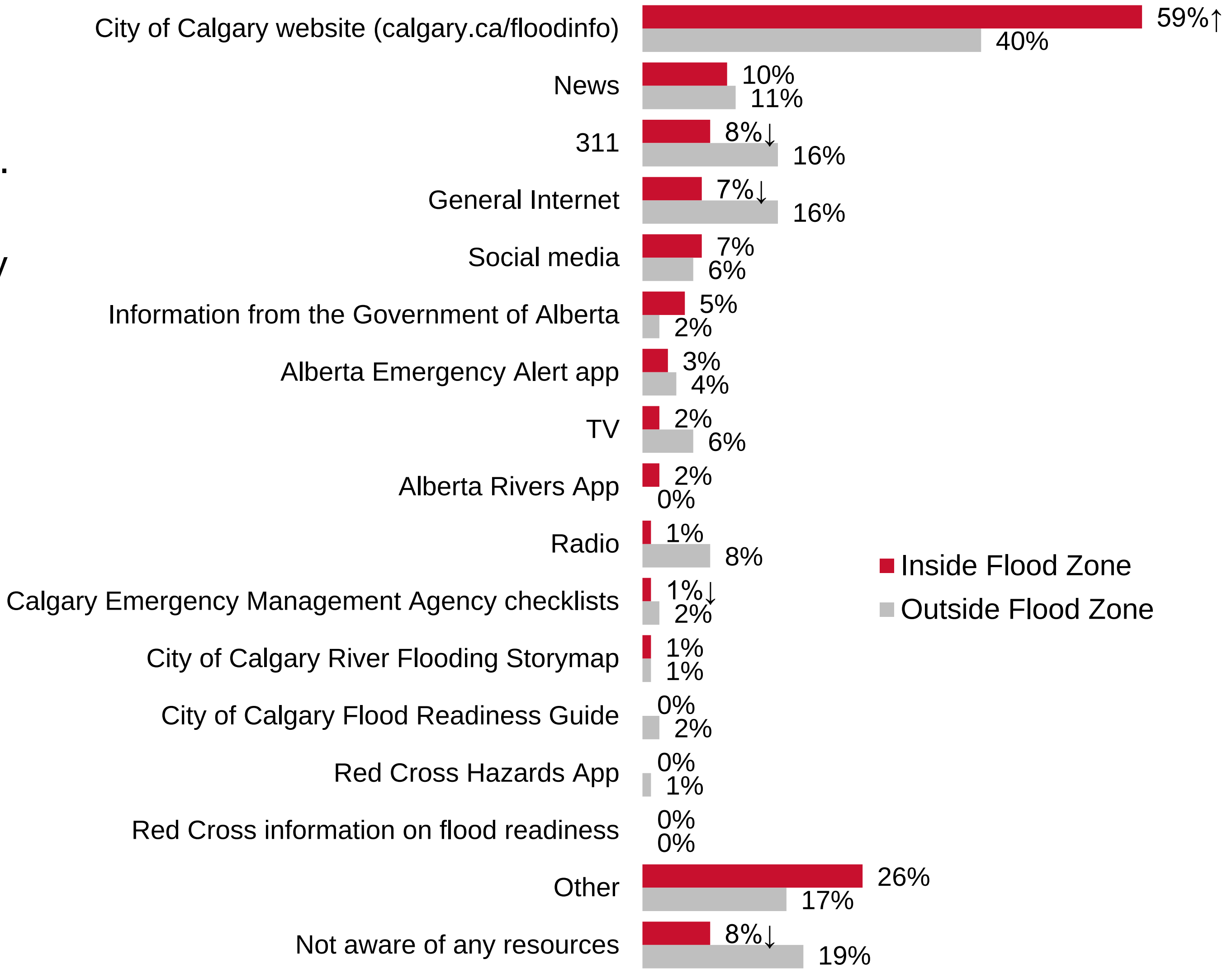
Base: Not at all likely to install a sump pump (excluding Don't know/Not Applicable) (1:100 n=32; 1:200 n=21)
B4f3. What makes you unlikely to install a sump pump?

Detailed Findings:
Flood Support

Inside vs. Outside Flood Zone

Awareness of Flood Preparedness Resources

The City of Calgary website is by far the best known flood preparedness resource. There is much lower awareness of other City resources such as the River Flooding Story map, the Readiness Guide, and CEMA checklists.

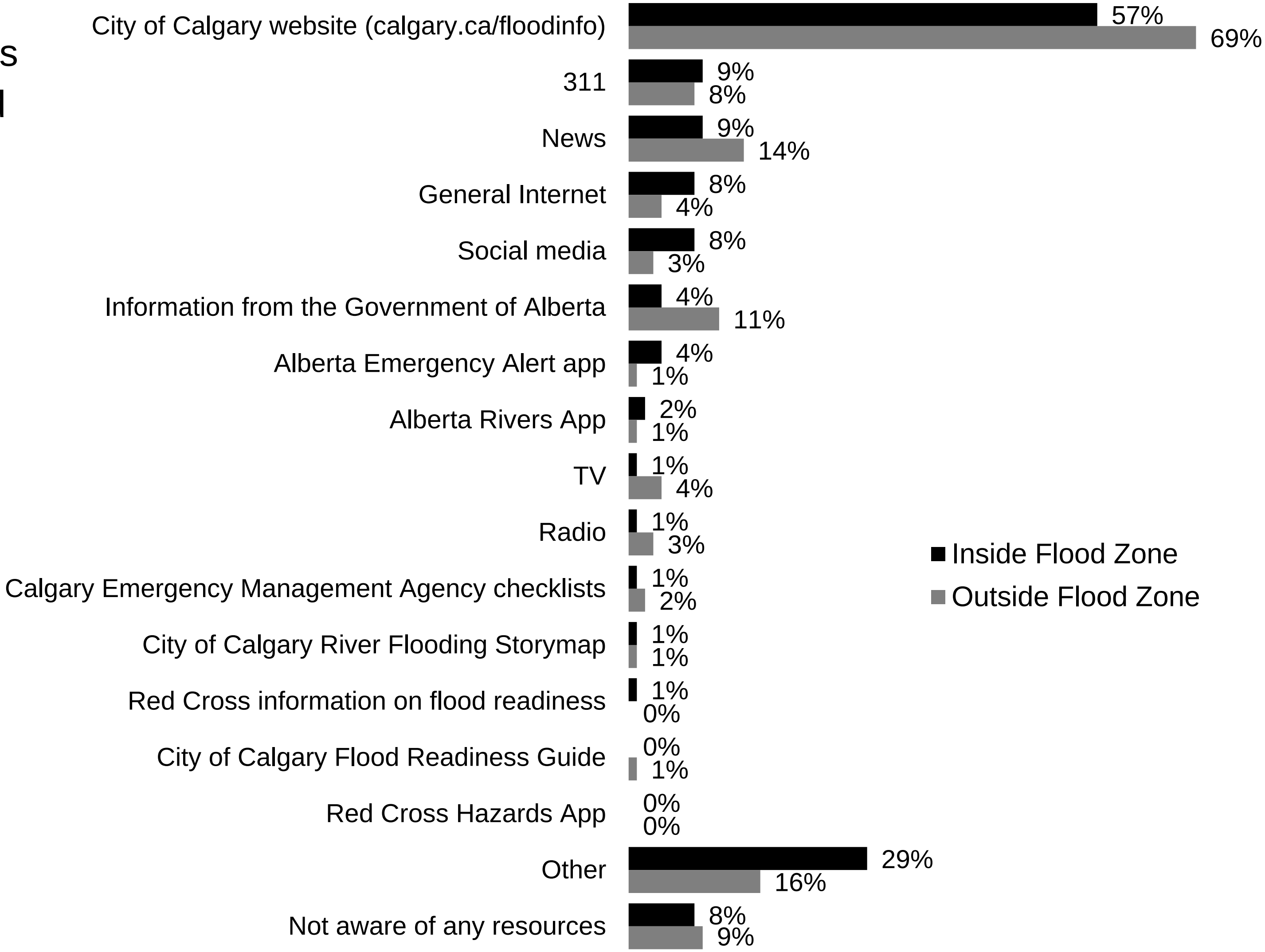


Base: All respondents (excluding Don't know) (Inside Flood Zone n=372; Outside Flood Zone n=376)
C2a. What resources are you aware of that provide information to help you be more prepared for potential river flooding at your property or handle other disruptions caused by potential river flooding in our city?

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Awareness of Flood Preparedness Resources

There are similar levels of awareness of the various flood preparedness resources among those in the 1:100 and 1:200 flood zones.

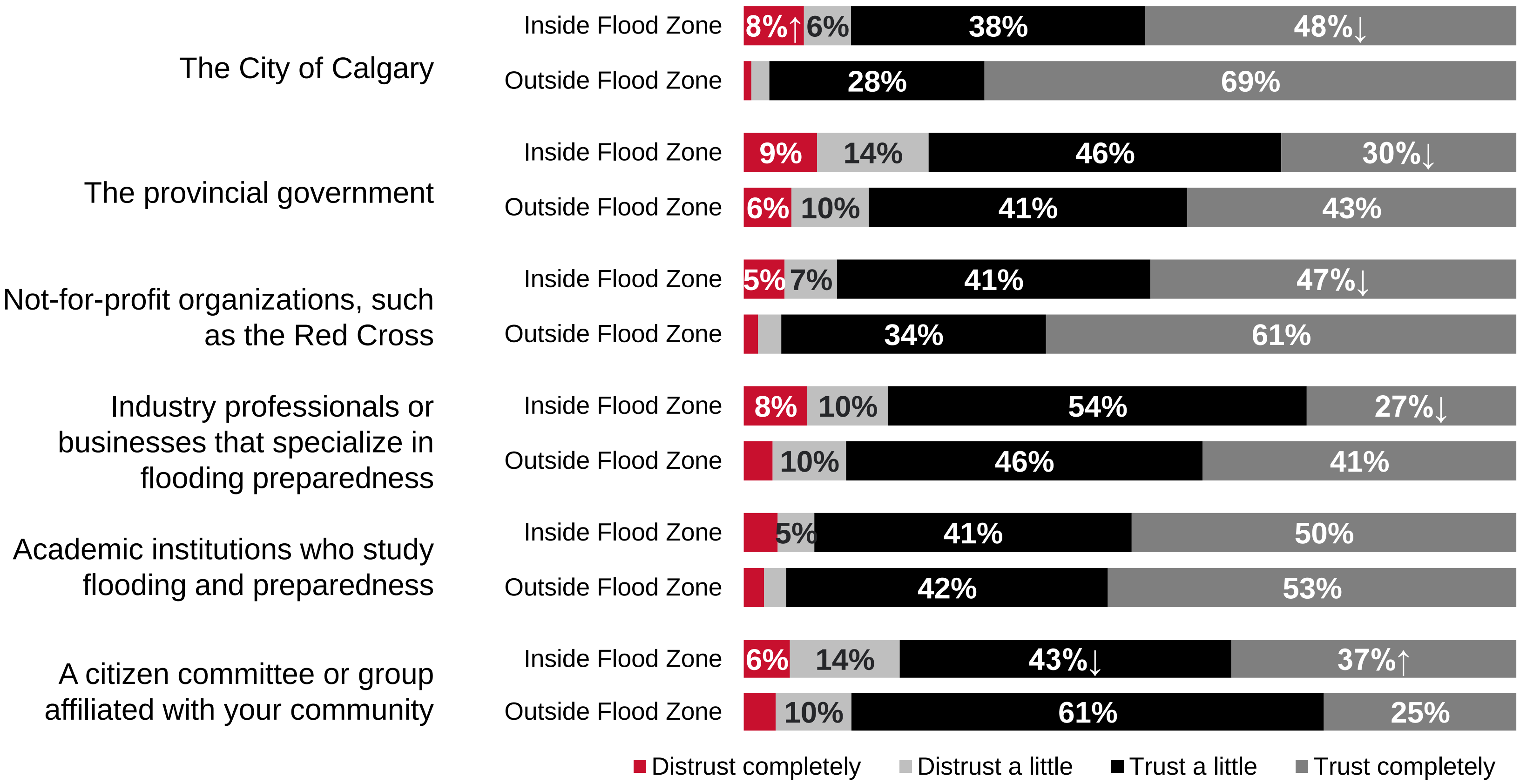


Base: All respondents (excluding Don't know) (1:100 n=277; 1:200 n=95)
C2a. What resources are you aware of that provide information to help you be more prepared for potential river flooding at your property or handle other disruptions caused by potential river flooding in our city?

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Trust in Specific Organizations

Efforts to increase trust among citizens inside the flood zone would be useful: compared to those outside the flood zone, those inside the flood zone have substantially lower levels of trust in The City of Calgary and not-for-organizations.

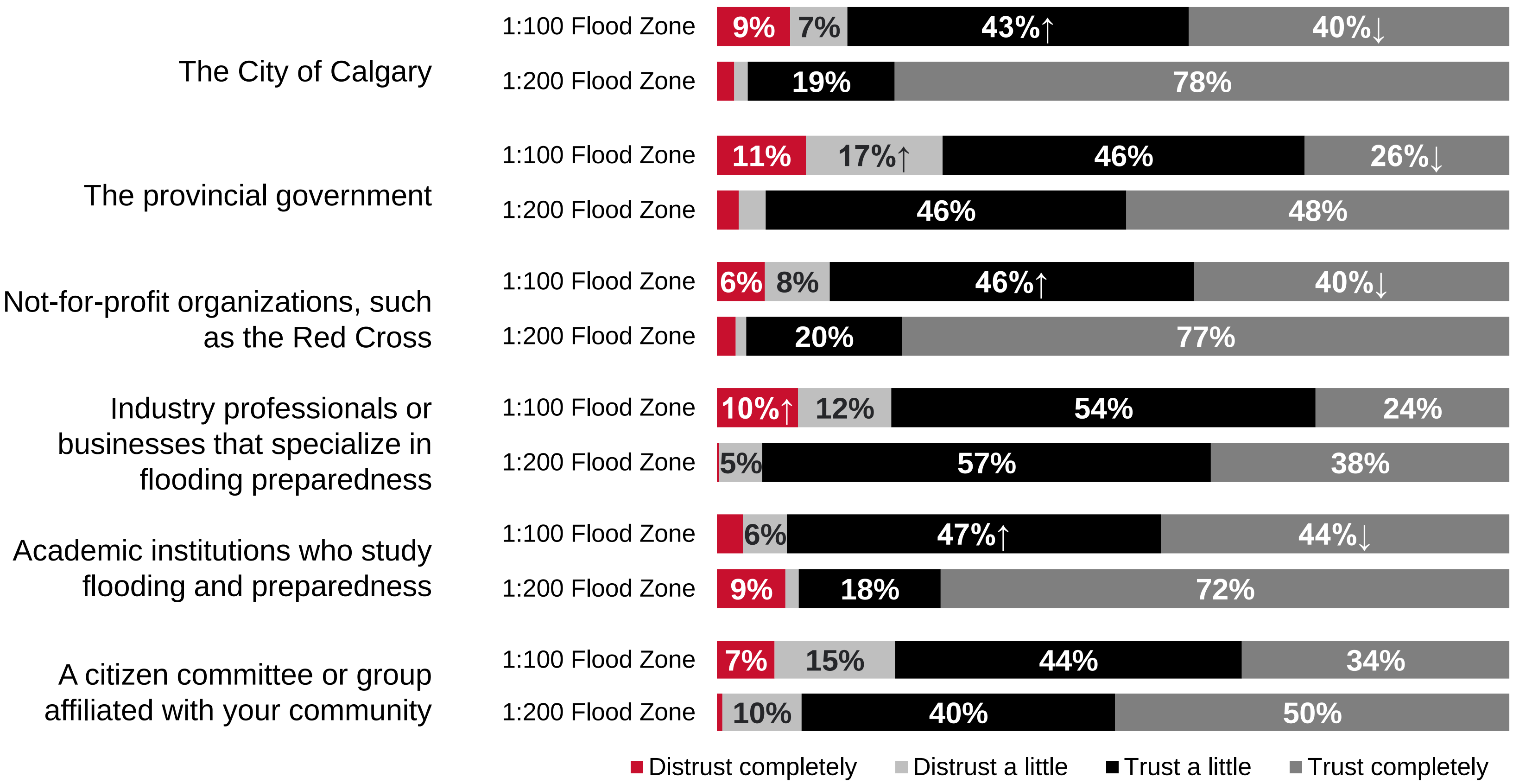


Base: All respondents (excluding Refused/Don't know) (Inside Flood Zone n=369-396; Outside Flood Zone n=384-401)
C3. Next, I will read out a list of different types of organizations. Please let me know how much you would trust or not trust each of these to provide you with reliable information about the risks of potential river flooding and how to prepare for potential river flooding. Would you say …

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Trust in Specific Organizations

Especially in the 1:100 flood zone, there are lower levels of trust in The City of Calgary, the provincial government, not-for-profits, and academic institutions.

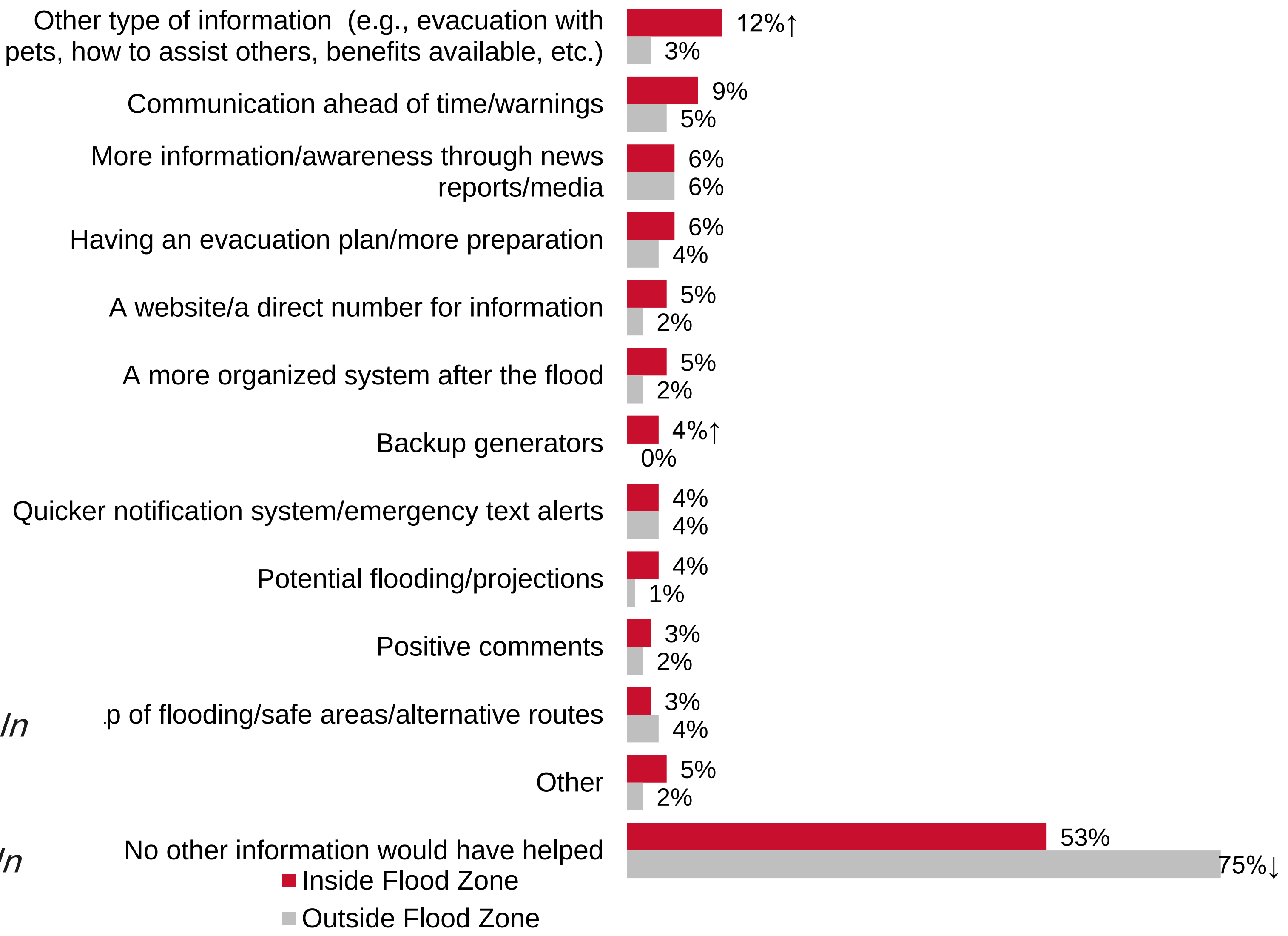


Base: All respondents (excluding Refused/Don't know) (1:100 n=271-296; 1:200 n=96-100)
C3. Next, I will read out a list of different types of organizations. Please let me know how much you would trust or not trust each of these to provide you with reliable information about the risks of potential river flooding and how to prepare for potential river flooding. Would you say …

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Information That Would Have Been Helpful Before / During / After 2013 Flood

For those living in Calgary in 2013, three-quarters of those living outside of the flood zone and just over half of those inside the flood zone felt that no other information would have helped them.



Base: Lived in Calgary in 2013 (excluding Don't know/Not Applicable/None) (Inside Flood Zone n=357; Outside Flood Zone n=331)
C1b. Thinking back to the 2013 flood, is there any information or resources that would have helped you be more prepared, or that would have made your response, recovery, or your overall experience during that time go smoothly?

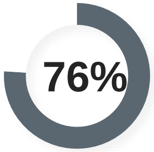
↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

1:100 vs. 1:200 (Inside Flood Zone)

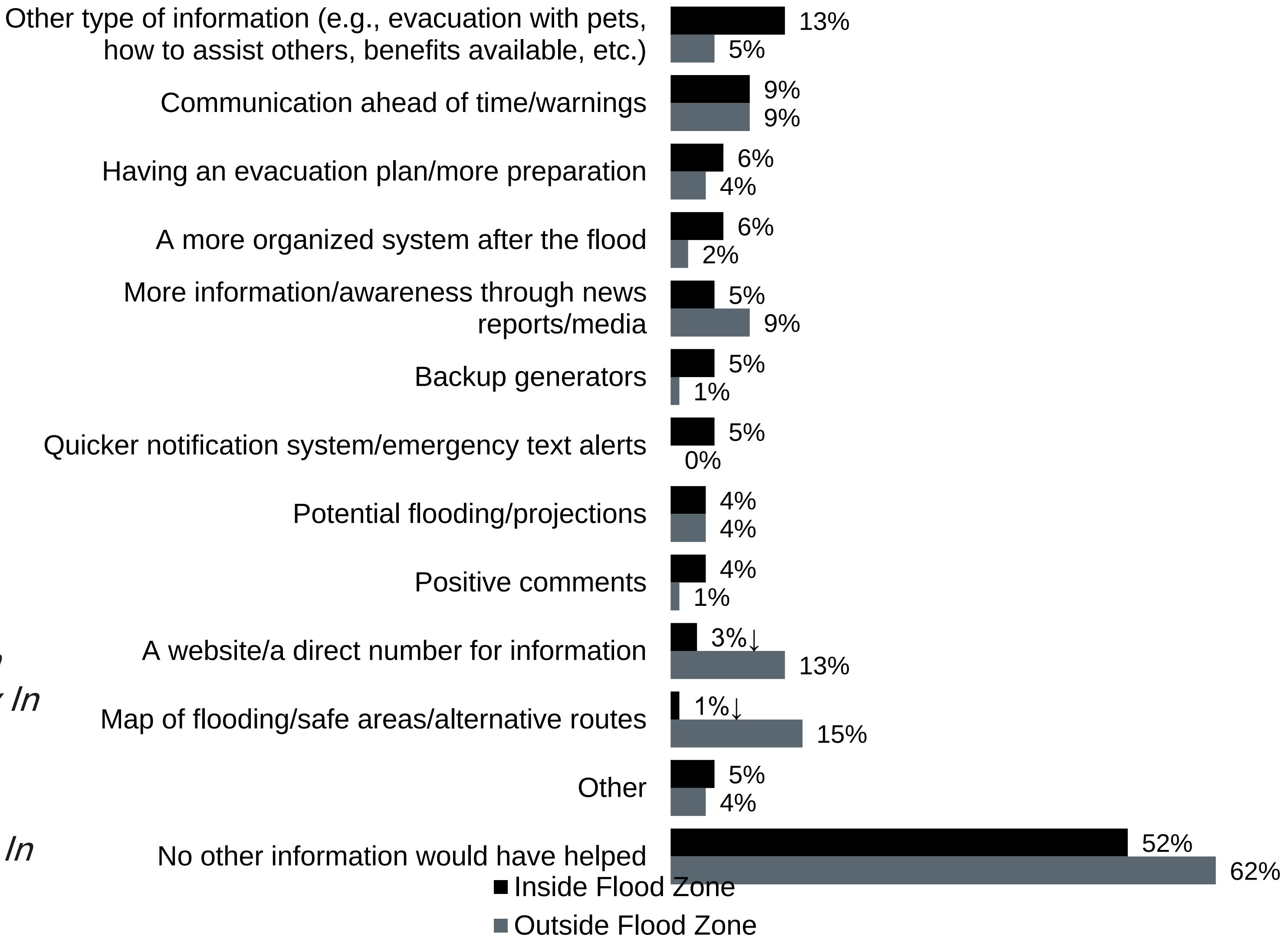
Information That Would Have Been Helpful Before / During / After 2013 Flood

Compared to those in the 1:100 zone, those in the 1:200 zone are more likely to have found flood maps and a website or phone number for information helpful.

Lived in Calgary In 2013



Lived in Calgary In 2013



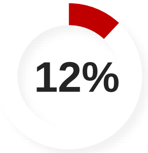
Base: Lived in Calgary in 2013 (excluding Don't know/Not Applicable) (1:100 n=272; 1:200 n=85)
C1b. Thinking back to the 2013 flood, is there any information or resources that would have helped you be more prepared, or that would have made your response, recovery, or your overall experience during that time go smoothly?

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

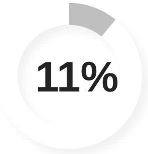
Aggregate

Information to Prepare for Potential Flooding

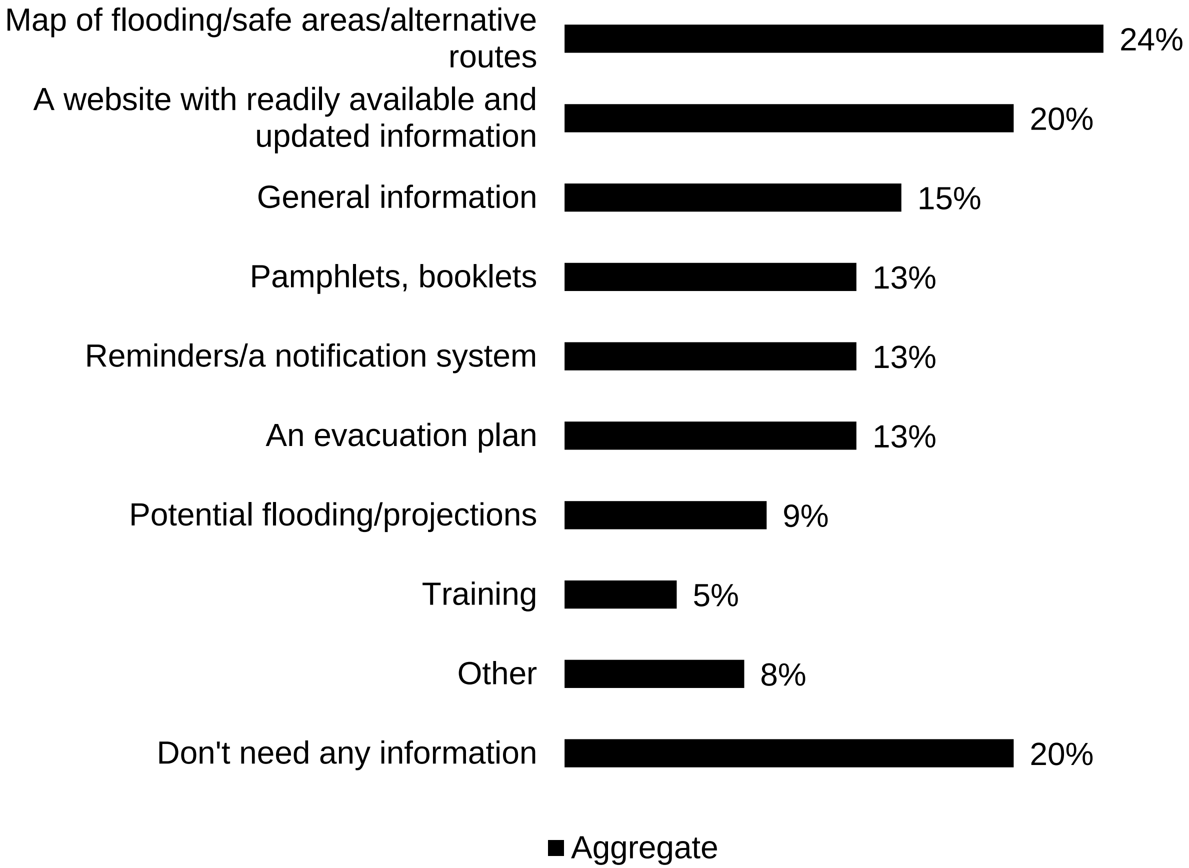
Those who did not live in Calgary in 2013 mention maps (24%) and a website with current information (20%) most frequently as being useful to prepare for potential flooding. 1 out of 5 indicate they don’t need any information.



Did not live in Calgary In 2013



Did not live in Calgary In 2013

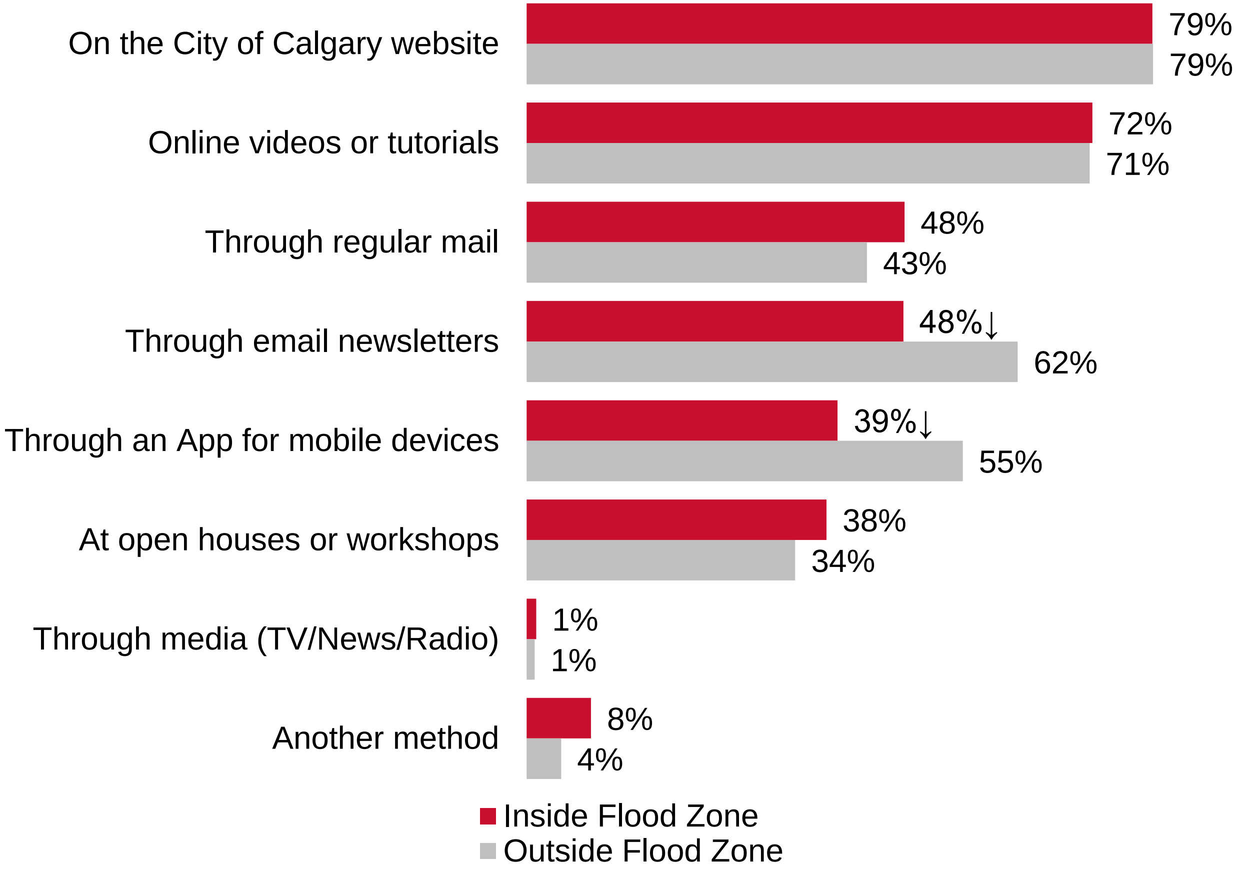


Base: Did not live in Calgary in 2013(excluding Don’t know/Not Applicable) (n=40)
C1a. What support or information would be helpful to you to prepare for potential river flooding either at your property, or in our city?

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Preferred Resource Communication Channels

A range of communication methods would be preferred to communicate additional flood preparedness information, with The City of Calgary website and online videos or tutorials being most preferred.

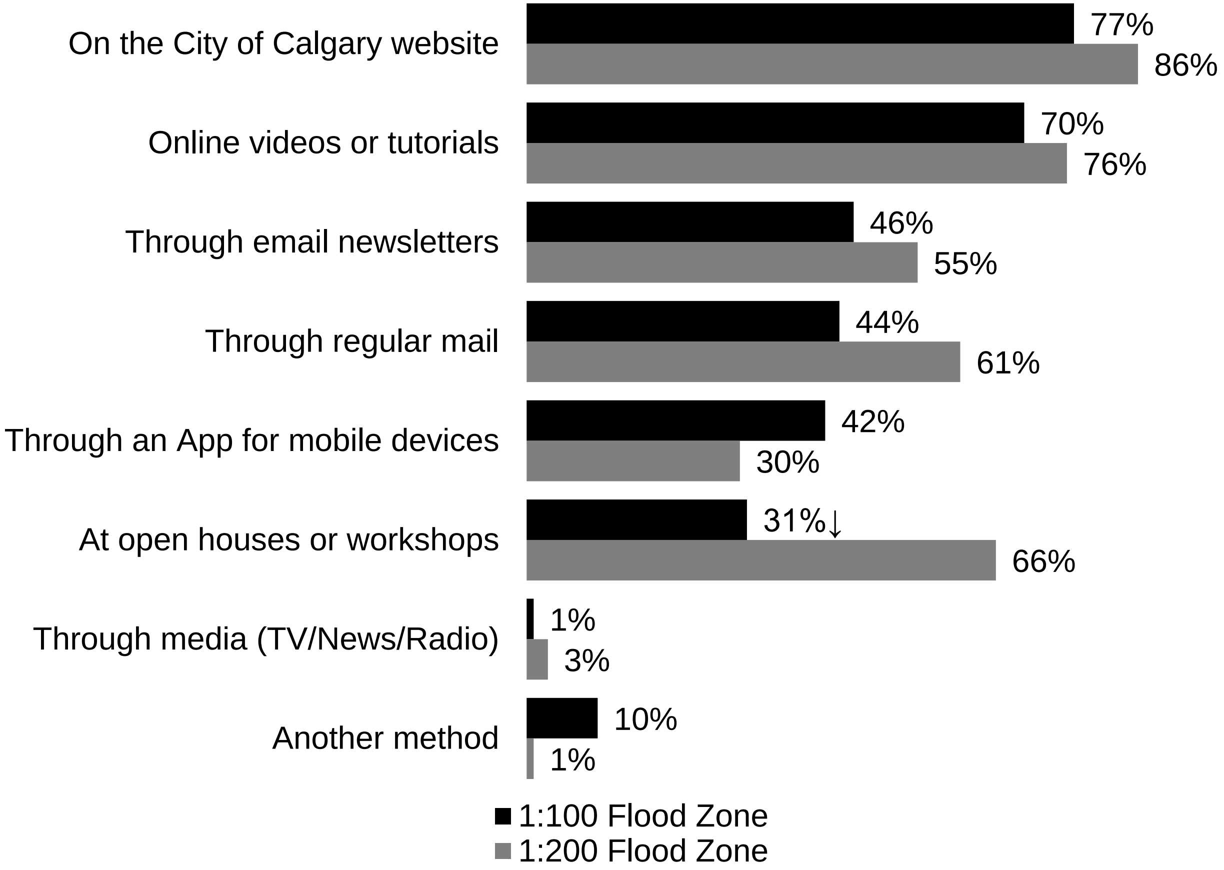


Base: Did not live in Calgary in 2013 (excluding Don't know) (Inside Flood Zone n=395; Outside Flood Zone n=397)
C4a. If The City were to develop additional resources with information, how would you prefer that they make those resources available to you?

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Preferred Resource Communication Channels

The City of Calgary website and online videos or tutorials are the preferred methods of communication in both the 1:100 and 1:200 flood zones. Those in the 1:200 zone are more likely to prefer open houses or workshops than those in the 1:100 flood zone.



Base: All respondents (excluding Don't know) (1:100 n=294; 1:200 n=101)
C4a. If The City were to develop additional resources with information about how to prepare for potential river flooding and to lower your risk of future flood damage, how would you prefer that they make those resources available to you?

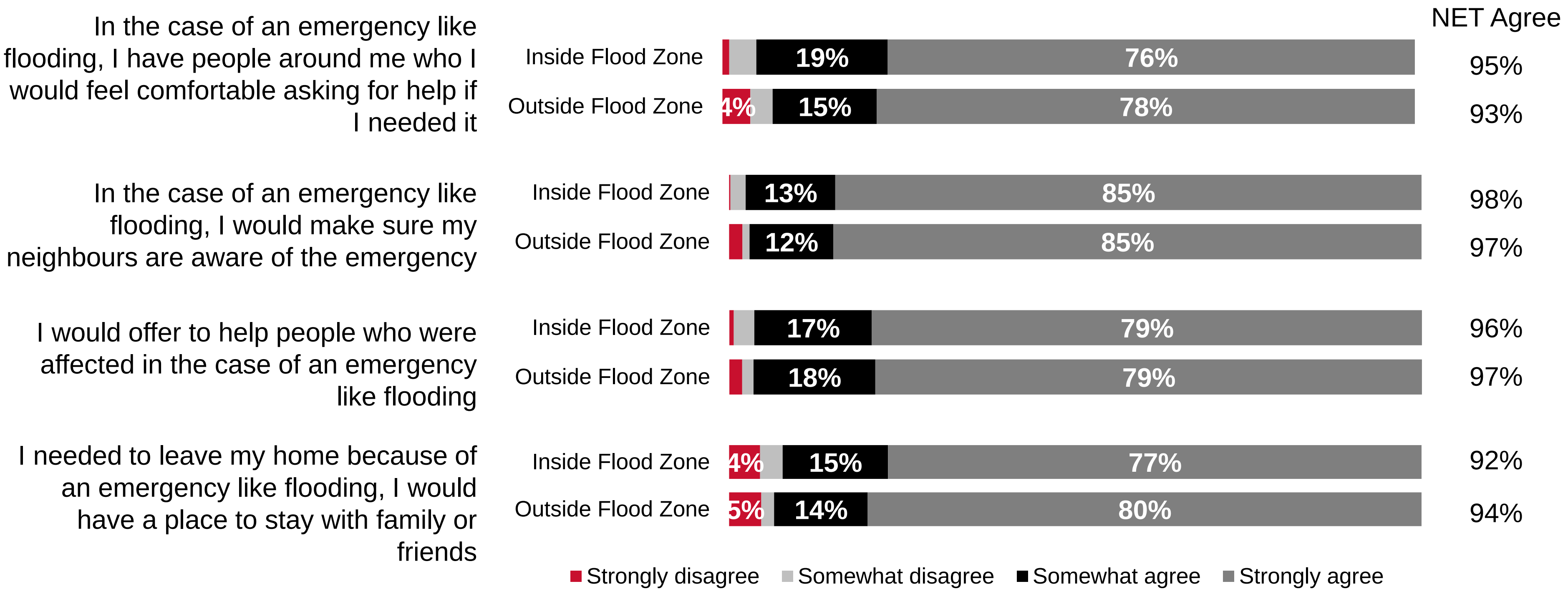
↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Detailed Findings:

Social Resiliency and Mental Health Support

Community Support

In light of high levels of community supports, it would be helpful to engage local communities to increase flood preparedness.

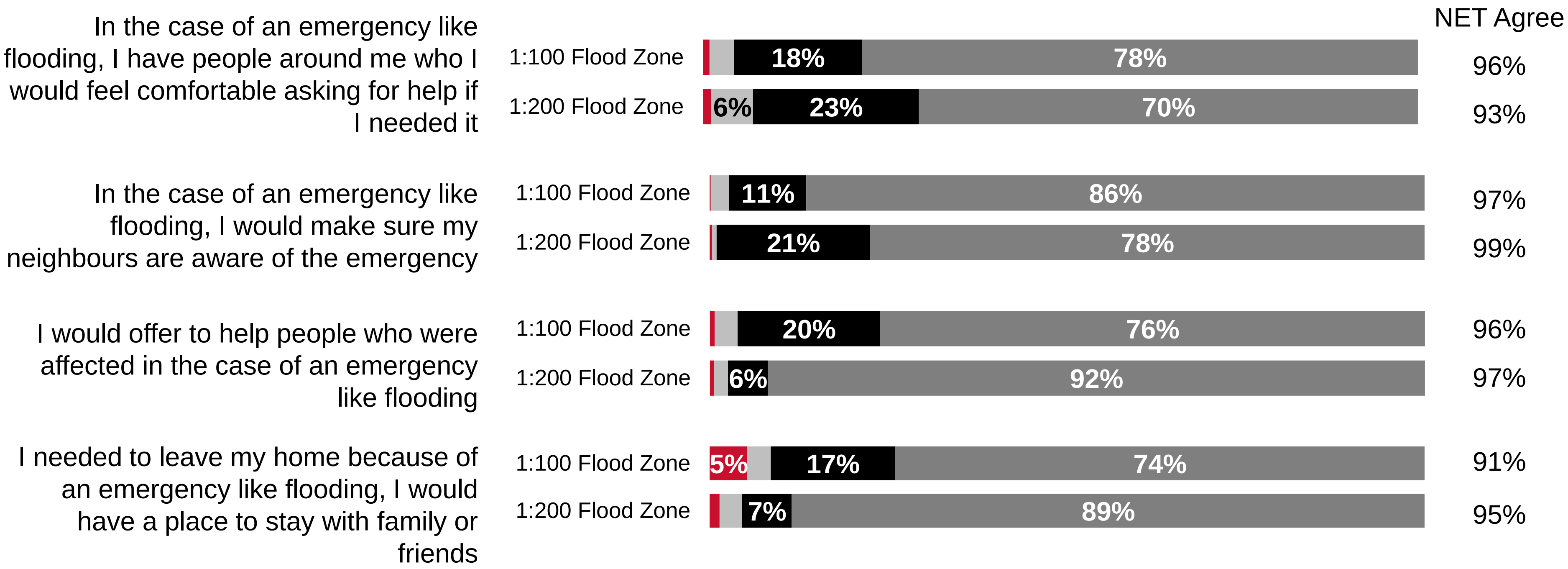


Base: All respondents (excluding Don't know) (Inside Flood Zone n=393-399; Outside Flood Zone n=400-401)
D1. For each of the following statements, please let me know if you strongly agree, somewhat agree, somewhat disagree, or strongly disagree.

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Community Support

The high levels of community support hold true in both the 1:100 and 1:200 flood zones.

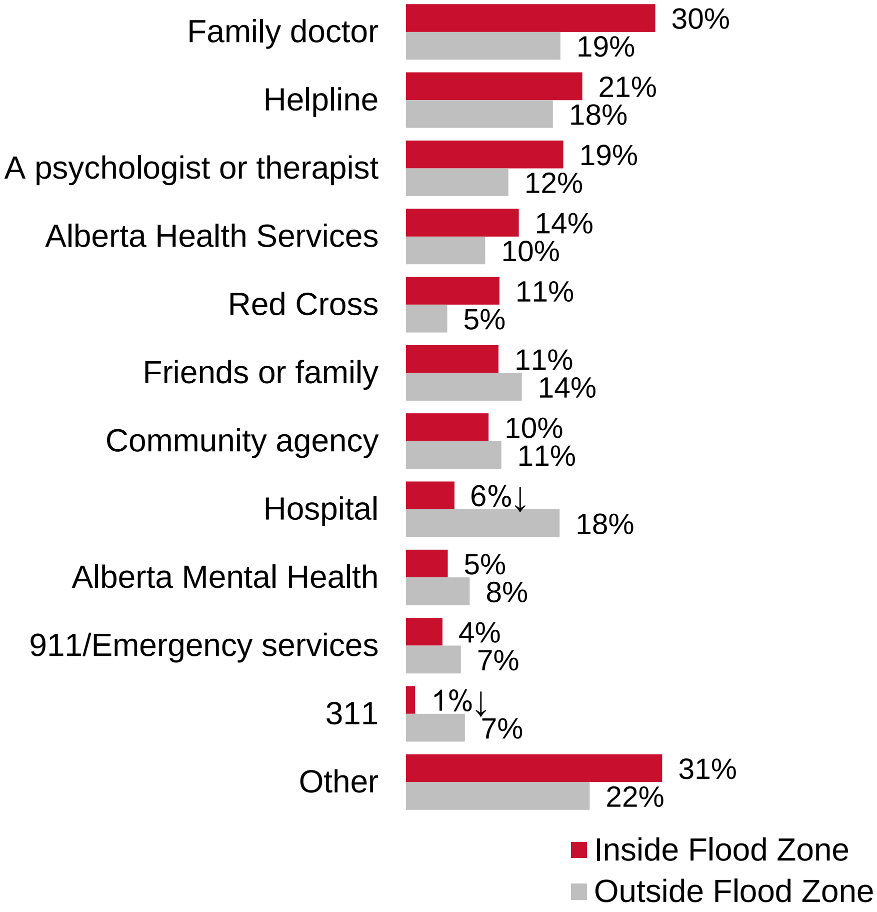


Base: All respondents (excluding Don't know) (1:100 n=293-298; 1:200 n=99-101)
D1. For each of the following statements, please let me know if you strongly agree, somewhat agree, somewhat disagree, or strongly disagree.

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Awareness of Mental Health Resources

For those inside the flood zone, family doctors have the highest level of awareness as a mental health resource. For those outside the flood zone, family doctors, helplines, and the hospital have similar levels of awareness.

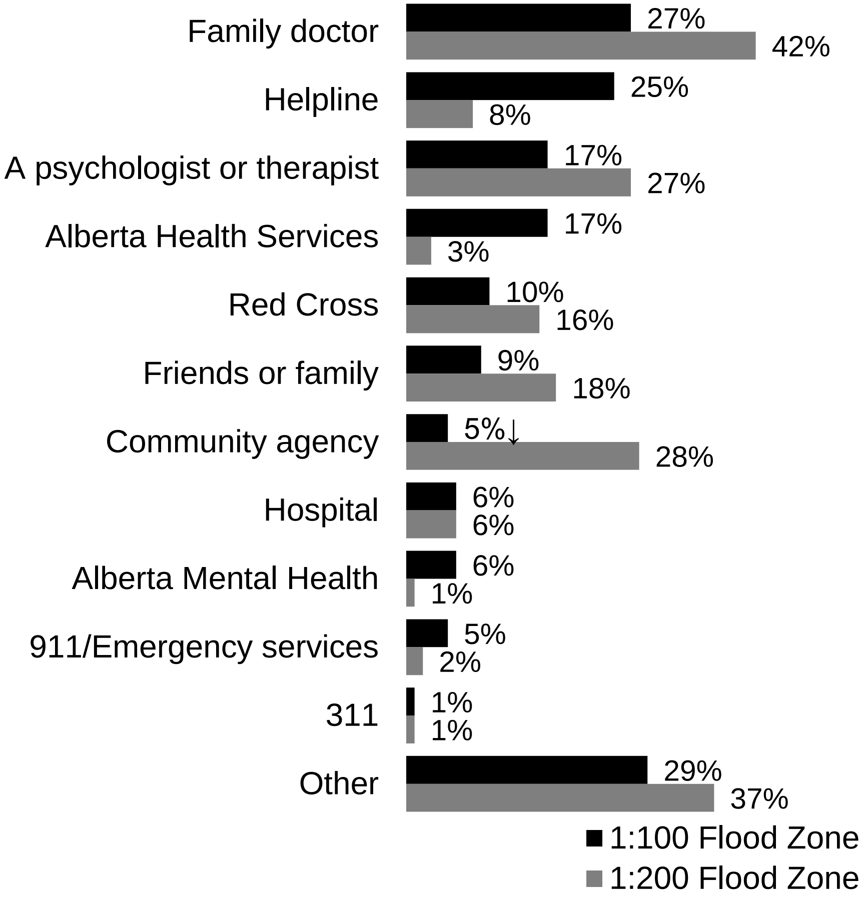


Base: All respondents (excluding Don't know) (Inside Flood Zone n=263; Outside Flood Zone n=250)
D3. Which resources, if any, are you aware of that you can access for help if you or someone you know were to experience a mental health issue due to trauma from an experience like a flood?

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Awareness of Mental Health Resources

For those in the 1:200 flood zone, family doctors, followed by community agencies and psychologists have the highest levels of awareness as mental health resources. In the 1:100 flood zone, family doctors and helplines have the highest levels of awareness.



Base: All respondents (excluding Don't know) (1:100 n=196; 1:200 n=67)
D3. Which resources, if any, are you aware of that you can access for help if you or someone you know were to experience a mental health issue due to trauma from an experience like a flood?

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Demographics

Quadrant and Flood Impact

Quadrant

	Inside Flood Zone	Outside Flood Zone
Southwest	59%↑	27%
Southeast	12%↓	24%
Northwest	27%	32%
Northeast	2%↓	17%

Live in Calgary during 2013 Flood (A4)

	Inside Flood Zone	Outside Flood Zone
Yes	88%	89%
No	12%	11%
Don’t know	0%	0%

Did your residence get flooded? (A5)

	Inside Flood Zone	Outside Flood Zone
Yes	46%↑	4%
No	54%↓	96%
Don’t know	0%	0%

Impact of 2013 Flood (A6)

	Inside Flood Zone	Outside Flood Zone
Emotional or psychological stress	51%↑	24%
Evacuation from your residence	72%↑	10%
Financial burden or stress	39%↑	10%
Health impacts or injury	9%↑	1%
Loss of important personal belongings	30%↑	3%
Property damage	36%↑	3%
Disruption to work, school, or daycare	59%↑	43%
Disruption to commuting routes or recreation	67%↑	47%
Anything else	6%	3%
None of the above	9%↓	35%
Don’t know	0%	0%

Base: All respondents (Inside Flood Zone n=401 Outside Flood Zone n=402)
A4. Did you live in Calgary during the 2013 flood?
Base: Lived in Calgary during 2013 flood (Inside Flood Zone n=389; Outside Flood Zone n=366)
A5. Did the residence you lived in at the time of the flood get flooded?
A6. Did you experience any of the following as a result of the 2013 flood?

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Demographics

Type of Home (E4)

	Inside Flood Zone	Outside Flood Zone
Single, detached house	52%↓	69%
Duplex, triplex, or fourplex	6%	8%
Townhouse or rowhouse	3%↓	10%
Apartment or apartment-style condominium	39%↑	11%
Another type of multi-unit complex	0%	2%
Prefer not to say	0%	0%

Basement ever flooded? (A10)

	Inside Flood Zone	Outside Flood Zone
Yes	68%↑	20%
No	32%↓	76%
Don’t know	0%↓	3%
Not applicable	0%	1%

Have dependents? (E7)

	Inside Flood Zone	Outside Flood Zone
Yes	33%↓	49%
No	67%↑	51%
Prefer not to answer	0%	0%

Own or Rent (E5)

	Inside Flood Zone	Outside Flood Zone
Own	69%	76%
Rent	31%	22%
Other	0%	1%
Prefer not to say	0%	1%

Base: All respondents (Inside Flood Zone n=401; Outside Flood Zone n=402)
E4. What type of home do you live in? Is it a ...
E5. And do you own or rent your current residence?
E7. Do you have anyone in your household, of any age, who would be dependent on you in an emergency such as a flood?
Base: Lives in a house(Inside Flood Zone n=308; Outside Flood Zone n=355)
A10. Has your basement ever flooded for any reason?

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Demographics

Gender (E9)

	Inside Flood Zone	Outside Flood Zone
Male	52%	50%
Female	48%	50%
Other	0%	0%
Prefer not to answer	0%	0%

Age (Int1)

	Inside Flood Zone	Outside Flood Zone
18 to 24	3%↓	8%
25 to 34	19%	18%
35 to 44	42%↑	26%
45 to 54	8%↓	17%
55 to 64	16%	16%
65+	12%	15%
Prefer not to answer	0%	0%

Household Income (E8)

	Inside Flood Zone	Outside Flood Zone
Less than $30,000	7%	9%
$30,000 to just under $45,000	7%	8%
$45,000 to just under $60,000	7%	10%
$60,000 to just under $75,000	9%	10%
$75,000 to just under $90,000	11%	7%
$90,000 to just under $105,000	4%	7%
$105,000 to just under $120,000	6%	8%
$120,000 to just under $135,000	4%	4%
$135,000 to just under $150,000	5%	5%
$150,000 and over	29%↑	17%
Don’t know	2%	3%
Prefer not to answer	8%	11%

Base: All respondents (Inside Flood Zone n=401; Outside Flood Zone n=402)
E9. What is your gender?
Int1. Which of the following age categories do you fall into?
E8. Which of the following categories best describes your total household income in 2018 before taxes? Is it ...

↑ Significantly higher than Outside Flood Zone
↓Significantly lower than Outside Flood Zone

Quadrant and Flood Impact

Quadrant

	1:100 Flood Zone	1:200 Flood Zone
Southwest	57%	65%
Southeast	12%	12%
Northwest	28%	21%
Northeast	2%	2%

Live in Calgary during 2013 Flood (A4)

	1:100 Flood Zone	1:200 Flood Zone
Yes	91%↑	76%
No	9%↓	24%
Don’t know	0%	0%

Did your residence get flooded? (A5)

	1:100 Flood Zone	1:200 Flood Zone
Yes	52%↑	17%
No	48%↓	83%
Don’t know	0%	0%

Impact of 2013 Flood (A6)

	1:100 Flood Zone	1:200 Flood Zone
Emotional or psychological stress	54%	35%
Evacuation from your residence	78%↑	41%
Financial burden or stress	43%	23%
Health impacts or injury	11%	2%
Loss of important personal belongings	34%↑	7%
Property damage	42%↑	8%
Disruption to work, school, or daycare	61%	48%
Disruption to commuting routes or recreation	66%	70%
Anything else	6%	2%
None of the above	8%	15%
Don’t know	0%	0%

Base: All respondents (1:100 n=300; 1:200 n=101)
A4. Did you live in Calgary during the 2013 flood?
Base: Lived in Calgary during 2013 flood (1:100 n=293; 1:200 n=96)
A5. Did the residence you lived in at the time of the flood get flooded?
A6. Did you experience any of the following as a result of the 2013 flood?

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Demographics

Type of Home (E4)

	1:100 Flood Zone	1:200 Flood Zone
Single, detached house	56%	34%
Duplex, triplex, or fourplex	7%	2%
Townhouse or rowhouse	4%	1%
Apartment or apartment-style condominium	32%↓	62%
Another type of multi-unit complex	0%	1%
Prefer not to say	0%	0%

Basement ever flooded? (A10)

	1:100 Flood Zone	1:200 Flood Zone
Yes	70%	51%
No	30%	49%
Don't know	0%	0%
Not applicable	0%	0%

Have dependents? (E7)

	1:100 Flood Zone	1:200 Flood Zone
Yes	35%	27%
No	65%	73%
Prefer not to answer	0%	0%

Own or Rent (E5)

	1:100 Flood Zone	1:200 Flood Zone
Own	69%	67%
Rent	31%	33%
Other	0%	0%
Prefer not to say	0%	0%

Base: All respondents (Inside Flood Zone n=300; Outside Flood Zone n=101)
E4. What type of home do you live in? Is it a ...
E5. And do you own or rent your current residence?
E7. Do you have anyone in your household, of any age, who would be dependent on you in an emergency such as a flood?
Base: Lives in a house(1:100 n=255; 1:200 n=53)
A10. Has your basement ever flooded for any reason?

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

Demographics

Gender (E9)

	1:100 Flood Zone	1:200 Flood Zone
Male	54%	43%
Female	46%	57%
Other	0%	0%
Prefer not to answer	0%	0%

Age (Int1)

	1:100 Flood Zone	1:200 Flood Zone
18 to 24	4%	0%
25 to 34	16%↓	31%
35 to 44	47%↑	23%
45 to 54	7%	10%
55 to 64	15%	20%
65+	12%	16%
Prefer not to answer	0%	0%

Household Income (E8)

	1:100 Flood Zone	1:200 Flood Zone
Less than $30,000	6%	15%
$30,000 to just under $45,000	8%	4%
$45,000 to just under $60,000	6%	11%
$60,000 to just under $75,000	10%	4%
$75,000 to just under $90,000	12%	10%
$90,000 to just under $105,000	4%	3%
$105,000 to just under $120,000	7%	3%
$120,000 to just under $135,000	5%	1%
$135,000 to just under $150,000	1%↓	23%
$150,000 and over	33%↑	12%
Don't know	3%	0%
Prefer not to answer	6%	14%

Base: All respondents (1:100 n=300; 1:200 n=101)
E9. What is your gender?
Int1. Which of the following age categories do you fall into?
E8. Which of the following categories best describes your total household income in 2018 before taxes? Is it ...

↑ Significantly higher than 1:200
↓Significantly lower than 1:200

CALGARY'S FLOOD RESILIENT FUTURE

Report from the Expert Management Panel on River Flood Mitigation June 2014

CONTENTS

FOREWORD

In June 2013, Calgary and southern Alberta experienced the region's most severe floods since the early 1900s. Water levels and flows increased far beyond what was experienced during the last major flood in 2005. Large areas were inundated to depths never before seen; power supplies to large sections of downtown and residential areas were shut off; roads and light rail transit lines became impassable. Normal activities in the city stopped or changed significantly for the majority of Calgarians.

As the waters receded, an amazed populace took in the degree of the devastation. Homes, cars and valuables were damaged or destroyed. Offices, restaurants and shops were closed. Travel was difficult or halted in many areas. Extensive resources were mobilized by The City and the Province and an army of volunteers sprang up to deal with the immediate aftermath, trying to restore some semblance of normalcy. There are many for whom this event was devastating, both emotionally and financially, and who still struggle with the lingering impacts nearly a year later.

As the recovery process proceeded, Calgarians asked many questions, such as: How can we prevent this from happening again? What could we have done differently? When will it happen again? Is this normal or caused by a changing climate? How can I protect myself from future flooding?

The City of Calgary determined that a broad investigation of flood mitigation issues and responses was required. The City also decided that the investigation should be carried out by an arms-length body of experts who would bring to bear the most current knowledge available on these issues and who would extensively involve the public in their work. The River Flood Mitigation Program was established on those terms.

In order to lead the effort and to provide strategic direction, The City formed an Expert Management Panel as part of the mitigation program. The Panel gathered the input of many scientific and engineering experts, wide ranging public input and support from a number of City staff; from that, the Panel developed this report.

The report presents recommendations for making Calgary more resilient and prepared for future events. While the focus is on Calgary-specific measures, implementing the recommendations does not negatively impact communities outside of Calgary. To ensure there was coordination of these larger considerations and of the major investments being contemplated, Program staff have worked closely with the Province's Flood Recovery Task Force and other agencies and stakeholders.

Mitigating flood risks will not be achieved through a one-time report and set of recommendations. This report points to a way forward and contains only a few detailed actions. It outlines opportunities and also identifies where there is little to be gained – channeling future resources into appropriate areas. Much work will flow from this report and will have to be carried out by The City over time, often with provincial cooperation to achieve the desired outcomes.

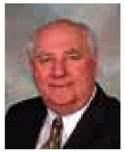
History shows that following through on recommended changes in the time after a disaster is always a challenge. Memories fade, other priorities arise and the will is lost to do the things that need doing. We encourage all parties to keep the financial and human costs of this event in mind and to maintain the determination to make Calgary more able to withstand, what will inevitably be, the next flood.

I want to note here my personal thanks for everyone's valuable advice and commitment to the mission.
One could not have expected more.

Wolf Keller
Chair of the Expert Management Panel
River Flood Mitigation Program

ACKNOWLEDGEMENTS

THE EXPERT MANAGEMENT PANEL



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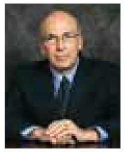

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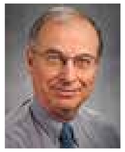

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THEME AREA SUBJECT MATTER EXPERTS

The following subject matter experts provided valuable input and feedback on the six theme areas:

Managing flood risk

Mary Axworthy, RPP, MCIP, Member, Alberta Municipal Government Board

Richard Boyd, Ph.D., M.Sc., B.A., C3 agency

Paul Kovacs, Institute for Catastrophic Loss Reduction, Western University

Punya Marahatta, Ph.D., M.Sc., M.Sc., McBride Career Group Inc.

Norma Nielson, Ph.D., University of Calgary

Gerald Osborn, Ph.D., P.Geol., University of Calgary

Watershed management

Richard Boyd, Ph.D., M.Sc., B.A., C3 agency

Werner Herrera, Environment and Sustainable Resource Development (former)

Chris Hugenholtz, Ph.D., University of Calgary

Danielle Marceau, Ph.D., University of Calgary

Cathryn Ryan, Ph.D., BSc, University of Calgary

Stewart Rood, Ph.D, B.Sc., University of Lethbridge

Michael Wagner, B.Sc., M.Sc., RPF, Alberta Environment and Sustainable Resource Development

Event forecasting

German Mojica, P.Eng., TransAlta Corporation

Colleen Walford, P.Eng., Alberta Environment and Sustainable Resource Development

Xin Wang, Ph.D., University of Calgary

David Watson, Alberta Environment and Sustainable Resource Development

Anthony Wimmers, Ph.D., University of Wisconsin

Wim Veldman, M.Sc., FEIC., P.Eng, Hydrotechnical Consultant

Storage, diversion and protection

Paul Breeze, B. Sc., P. Eng., C. Eng, Fellow of the American Concrete Institute, Fellow of the Canadian Precast/Prestressed Concrete Institute

Dave Chalcroft, P.Eng. FEC. FCAE, Consulting Engineer

Ron Chik-Kwong Wong, PhD., P.Eng, C.Eng., Head, Department of Civil Engineering, University of Calgary

Mike Kelly, Chair, Bow River Basin Council

Bunny Mah, M.Eng., P.Eng., Government of Canada (former), water resources manager in Alberta

Ken Manly, BSc, P.Eng, President C5 Engineering Ltd.

Infrastructure and property resiliency

John Brown, Architect, MAAA, FRAIC, University of Calgary

Laurian Farrell, P.Eng., MLA, PMP, Toronto and Region Conservation Authority

Donald Haley, P.Eng., Toronto and Region Conservation Authority (Retired)

David Lapp, FEC, P.Eng., Engineers Canada

Tang Lee, Architect, AAA, University of Calgary

Beverly Sandalack, Ph.D., FCSLA, MCIP, RPP, University of Calgary

Jishnu Subedi, Ph.D., MBA, University of Calgary

Changing climate

Heather Auld, M.Sc., Risk Sciences International

Jianxun (Jennifer) He, Ph.D., P.Eng., University of Calgary

Joelle Rekers, M.Sc., City of Calgary (former), environmental economist

David Sauchyn, Ph.D., P.Geo., University of Regina

Caterina Valeo, B.Sc., M.Eng., Ph.D., University of Victoria

EXECUTIVE SUMMARY

Although the 2013 flood was the largest in recent memory, historical records indicate that Calgary experienced floods of similar magnitude in 1879, 1897 and 1932. The impacts of these earlier floods were less severe because Calgary was not as densely developed at the time. There will always be a risk of flooding within the floodplain and a flood larger than the 2013 flood will likely occur in Calgary's future. While future floods cannot be prevented, action can be taken to better ensure public safety and minimize flood damage. Urban centres around the world are challenged by the need to improve resiliency to extreme floods; best practices from a number of these cities can help inform Calgary's ongoing resiliency efforts.

Without effective flood response measures during the 2013 flood and, flood-resiliency efforts that followed the 2005 flood, damage to Calgary in 2013 would have been even more devastating. Despite protective measures, the city experienced major flooding, required extensive evacuation, saw its downtown core rendered inaccessible for days and had significant flood damage to both private and public property. Damage estimates range into the billions of dollars.

Following the flood of 2013 The City of Calgary has been repairing damage, restoring services and making sure it is better prepared for the next extreme flood. The City established the River Flood Mitigation Program to recommend ways of managing future river flood risks in Calgary. Dialogue with Calgarians was a priority and included numerous community open houses and meetings with groups representing flood-affected communities. Close coordination with the Province allowed work plans and recommendations to be aligned. To guide the program, The City formed an independent Expert Management Panel who identified six theme areas to guide the development of recommendations.

This report presents recommendations from the Panel in six action areas that emerged across the six themes. The Panel also identified actions that it does not recommend The City undertake. In addition to the recommendations, the Panel identified major findings from each of the six themes investigated.

MAJOR FINDINGS FROM THE SIX THEMES

Managing flood risk

- Living in a floodplain has inherent risks, which can be managed, but they can never be eliminated. As seen in the flood of 2013, the level of flood risk in Calgary is unacceptably high and it is time to invest in better managing that risk.
- Increasing the level of flood protection would result in less damage, disruption and risk to human life when flood occurs. Investing in greater flood protection will be expensive and may be disruptive.
- In some cases it is more practical to move development away from the water than to move water away from development. Relocating people, homes and businesses is inherently a painful process for a community, but it needs to be considered as part of an overall plan.
- Informing and communicating with Calgarians about flood risk requires relatively little investment and can provide a large benefit for individuals and communities.

Watershed management

- The 2013 floodwaters were mostly generated in the mountains and foothills and the Bow and Elbow Rivers rapidly carried them to Calgary and beyond. Land-use within the Bow Watershed has only a small influence on this type of extreme flood.
- An integrated approach to watershed management is important to buffer smaller floods and so water supply, water quality and natural habitats are not compromised.

Event forecasting

- After the 2013 flood, Calgarians in flood affected zones expressed that they wanted earlier notification of future floods to better prepare themselves. Because of Calgary's proximity to the mountains where river floods originate, warning of actual floodwaters approaching can only be given in hours, not days.
- The 2013 flood demonstrated high uncertainty in forecasting due to the nature of Alberta's watersheds and weather patterns. Earlier warning can be given to citizens but it will inevitably give false alarms as weather systems shift unpredictably.

Storage, diversion and protection

- Existing dams and reservoirs in the Bow and Elbow watersheds have limited flood reduction potential and are managed to balance a number of watershed objectives. The existing storage on the Bow and Elbow Rivers was used to buffer the 2013 flood. If not for these reservoirs, the flood would have been much more severe in Calgary.
- There are opportunities for additional floodwater control. Modified operation of the TransAlta dams on the Bow River, three potential large-scale civil works on the Elbow River, and opportunities for new permanent flood barriers are subjects of further study by The City and the Province. An integrated analysis is needed to identify the best combination of flood mitigation measures on each river.
- The City has emergency plans for constructing temporary barriers in the event of floods of various magnitudes. Temporary flood barriers are not feasible in some areas because they would be required along lengthy stretches of private riverside property.

Infrastructure and property resiliency

- Many communities in Calgary were built before there were criteria for locating development outside of the floodway or designing properties for flood-resilience. As a result, much private development in the floodplain is inadequately built to withstand floods.
- Policy and planning changes can be used to build flood resiliency into City-owned and managed public infrastructure over time. Building resiliency into utility and communication infrastructure involves working in partnership with the private sector and may require significant investments.
- Many of the recovery projects undertaken by The City to repair damaged infrastructure after the floods of 2005 and 2013 have included measures to improve resiliency.

Changing climate

- Changes in the global climate system are expected to bring more frequent and intense weather events around the world, including to the Canadian prairies. The probability of experiencing extreme floods in the future could be greater than in the past.
- Flood mitigation work should be done with a view to several possible climate scenarios including drought. Design standards and mitigation measures should be versatile as part of a comprehensive approach to climate adaptation.

Building resilience to flooding requires action across many disciplines and organizations. The Panel worked particularly closely with several other initiatives critical to Calgary's flood resiliency to ensure efforts were coordinated: The City of Calgary Flood Recovery Task Force, the Calgary Emergency Management Agency and the Alberta Flood Recovery Task Force.

This report is one step of many towards greater resiliency to floods and other disruptive events in Calgary. The suite of recommended actions presents an approach that requires collaboration with the Province of Alberta and other stakeholders, and sets a direction towards Calgary's flood resilient future.

ACTION AREAS AND RECOMMENDATIONS

As potential flood mitigation measures were explored across the six themes, key recommendations emerged and were divided into six action areas based on common goals. The Expert Management Panel recommends that The City of Calgary undertake the following suite of actions as part of a multi-faceted approach to continue making Calgary more resilient to future river floods.

Immediate actions should be undertaken and completed as soon as possible.

Mid-term actions should be completed within The City's Action Plan 2015-2018.

Long-term actions should be initiated within Action Plan 2015-2018.

Ongoing actions are existing initiatives that should receive additional attention.

Through its investigation of potential flood mitigation measures, the Panel concluded that some options should not be considered further. The Panel **does not** recommend the following:

- Dredging the Glenmore Reservoir, the Bow or the Elbow Rivers, because of high costs, negative impacts, and a negligible effect on flood mitigation.

ACTION AREAS AND RECOMMENDATIONS	TIMEFRAME	PAGE
ACTION AREA 1: DEVELOP OPTIONS FOR PROTECTING COMMUNITIES, INFRASTRUCTURE AND PRIVATE PROPERTY TO A HIGHER FLOOD LEVEL.		
a. Perform a social, economic and environmental analysis to evaluate the need for a minimum flood protection level above the 1:100 flood currently used for land-use planning and structural protection across Calgary.	MID-TERM	19
b. Create graduated flood protection level requirements for City infrastructure.	MID-TERM	47
c. Expand the review of the Land Use Bylaw and other development regulations to update flood resiliency requirements for private property in flood risk areas.	MID-TERM	50
d. Strengthen partnerships with utility providers to improve resiliency of their infrastructure and operations, with first priority to energy supply and communication networks.	ONGOING	49
ACTION AREA 2: SUPPORT CALGARIANS IN MANAGING THEIR FLOOD RISK THROUGH IMPROVED NOTIFICATION, FORECASTING AND PREPAREDNESS.		
a. Pursue a common river forecasting platform with Alberta Environment and Sustainable Resource Development (AESRD) and TransAlta for faster and more accurate information and alerts about future flood events.	MID-TERM	32
b. In partnership with AESRD and TransAlta, expand the network of river and weather monitoring stations upstream of Calgary and protect stations from damage during flooding.	MID-TERM	31
c. Incorporate lessons learned from the 2013 flood to enhance communication channels to keep Calgarians informed of conditions that may lead to high river levels.	IMMEDIATE	34
d. Expand the flood risk communication strategy and provide information and tools that empower Calgarians to make informed choices and better manage their personal flood risk.	ONGOING	24
e. Develop programs that support building-owners to implement flood resiliency measures.	MID-TERM	51
ACTION AREA 3: AS PART OF AN INTEGRATED CITY AND PROVINCIAL PROGRAM, PERFORM SOCIAL, ECONOMIC AND ENVIRONMENTAL ASSESSMENTS OF CAPITAL WORKS OPTIONS TO INCREASE STORAGE, DIVERT WATER AND INCREASE PROTECTION.		
a. In partnership with the Province, compare the three major capital works options for mitigating floods on the Elbow River and identify the optimal investment plan: i. A diversion from the Elbow River to the Bow River, in accordance with the conclusions of the feasibility studies underway. ii. The Springbank off-stream diversion and storage site. iii. The McLean Creek dry dam.	MID-TERM	42
b. Increase the operating water storage capacity of the Glenmore Reservoir on the Elbow River through modifications to the Glenmore Dam.	MID-TERM	40

- Moving **all** development out of the floodplain, as Calgary is strongly established in some floodplain areas. Removal of buildings in strategically selected locations may be warranted where the risk is unacceptably high or the buildings prevent the construction of flood barriers that would protect the broader community.
- Investing in watershed stewardship actions in the context of a river flood mitigation strategy, because these actions would have minimal benefit in preventing alpine flood events. Watershed management is, however, recognized as critical for achieving other environmental objectives.
- Building permanent or temporary flood barriers directly along the shore of the Elbow River residential areas because of challenges with private property. Where critical stretches of riverside land are available and identified as appropriate for flood protection, flood barriers should be considered.
- Diverting floodwaters from the Bow River through the Western Irrigation District canal system at Harvie Passage, because the canal system would likely be damaged and does not provide the opportunity to divert significant flood volumes.
- Focusing climate adaptation planning exclusively on flood potential. Instead, a comprehensive approach allows many possible climate scenarios to be addressed, including the possibility of more severe droughts.

ACTION AREAS AND RECOMMENDATIONS	TIMEFRAME	PAGE
c. Continue to cooperate with TransAlta and the Province to increase flood storage on the Bow River through existing TransAlta facilities.	ONGOING	38
d. Construct additional or higher flood barriers in key locations throughout the city and update temporary flood barrier plans to protect against higher flood levels.	MID-TERM	44
ACTION AREA 4: MANAGE CALGARY'S FLOODPLAIN TO REDUCE IMPACT FROM RIVER FLOODS OVER THE LONG-TERM.		
a. Review The City's existing land-use planning documents and develop amendments, new guidelines or policies that will minimize development in the floodplain over time.	MID-TERM	22
b. Prepare a time-phased plan to modify structures that constrain river flow during flood events, such as pathways and bridges.	LONG-TERM	44
c. In partnership with the Province, develop a time-phased plan to remove buildings from areas with high flood risk, while minimizing the disruption to affected communities.	LONG-TERM	22
ACTION AREA 5: IMPROVE UNDERSTANDING OF FLOOD RISKS, PRESENT AND FUTURE.		
a. Publish up-to-date, graduated flood maps for public information.	ONGOING	21
b. Urge the Province to regularly review and update official flood hazard maps.	IMMEDIATE	21
c. Maintain a comprehensive flood risk database integrated with existing geographic information systems (GIS).	ONGOING	47
d. Develop a suite of watershed-scale climate models to capture various weather event scenarios, with input from regional partners, post secondary institutions and other levels of government.	MID-TERM	54
e. Collaborate with academic and other partners to develop computer models that identify groundwater movement in Calgary in relation to flood conditions.	MID-TERM	28
ACTION AREA 6: ESTABLISH A VISION AND FRAMEWORK FOR ONGOING FLOOD RESILIENCY ACTIVITIES FOR THE CITY.		
a. Establish a permanent team within The City to oversee flood preparedness and resilience.	MID-TERM	55
b. Connect with the provincial body overseeing flood protection and loss reduction and support the Province's continuing analysis of flood mitigation options and implementation of appropriate measures throughout the Bow and Elbow watersheds.	IMMEDIATE	56
c. Evaluate social, economic and environmental impacts of flood mitigation options.	MID-TERM	56
d. Develop a comprehensive climate adaptation plan and implementation tools to reduce The City's infrastructure and operational vulnerabilities.	MID-TERM	53
e. Host a national flood risk management workshop to share best practices and develop an ongoing networking group.	IMMEDIATE	56
f. Provide an annual update to City Council on progress related to the recommendations from the Expert Management Panel on River Flood Mitigation.	IMMEDIATE	55

INTRODUCTION

Resilience is the capacity to endure and recover from disruptive events. Resilience requires appropriate action before, during and after an event to minimize negative effects. A more resilient city suffers less impact when disasters occur and recovers more quickly.

The flood of June 2013 was the largest flood in Calgary since 1932. Extraordinary rainfall in the Rocky Mountains and foothills over several days led to high water levels in and around the city.

Across Alberta, the flood resulted in the loss of five lives and as much as $6 billion in financial losses and damage to property. Those who were evacuated and whose homes were flooded were faced with trauma, loss, and the challenge of rebuilding or the permanent loss of their home. Flooding disrupted businesses and damaged critical infrastructure. It also led to power outages across some parts of Calgary.

Increased population growth and urbanization result in a greater impact to people and economies when these extreme weather events occur.[i] Natural catastrophes are also becoming more common around the world, driven in part by changes in weather patterns. Cities need to invest in preparing for more frequent and severe natural events to protect their citizens, their infrastructure and their finances.

THE WEATHER

THE CALGARY DAILY HERALD

5 O'CLOCK EDITION

HUNDREDS OF CITY HOMES MENACED BY RIVERS

Baldwin Gov't Votes to Hand In Resignation

Ghost River Dam Menaced by Floods

Worst Floods Since '02 Ravage Calgary And South Districts

Two Streams Pouring Flood Waters Over Big Sections of the City

Swollen Highwood Flowing Through High River Streets

Bow and Elbow Rivers

It has been about 80 years since the last extreme flood struck Calgary.

THE 2013 FLOOD

An extreme weather event - a successful civic response - Heavy rains on melting snowpack in the Rocky Mountains combined with steep, rocky terrain caused rapid and intense flooding in several southern-Alberta watersheds in June 2013. As the waters rushed down the rivers in the steep alpine region and through the foothills towards Calgary, The City issued a flood warning, activated the Municipal Emergency Plan, declared a state of local emergency and gave an evacuation notice for communities at risk.

To protect the city from impending floodwaters, The City had lowered the water level in the Glenmore reservoir to the limit at which drinking water could still be supplied by the treatment plant, maximizing the volume of floodwaters that were captured by the reservoir. Temporary flood barriers were constructed at many critical locations throughout the city. TransAlta also responded quickly and was able to reduce the flood level in the Bow River through operations at its six upstream reservoirs. Throughout all of this, The City was able to maintain drinking water quality for Calgarians. Without these flood response measures, damage to Calgary would have been much more devastating.

Despite these protective measures, there was major flooding over the banks of the lower Elbow River, and the Bow River over-topped its banks in several locations. Calgary efficiently carried out its emergency response plan, including approximately 80,000 evacuations. The time for warning is short given the close proximity of the mountains, where river floods originate. Extensive emergency response was required across 32 communities in Calgary and the downtown was inaccessible for days.

Significant flood damage was caused to both private and public property by overland flooding, rising groundwater, storm water back-up and sewer back-up. The impact to individuals from the trauma of emergency evacuations and the damage to private property was immense. Recovery continues to be costly for both public and private property.

How often have floods like 2013 happened? - Although the 2013 flood was the largest in recent memory, it was within the range of natural variability for the Bow River. Historical records indicate that Calgary experienced floods of similar magnitude in 1879, 1897 and 1902 on the Bow River. Other large floods occurred in 1929 and 1932 on both the Elbow and the Bow Rivers. No floods of the magnitude of the 2013 event have occurred since 1932 (Figure 1).

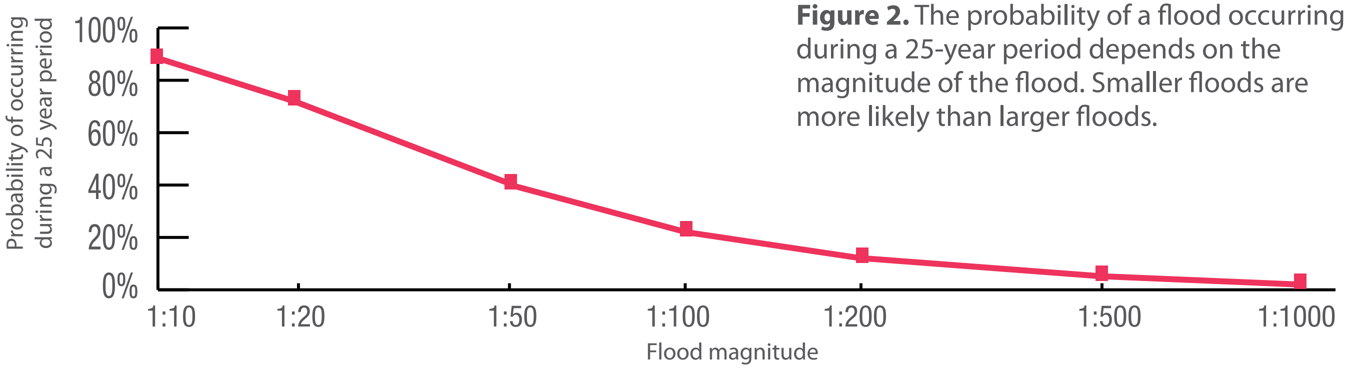


Figure 2. The probability of a flood occurring during a 25-year period depends on the magnitude of the flood. Smaller floods are more likely than larger floods.

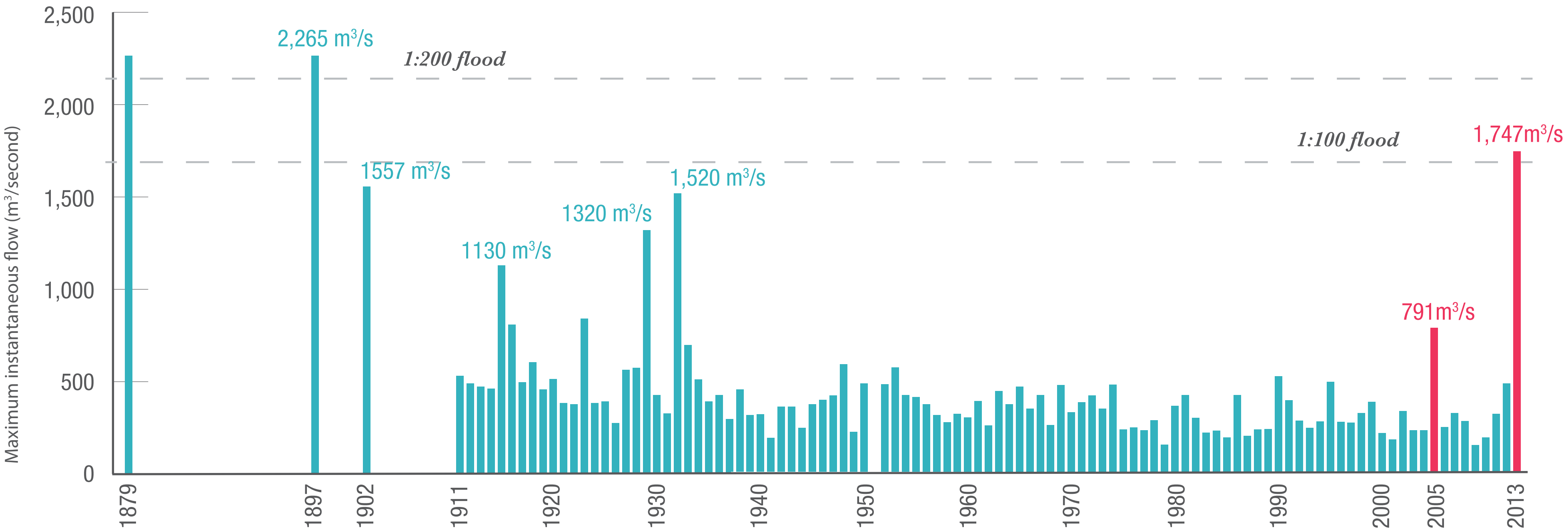


Figure 1. Maximum flow in the Bow River at Calgary between 1879-2013.

What is a 1:100 flood?

A 1:100 (or 100-year) flood is a flood event that has a one per cent chance of happening in any given year. This does not mean that after a 1:100 flood occurs it will not happen again for another 100 years; a similarly sized flood has a one per cent chance of happening again the following year and every year after that. Likewise, a 1:10 flood has a 10 per cent chance of happening and a 1:200 flood has a 0.5 per cent chance of happening in any given year.

During the lifetime of a 25-year mortgage, there is a 22 per cent chance of a 1:100 flood occurring (Figure 2).

The 2013 flood was approximately a 1:100 flood on the Bow River and downstream of the Glenmore Dam on the Elbow River. It was approximately a 1:500 flood upstream of the Glenmore Dam; the difference was the short-term flood storage in the Glenmore Reservoir. In comparison, the 2005 flood was approximately a 1:10 flood on the Bow and a 1:20 flood on the Elbow downstream of the Glenmore Dam.

THE COSTS OF THE 2013 FLOOD

The emotional and health costs of the 2013 flood were borne by over 100,000 Calgarians directly impacted. The financial costs continued to be shared by individuals, private companies, insurers, The City of Calgary, the Government of Alberta and the Government of Canada, and through them by taxpayers.

The full impact of the flood to Alberta, and Calgary in particular, is still being assessed. Estimates place the total costs for Alberta at $5 billion to $6 billion. The total estimated costs across Alberta that will be covered by the provincial and federal governments are $5 billion.[ii] The federal government reimburses provinces for up to 90 per cent of claimed disaster expenses.[iii]

A total of $445 million in damages City of Calgary infrastructure alone was identified by The City's Flood Recovery Task Force. Estimated costs recoverable by The City of Calgary through insurance are $166 million. The City is seeking full reimbursement from the Province for the $55 million cost of emergency response and additional provincial support for damages and staff costs (Figure 3).

The Province also provided immediate financial support for Albertans who lost their homes or were dislocated during the flood. It has grant programs in place to reimburse homeowners and businesses for costs related to flood recovery and relocating out of areas of highest flood risk.

Insured losses are estimated at $1.7 billion across Alberta.[iv] Canadian insurers are redesigning their policies or increasing premiums to respond to recent years' storm events in Alberta; more than half of Canada's insured losses since 2009 have occurred in this province.

Figure 3. Costs of the 2013 flood.

(Source: City of Calgary Flood Recovery Task Force: Update Report December, 2013.)

RIVER FLOOD MITIGATION PROGRAM

The City of Calgary established the River Flood Mitigation Program to investigate and initiate ways of mitigating future river flood risks. To guide the program, The City created the Expert Management Panel: a five-member panel of nationally and internationally recognized experts.

The Panel identified six theme areas that would guide the investigation:

- Managing flood risk
- Watershed management
- Event forecasting
- Storage, diversion and protection
- Infrastructure and property resiliency
- Changing climate

Dividing the work along the lines of the six themes allowed for a focused approach on each area of specialized knowledge. To provide subject-matter expertise, specialists in relevant areas were invited to generate and assess options for each theme. Many expressions of interest were received and a final selection resulted in 36 experts working on the six themes.

City staff managed the program and supported the Expert Management Panel and technical committees by providing information needed for assessing options and summarizing and presenting the results of discussions and technical input. In addition, they engaged extensively with Calgarians and contacted communities around the world to understand shared experiences and innovative approaches to dealing with similar challenges.

Building resilience to flooding requires action across many disciplines and organizations. From forecasting and monitoring weather, to engineering design standards and emergency preparedness, there are many planning processes and activities that are all critical for improving flood resilience. Many organizations and initiatives across Canada are improving flood resiliency. The Panel worked particularly closely with several other initiatives that are especially critical to Calgary's flood resiliency:

The City of Calgary Flood Recovery Task Force - This task force was created following the 2013 flood and includes representatives from across The City. This team has been essential in identifying and resourcing immediate flood recovery activities and supporting the development of recovery, mitigation and resilience recommendations for The City's 2015-2018 business planning and budgeting cycle. The task force is focused on five priority areas: people, housing and property, infrastructure, services and funding.

Calgary Emergency Management Agency (CEMA) - CEMA works with City departments and the community to increase Calgary's capacity to be prepared for and recover more quickly from a disaster. During the 2013 flood, CEMA worked with the Water Emergency Operation Centre, emergency responders, other City departments and outside agencies to provide a coordinated multi-service and multi-jurisdictional response.

Alberta Flood Recovery Task Force - This task force coordinates the provincial intermediate and long-term recovery efforts, including supporting community recovery efforts through funding and information and ensuring effective flood hazard mitigation to protect against potential future damage.

The Panel also heard from Calgarians

Early in the program, the Panel invited Calgarians to share their ideas and comments to cast a wide net for possible actions and to try to understand the questions that needed to be addressed in the final report. Over 200 written submissions were received from citizens in over 70 communities. Dialogue with communities has been a priority and has included numerous community open houses and meetings with groups representing flood-affected communities.

Public input provided insight into how the 2013 flood affected people in the city and ideas for preparing better for the next flood event. Quotes from Calgarians appear throughout this report.

Calgary is more flood resilient today than in 2013

Since the flood of 2013 The City of Calgary has been actively repairing damage, restoring services and making sure The City is better prepared for the next extreme flood. Learning from the effects of the 2013 flood, activities undertaken by The City include making infrastructure more flood resilient as it is rebuilt, reviewing legislation that governs flood protection for private property and stockpiling additional supplies for emergency flood response. The City is also working closely with utility providers to improve the resilience of power supply and communication systems.

PRINCIPLES FOR FLOOD RESILIENCE

Future floods cannot be prevented, but The City can take action to protect public safety and minimize the damage that floods cause. The focus of the Panel's work has been to develop recommendations to The City of Calgary on how to continue improving resilience to extreme river floods. The development of recommendations was guided by the following four principles:

1. **Building resiliency:** Addressing vulnerabilities and taking proactive measures to safeguard infrastructure, minimize social, environmental and economic impacts, and protect public and private property

2. **Long-term vision:** Considering what Calgary should look like in the future and recognizing it will take time to achieve goals. Flood risks can be managed over time by using and building on existing initiatives.

3. **Watershed approach:** Looking at the Bow River Watershed for flood mitigation opportunities, and the implications of these opportunities for drought and potential upstream and downstream impacts. Measures must consider watershed-scale, city-scale and community-scale mitigation opportunities. Flood protection actions should not jeopardize the wealth that the rivers provide in the process. Safeguarding drinking water, natural habitats and recreational opportunities are also important priorities for all decisions affecting the river valleys

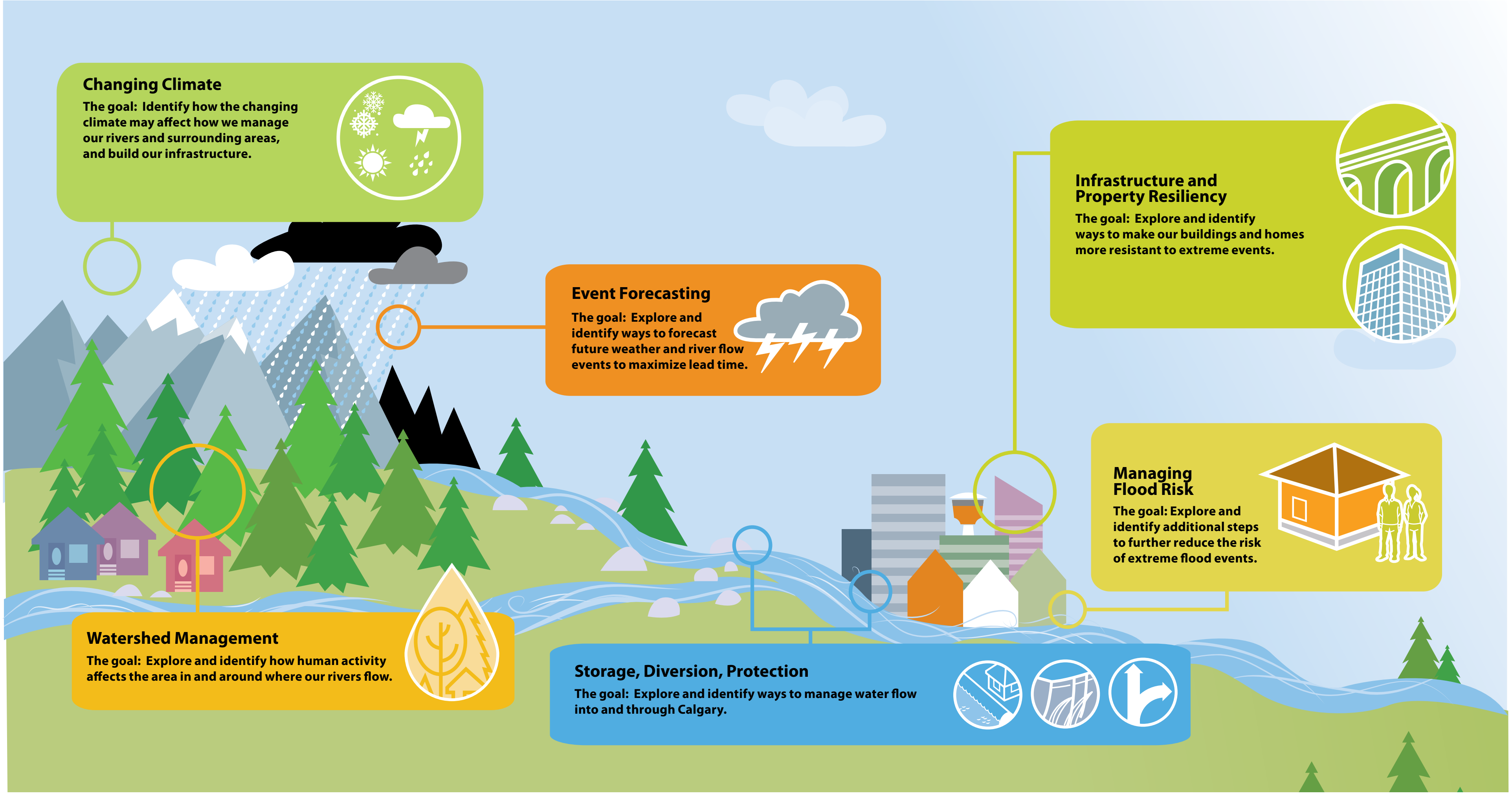
4. **Working with the river:** Enhancing value throughout the city by protecting and conserving natural systems, protecting water resources and riparian areas and integrating non-infrastructural, ecosystem-based approaches. Approaches should seek to accommodate the natural hydrology of the region, including the consequences of drought.

Infrastructure	Planning and Assessment		Response
Riverbank stabilization	Survey of riverbed	River Flood Mitigation Program - Expert Panel	Training
River debris removal	River modeling and mapping	Development & Building Approvals flood team	Temporary barriers
Storm & sanitary sewer upgrades	Permanent flood barrier assessment	Environmental & fisheries studies	Stockpile supplies
Repair of bridges, pathways, roads	River morphology study	Assess Bylaw and other policies	Forecasting & monitoring
Water & wastewater plants repair	Engagement		Communication
	Community	Province	

Figure 4. The City of Calgary has undertaken many actions since the 2013 flood to improve resiliency.

RIVER FLOOD MITIGATION THEMES

Figure 5. The Expert Management Panel on River Flood Mitigation established six themes to focus on.



Changing Climate

The goal: Identify how the changing climate may affect how we manage our rivers and surrounding areas, and build our infrastructure.

Event Forecasting

The goal: Explore and identify ways to forecast future weather and river flow events to maximize lead time.

Infrastructure and Property Resiliency

The goal: Explore and identify ways to make our buildings and homes more resistant to extreme events.

Managing Flood Risk

The goal: Explore and identify additional steps to further reduce the risk of extreme flood events.

Watershed Management

The goal: Explore and identify how human activity affects the area in and around where our rivers flow.

Storage, Diversion, Protection

The goal: Explore and identify ways to manage water flow into and through Calgary.

MANAGING FLOOD RISK

Over the past century Calgarians have collectively chosen to develop a portion of Calgary in the floodplain. Living in a floodplain has inherent risks, as the flood of 2013 made obvious. These risks can be managed, but they can never be eliminated. Following the flood of 2013, there has been a strong sense that the flood risk in Calgary may be unacceptably high.

To effectively manage flood risk, the probability and impact of flood events must first be understood. The better risk is quantified, the more informed risk management decisions can be. There are four general strategies for managing any kind of risk, including floods:

Avoid risk: Calgarians can choose to live, work and play in areas with higher risk or areas with lower risk. New development can be located away from high risk areas and existing development can be moved out of high risk areas. Relocating development is costly and disruptive.

Reduce risk: Many actions can reduce risk so it becomes more tolerable. Reducing risk may entail implementing flood resiliency measures for buildings, erecting flood barriers, constructing large scale infrastructure such as dams or diversions and emergency preparedness.

Transfer risk: Some financial risk can be transferred to other parties, for a cost. The City of Calgary has transferred some of its risk to insurance companies and some of the risk is shared with the provincial and federal governments. Homeowners in Canada have limited options for insuring against floods.

Accept risk: Risk that is not avoided, reduced or transferred is necessarily accepted by everyone who locates in areas with flood risk. This may be termed "tolerable risk"; it is not welcomed, but it is tolerated. The amount of flood risk tolerated affects how heavily impacted Calgary will be when floods occur.

Within each of these strategies there are actions that have already been taken by The City of Calgary and opportunities for The City, individuals and businesses to further manage flood risk (Table 1).

		GOVERNMENT	INDIVIDUALS & BUSINESSES
UNDERSTAND RISK		• Identify likelihood of floods and potential impacts	• Understand likelihood of floods and potential impacts
MANAGE RISK	AVOID	• Move and keep development out of flood risk areas	• Locate outside of flood risk areas
	REDUCE	• Construct and maintain flood defences • Set flood protection requirements for development • Undertake flood forecasting • Prepare for flood response	• Design and build property for flood resilience • Understand flood risks • Prepare for to respond effectively to flood warnings
	TRANSFER	• Insure public infrastructure	• Insure private property (limited options in Canada)
	ACCEPT	• Accept residual risk of development in flood risk areas • Prepare for recovery	• Accept residual risk of locating in a flood risk area

Table 1. Actions that governments, individuals and businesses can take to understand and manage flood risk.

Understanding and managing flood risk is a continuous process. It is prudent for municipalities, businesses and individuals to consider the amount of flood risk they tolerate, and whether it is appropriate to avoid, reduce or transfer more of that risk. This section discusses a number of ways The City of Calgary can further manage flood risk:

- Increase Calgary's flood protection level.
- Reduce development in flood risk areas.
- Support Calgarians to manage their personal flood risk.

Flood protection levels

Winnipeg is protected to the highest flood level of any city within Canada; the Red River Floodway diversion system provides protection up to a 1:700 flood. Manitoba uses the 1:100 flood level for flood protection across the province and is considering increasing this to a 1:200 flood.[v] *The protection of Winnipeg to a higher level was based on a cost-benefit analysis , and the local geography allowed for a practical capital project in the form of the Red River Floodway.*

British Columbia recently increased its flood protection level from a 1:100 flood to 1:200 flood for new flood protection works, but it does not require existing flood protection to be raised to meet this new standard. Calgary and Alberta use a 1:100 flood level for protection planning and Alberta has guidelines for locating new critical structures such as schools and hospitals where they will be protected to as high as a 1:1000 flood level.[vi] *Ontario uses the 1:100 flood or the largest flood on record, whichever is largest.*[vii]

The flat geography of The Netherlands, much of which is below sea level, means that if dikes were breached, results would be catastrophic. The Dutch build dikes to protect against river flooding to a 1:1250 flood level; this protection level was set qualitatively and then reviewed according to cost-benefit and risk of loss of life analyses. Given the extensive engagement and analysis required for this assessment, the Netherlands has determined that every 50 years is an appropriate period of time to review flood protection levels.

CALGARY'S FLOOD PROTECTION LEVEL

Much of Calgary's flood management is based on the 1:100 flood, but this is not universally applied across the city. Some parts of Calgary have a flood protection level lower than the 1:100 flood and a few isolated areas have a flood protection level higher than the 1:100 flood. The *Storage, Diversion and Protection* section of this report discusses the protection level provided by flood barriers and why it varies across Calgary.

- Permanent and temporary flood barriers in Calgary are primarily designed to protect against floods as high as the 1:100 flood, plus a margin of safety where possible. However, not all parts of the city's floodplain are protected to this level, leaving some areas vulnerable to more frequent flood events. In several locations, flood barriers have been built to above a 1:100 flood level to provide additional protection.
- The official provincial flood hazard maps show areas that may be impacted by a 1:100 flood. These maps are the basis for flood-related land-use planning and bylaws, governing where development is allowed to occur and according to which requirements.
- Private property has to meet specific flood protection requirements under The City's Land Use Bylaw if it is built within the flood fringe as indicated by the official 1:100 flood hazard maps.

In this way, Calgary tolerates more flood risk than some cities and provinces in Canada and abroad that have chosen to invest in protecting to a higher flood level than the 1:100 flood.

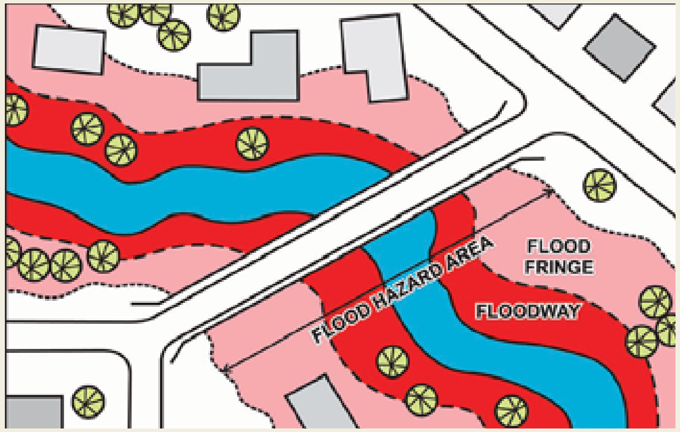


Figure 6. Plan view showing flood hazard areas where red is the floodway, blue is the normal river channel and pink is the flood fringe.

Source: Government of Alberta, 2013 (http://environment.alberta.ca/01655.html)

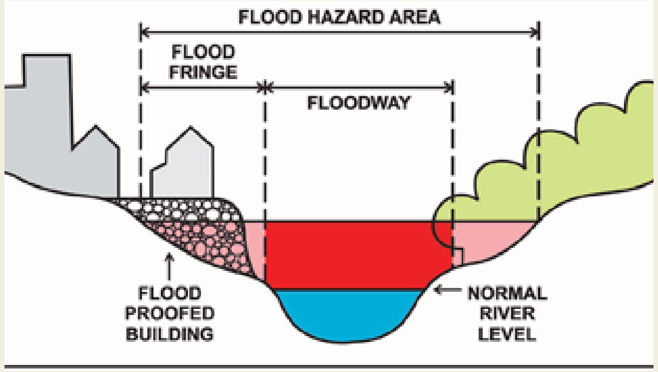


Figure 7. Cross sectional view of flood hazard areas. Development within the flood fringe is permissible providing it is flood resilient. Development in the floodway is not permitted.

Floodway, flood fringe and overland flow: flood hazard maps

Flood hazard maps are official provincial maps that define the areas likely to be affected by surface water during a 1:100 flood. The flood hazard area is divided into floodway and flood fringe zones (Figure 6 and Figure 7).

The floodway is the portion of the flood hazard area where floodwaters are the deepest and most destructive. Floodwater in the flood fringe is generally shallower and flows more slowly than in the floodway. Within Calgary a special type of flood fringe area has been defined: overland flow areas. Overland flow areas are parts of the flood fringe where water is assumed to flow along the ground at very shallow depths and slow velocities, often along roads or across fields.

Flood hazard maps for Calgary were passed into legislation by the Government of Alberta in 1983. These official maps were updated in 1996 following additional modeling work. The Province has updated the criteria for defining the floodway since the Calgary maps were prepared in 1983. The updated definition for the floodway includes any area that experiences floodwaters deeper than one metre or flowing faster than one metre per second. Flood hazard maps throughout the rest of Alberta use this broader definition of floodway, but the Calgary floodway has not been re-mapped according to the new criteria.

Increasing Calgary's flood protection level

The level of flood protection that is appropriate for a specific city, or a specific neighbourhood, is a financial, environmental and social consideration. Investing to achieve a higher flood protection level would result in less damage, disruption, and risk to human life when floods occur. A higher flood protection level would also reduce demands on emergency response service during floods and speed up recovery after floods.

However, achieving higher flood protection involves substantial trade-offs that would affect some parties negatively. It could require greater investment in flood barriers, stricter land-use planning, additional requirements and limitations for development in flood risk areas and large capital works, among other actions. Many of these measures are expensive and disruptive and some would also have aesthetic and environmental impacts.

Given that flood risk changes with time, as do social values and the physical environment, the appropriate level of flood protection should be reassessed periodically. After the 2013 flood, The City of Calgary should consider whether protection above the 1:100 flood level is warranted across all or some parts of Calgary.

> "When The City grants approvals to build on or adjacent to the current [1:100] floodway line, The City is asking for trouble. The [1:100] flood is a statistical prediction that does not include the really large floods that could happen in the near or distant future." – Public input

Recommendation: Perform a social, economic and environmental analysis to evaluate the need for a minimum flood protection level above the 1:100 flood currently used for land-use planning and structural protection across Calgary.

> "Assess the appropriate level of [flood protection], i.e., 1:100 or 1: 200 or 1:500, etc. Other jurisdictions have adopted substantially higher levels of [flood protection] given the resulting damage and rehabilitation costs of the system being swamped by flood flows." - Public input

Overland flow area operating as designed in Erlton neighbourhood

MANAGING DEVELOPMENT IN THE FLOODPLAIN

Calgary, like many other communities in Canada and around the world, has historically developed within the floodplain. As a consequence, portions of the city are inherently vulnerable to flood impacts from extreme events. The downtown core and several communities within the city are built in low-lying areas that are prone to surface flooding, high groundwater levels and sewer back-up during river floods. Since 1985, limited new development has been permitted in the floodway and flood resilience requirements guide new development in the flood fringe. At times these limitations are relaxed for development.

The amount of development in the floodplain has a significant impact on Calgary's vulnerability to flood events. Development along riverbanks also limits the protection that can be provided to entire neighbourhoods as land is unavailable for The City to construct either permanent or temporary flood barriers in these locations.

IMPROVING MANAGEMENT OF FLOODPLAIN DEVELOPMENT

The City can improve management of floodplain development by:

- Urging the Government of Alberta to update official flood hazard maps.
- Publishing up-to-date, graduated flood maps.
- Reviewing land-use planning policies and documents.
- Relocating selected development out of high risk areas.

Flood hazard maps - The official flood hazard maps prepared by the province show approximately 5,300 buildings in flood hazard areas within Calgary. Of these, only approximately 83 are fully or partially in the floodway. However, the river flood risk is greater than indicated by the maps. Experience from 2013 and the most recent modeling by The City of Calgary and the Province have shown:

- The 1:100 floodway could be significantly larger in some places than shown in the official flood hazard maps.
- The official flood hazard maps do not show the areas that would be affected by a flood larger than a 1:100 event.
- The official flood hazard maps do not show areas that are likely to be affected by groundwater or sewer back-up flooding as a result of river flood events.

The greatest damage to public and private property from the 2013 flood was sustained within the official flood hazard areas, but The City estimates that about 20 per cent of the buildings damaged were outside of official flood hazard areas. This suggests that the current flood hazard maps are inadequate to communicate the extent of river flood risks in Calgary.

Flood maps need to be regularly assessed to ensure they reflect changing river morphology, development and climate and the latest technology for flood forecasting and modeling. The expanded criteria for defining the floodway, as used across the rest of the province, should be considered in an update to Calgary's flood hazard maps. Provincial legislative approval is needed to issue official flood hazard maps. This should be done regularly enough to reflect any significant changes to the best understanding of flood risk, so the municipal development approval process can be supported with up-to-date information.

Recommendation: Urge the Province to regularly review and update official flood hazard maps.

Graduated flood maps - A new model to generate flood maps in Calgary was completed in 2012 in partnership with the Province and is now being updated to reflect changes to the rivers from the 2013 flood. The maps generated by this model were accurate in predicting the extent of the 2013 flood and they are currently used to inform City of Calgary projects such as erosion control along riverbanks, bridges, flood barriers and emergency response plans. These flood maps provide information on flood events from as small as a 1:5 flood to as large as a 1:1000 flood. In May 2014, The City released maps up to a 1:100 flood on its website.

The maps do not, however, include information on the extent of groundwater flooding, which impacted many residences and businesses outside of the areas affected by surface water in 2013. Flood risk mapping should be expanded to include information about groundwater risks once these are further investigated, as discussed in the *Watershed Management* section of this report.

The City should generate user-friendly flood maps that show risk from larger flood events and groundwater and stormwater. Sharing the best available information will:

- Support Calgarians in understanding and managing their flood risk.
- Allow insurers to assess flood risk while designing insurance policies.
- Provide the possibility for graduated flood resilience requirements for private development.
- Inform discussions about the need for Calgary to consider higher levels of flood protection.

Recommendation: Publish up-to-date, graduated flood maps for public information.

> "Looking at the flood maps, it seems odd that the buildings across the street from us are in the floodway and we are in the flood fringe when there is very little (if any) elevation change between the two sides of the block." – Public input

"Do not allow construction in high flood risk areas. If areas are already occupied, The City should buy properties and assist in the relocation of occupants. Return areas to a natural state and designate as parks. The parkland can also act as a buffer for flood waters. Yes it is a very expensive and disruptive suggestion, but is it more expensive and disruptive than a major flood event?" – Public input

Land-use planning policies and documents

Resilience planning must be incorporated into long-term civic planning, such as zoning considerations and new infrastructure location and design. To ensure resilience considerations continue beyond the 2013 flood recovery program, they should be included in key City policy and planning documents.

Recommendation: Review The City's existing land-use planning documents and develop amendments, new guidelines or policies that will minimize development in the floodplain over time.

Relocating out of the floodplain - In Alberta, as in many places throughout the world, there are increasing examples of communities relocating development away from flood risk areas. Moving development away from rivers allows rivers to flood without damaging property or risking lives and preserves the ecological functions of riparian areas along riversides. In many cases it is more practical to move development away from the water, than to move water away from development.

In the fall of 2013, Alberta introduced legislation to prohibit future development in the floodway and initiated a relocation program for homes in the floodway, which has been extended until August 2014. As of April 2014, approximately 11 homes within Calgary have been purchased by the Province under this program. The houses are being removed from these properties and future development will never be allowed in these locations.

The purchased properties are scattered along the Elbow River, creating a speckled empty-lot effect throughout these neighbourhoods and raising challenges for maintenance and community integrity. Individual lots also provide very limited potential for The City to provide additional flood protection to the broader neighbourhood. Strategically selected, longer stretches of riverside land would be needed for permanent or temporary flood barriers. The City will likely take ownership, or at least maintenance, of these properties from the Province within several years.

It is a momentous decision for people to choose to relocate from their homes, and relocating people, homes and businesses is inherently a painful process for a community. The City should ensure that any further relocation is planned through close collaboration with affected communities and that property-owners are granted sufficient time to consider their options. Relocating development must also be planned with consideration of other flood mitigation measures that The City and the Province will undertake, which may reduce flood risk in some parts of Calgary.

The City should investigate whether removing buildings from flood-risk areas is warranted, and, if so, prepare a time-phased plan to support flood risk communities that will experience development relocation. This should include identification of areas that may be targeted for relocation, such as specific riverside areas that have the highest risk or restrict opportunities for flood protection for the broader neighbourhood. Relocation may include residential, commercial and public buildings.

If additional relocation is considered, it should be coordinated with the Province as a possible expansion of their current relocation program. This may be particularly applicable to properties that are not identified as being in the floodway under the official flood hazard maps, but are within the floodway according to more current flood maps. Residents in this expanded risk area may be unaware of their personal risk and need a reasonable opportunity to face this reality and its consequences.

Recommendation: In partnership with the Province, develop a time-phased plan to remove buildings from areas with high flood risk, while minimizing the disruption to affected communities.

"Neighbourhoods like mine are dying. Dying because many people cannot financially or emotionally afford to rebuild. Had a buyout offer been presented to me I would have taken it. We cannot afford to move. Our equity was in our home. So we rebuild. Where else can we go?" – Public input

Leaving the floodplain

In Alberta, the communities of Fort MacLeod, Medicine Hat, High River and Edmonton have all relocated development away from specific areas with high flood risk.

Houses in flood risk areas may be raised above flood levels rather than removed. Across the United States, homes that are substantially damaged by a flood are required to be raised above the flood safety level, as mapped by the Federal Emergency Management Agency (FEMA). Homes in designated flood zones that are not raised above this level have significantly higher rates for mandatory flood insurance.[viii] *Some states are providing grants to help homeowners raise houses that were damaged by Hurricane Sandy.*[ix]

Managing the floodplain for flood control

The Miami Conservancy District in Ohio manages more than 4,500 acres of protected floodplain land, in cooperation with municipal governments and local park districts and funded by the Ohio Greenspace Preservation Grant Program.[x]

Over 5,000 acres of land around the main river through Curitiba, Brazil, were purchased to create a large public park for flood control following a destructive flood in 1995. The population was resettled out of this new parkland, a secondary channel was constructed through the park to help carry flood flows and the park now serves as a buffer between the flood-prone river and the city.[xi]

MANAGING PERSONAL FLOOD RISK

Calgarians potentially affected by floods must determine the amount of flood risk that they are willing to tolerate. Calgarians can manage their flood risk through actions that include:

- Knowing the flood risk in their neighbourhood and staying informed during flood season.
- Protecting property against flood damage:
    - Designing and building private property to meet and exceed The City's requirements for flood protection if they are located in the flood fringe.
    - Undertaking flood protection measures such as installing backflow prevention devices even if they are outside of the official flood hazard area and particularly if they have been impacted by a previous flood.
- Insuring private property against flood damage to the extent that insurance is available.
- Preparing personal emergency and evacuation plans for themselves and their family.
- Choosing to locate outside of the floodplain.

> "People and businesses along the banks, especially the Elbow, must take action for themselves. Let's keep in mind that this is mother nature and people living in the floodplain must take that into account."
> – Public input

The extent of the 2013 flood came as a shock to most Calgarians. Evacuations covered large areas of the city and many people were surprised to find that their properties were flooded. The buildings that were most heavily damaged by surface flooding were properties constructed prior to regulations that offer additional flood protection through location restrictions and design requirements. However, flooding was widespread through the city's floodplain and included locations beyond the official flood hazard areas.

The costs to repair private property damage have been carried by individuals, insurance companies, the Province and the Federal Government. Property owners in the official flood fringe who received funding from Alberta's 2013 Disaster Recovery Program will not be eligible for future flood-relief funds unless they rebuild to meet flood mitigation requirements.

Properties in the floodway that are rebuilt with provincial funds are ineligible for any future flood relief regardless of the property's flood resiliency.[xii] Although the Province considered putting a notice on the land-titles of properties in the official flood hazard area that were damaged during the 2013 flood, it has chosen to examine other options to communicate with prospective property-buyers about flood risk.

There will always be a risk of flooding within the floodplain and a flood larger than the 2013 flood will likely occur at some point in Calgary's future. There are limits to the protection that can be provided by The City through large-scale flood diversions and barriers, as well as flood protection measures for homes and buildings. Protective measures could give Calgarians a false sense of security, reducing the likelihood that they will evacuate during future floods or otherwise manage their flood risk. It is critical that The City continue to inform Calgarians about the risk of flood and the importance of understanding and managing personal flood risk.

> "Manage expectations with the general public of how well flood mitigation measures will or will not work in future floods." – Public input

Insurance is a common mechanism used by homeowners and businesses to manage the risk of loss and damage from most hazards. Flood insurance is available for businesses in Canada, and insurance for homeowners for sewer back-up is widely available. Following the 2013 flood, payouts from insurance companies to property owners provided essential funds to support recovery. However, insurance against overland flooding (water that enters from the surface, typically through doors or windows) is not presently available for most homeowners in Canada.

Overland flood insurance is available to homeowners in many other countries, including the United States, United Kingdom, Germany and France. Canadian insurance companies have stated that flood risks are too high to be insurable in some places and municipalities like Calgary will have to reduce risk to make overland flood insurance feasible.[xiii] The insurance industry and the Government of Canada have begun discussing introducing residential overland flood insurance. In 2014 at least one insurance provider started to offer limited private property insurance for overland flood in Calgary.[xiv] Where uncertainty about the probability of flooding exists, insurance premiums will likely be unaffordable for many Calgarians.

Supporting Calgarians to better manage their personal flood risk - The City can provide additional information, tools and programs that will support Calgarians in assessing and managing their personal flood risk. As it may be many years until the next major flood event, The City must maintain awareness of flood risks. Educating and communicating with Calgarians requires relatively little investment and provides a large benefit for individuals and communities. The City already provides flood-related information to Calgarians through multiple departments and channels. This information should be reviewed as part of a comprehensive flood risk communication program.

> "Establish a 'monument to the flood.' People's memories are too short and complacency about the river will soon be prevalent again." – Public input

Information and tools that would support Calgarians to manage their personal flood risk include:

- Interactive maps that easily communicate the flood risk for specific properties.
- Information on the flood protection level provided by flood barriers for specific neighbourhoods.
- A checklist for measures to make homes and buildings more resilient to floods.
- Information on how to prepare for evacuation and infrastructure outages.
- Flood education built into a school education program.
- Flood resiliency measures and products showcased through public events, such as a public exposition.

Some property-owners may prefer to not have such flood risk information made widely available because it may affect property values. While The City does not wish to adversely affect the economic circumstances of individual Calgarians, The City has a responsibility to full disclosure to prospective buyers. Precedents for situations involving disclosure about asbestos and other hidden real estate risks are well established.

Recommendation: Expand the flood risk communication strategy and provide information and tools that empower Calgarians to make informed choices and better manage their personal flood risk.

Communicating flood risk

In the United Kingdom a flood report that details the specific flood risks to a home is a standard element of property purchasing. The report outlines the degree of flood risk from various types of flood events and gives the home an overall flood risk rating. It also provides descriptions and estimated costs of measures that could make the home more resilient to flooding.

A similar program exists in Toronto, initiated with the real estate industry to ensure prospective owners are made aware of the existing flood risks.

> "Provide education and assistance on flood proofing measures: Do I have a backflow preventer? Do I need one? How much would it cost? What about sump pumps?" – Public input

WATERSHED MANAGEMENT

A watershed or drainage basin is an area of land that slopes toward and drains to the same place. Upstream of Calgary, the Bow River Watershed (which includes the Elbow River, Nose Creek, Fish Creek and Pine Creek tributaries) comprises about 10,000 km^2 of land. The Elbow River sub-watershed makes up 1,200 km^2 of this area.[xv] Much of the upper watershed is steep mountain or foothills that cause rainfall to rapidly runoff (Figure 8).

Calgary is the only large city in Canada that is located at the confluence of two mountain rivers that are subject to rapid development of flood conditions. The waterways flow from the mountains through the foothills towards Calgary, passing through various ecosystems and landscapes before reaching the city. The watershed provides habitat for a variety of plants and animals, and supports irrigation, hydro-power, industrial uses and recreational opportunities. The Bow and Elbow Rivers also provide the critical supply of drinking water to Calgary, as well as other communities along the rivers.

Flows in the Bow and Elbow Rivers change seasonally. Peak run-off typically occurs in June when both mountain snowmelt and rainfall occur at the headwaters in the Rocky Mountains. Snowmelt is a smaller fraction of the runoff and is an important contributor to summer flows needed for water supply to municipal, industrial and agricultural users. Flows decline over the late summer, fall and winter; during that time groundwater from aquifers becomes an important source for river flow. The amount of storage, such as reservoirs, lakes and wetlands in the watershed is not large enough to completely buffer the wide range of precipitation experienced in the watershed. The result is that the watershed is prone to both flood and drought, with drought being a more frequent occurrence. (Figure 9).

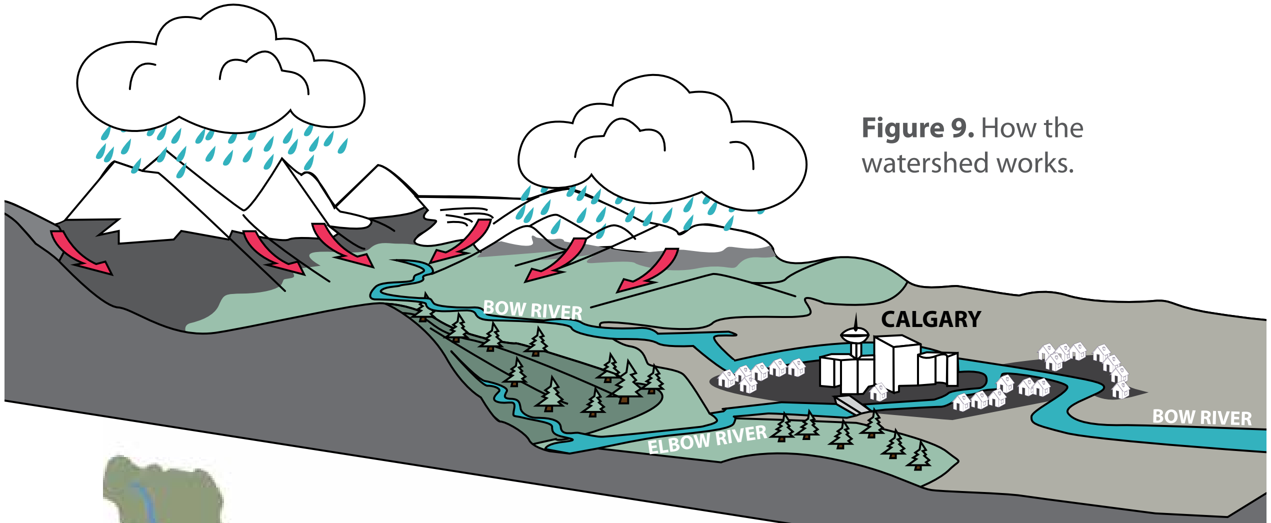


Figure 9. How the watershed works.

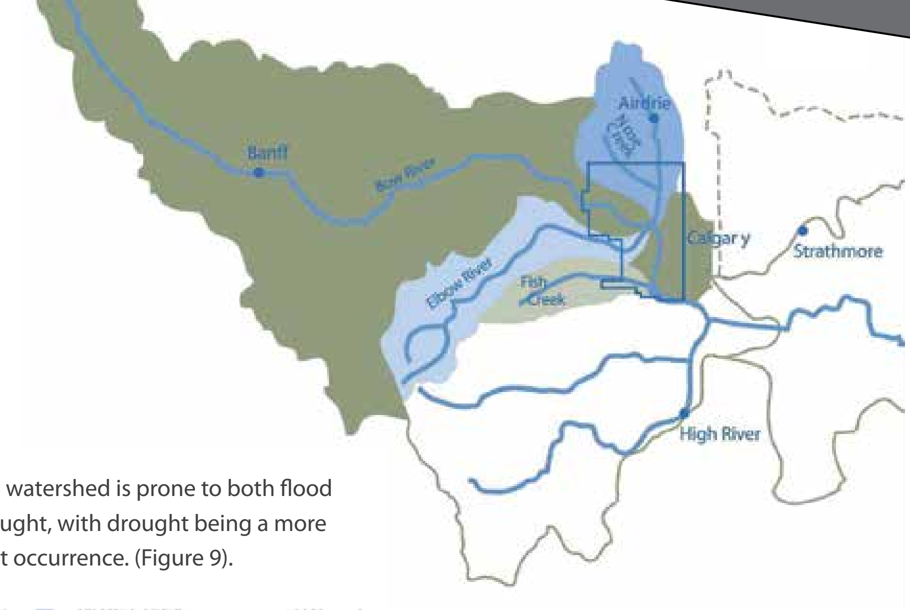
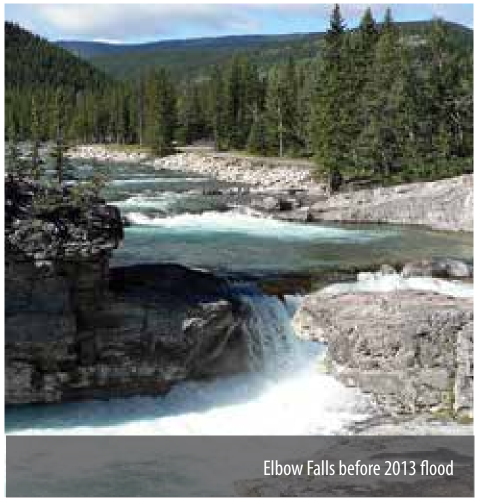
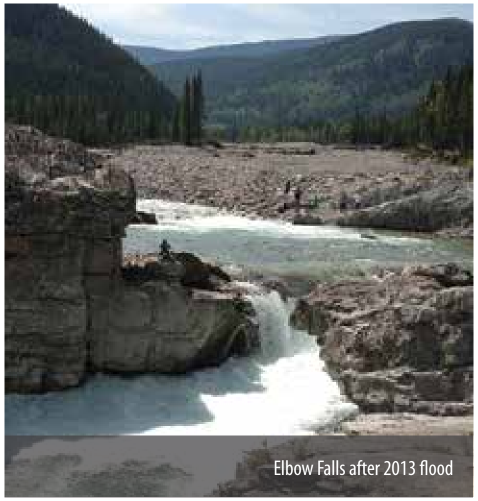


Figure 8. Regional watersheds.


Elbow Falls before 2013 flood


Elbow Falls after 2013 flood

The watershed during the 2013 flood - *The mountains, foothills and the city of Calgary experienced heavy, intense rainfall in the days leading up to June 20, 2013. The rain was centred in the mountains and foothills, where it also melted a large accumulated snowpack, adding to the volume of water rushing down the rivers from the steep upper alpine region.*

Since the flow was generated mostly in mountains and foothills, the Bow and Elbow Rivers on the prairies acted like a pipeline rapidly transmitting high flows from the upper watershed, to Calgary and beyond. Factors such as urban development, patterns of agricultural and resource use, commercial and recreational activity have small influences on this type of flood.

WATERSHED HEALTH

The mountain zones of the Bow River Watershed are largely protected areas, including Banff National Park, Peter Lougheed and the Elbow-Sheep Wildland Provincial Parks, and Kananaskis Country. In these parklands, the forest zones are relatively unaltered from their natural condition, although there are some roads and other corridors that alter runoff. Since the upper watershed is generally intact, there would be limited benefit in changes in land use to restore the condition of the upper watersheds where much of the runoff originated in the 2013 flood.

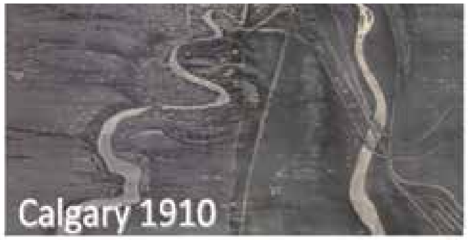
Because most of the river flow is generated in the upper watershed where there is little development, current land uses within the lower parts of the watershed do not substantially contribute to severe flood potential. In contrast, the watershed does play a role in mitigating the type of flood seen in 2005, where long steady rainfall in the lower reaches saturates the ground and eventually causes rivers to overflow. Nevertheless, residential, recreational, industrial and other land-use pressures continue to grow in the watersheds and these pressures may impact water quality. It is important to manage the watersheds so they can buffer small floods and so water supply, water quality, habitat and environmental protection are not compromised.

> “We have allowed development to encroach closer and closer to the banks of ALL our rivers, lakes, reservoirs and streams. We ignore the importance of Riparian areas, those ‘buffer zones’ between the banks of water bodies and human habitat.”
> – Public input

Logging in the watersheds - *Logging occurs in about one to two per cent of the Bow River Watershed. Forest soils are capable of reducing runoff, but generally this is true only for small-scale rainfall events which are not responsible for severe flooding. Forests and land cover have only a limited influence on large-scale floods*[xvi] *such as the one southern Alberta experienced in 2013. Water quality can certainly suffer because of increased erosion as a result of logging.*

REGIONAL WATERSHED MANAGEMENT

Regional partnerships are key to implementing integrated watershed management planning. Flood, drought and other issues are more challenging to address if efforts are implemented in isolated parts of a watershed, without considering upstream and downstream users. Dedicating adequate resources to these partnerships ensures that projects and programs are carried through and that The City of Calgary’s interests are represented. The City has an influential role as one of many stakeholders in protecting the watershed, but has direct control only over the urban watershed within Calgary’s boundaries.



Calgary’s creeks and rivers are a defining feature of Calgary’s character and the banks and areas beside these rivers are an integral part of a healthy watershed. They provide a variety of benefits for Calgarians and keeping these riparian areas healthy allows them to naturally moderate impacts such as flooding and drought.

The land adjacent to Calgary’s rivers has been developed since the city’s inception. The areas of highest flood risk in Calgary were the first to develop, altering many of Calgary’s natural riparian zones.

Keeping the land next to the rivers healthy is important to flood risk management. Riparian zones can help store and slow down water during small scale floods. They can help mitigate the risk of damage due to smaller scale flooding, and reduce the need for flood and erosion control structures and post-flood repairs to bridges, outfalls or buildings. Riparian buffers allow natural changes to watercourses and mitigate damage from small-scale flooding.[xvii]

A post 2013 flood assessment was performed by The City to determine the flood effects on riparian areas. The study found that many sites impacted by human uses were not as resilient as natural riparian zones. In the year following the flood, The City has repaired six critical erosion sites along Calgary’s rivers and plans to address an additional 27 vulnerable sites by 2015. However, those sites that had been assessed as healthy in the past survived very well in the flood.

The City’s Environmental Reserve Setback Policy, Riparian Strategy, Wetlands Policy, Land Use Bylaw, Municipal Development Plan and Stormwater Management Strategy help to ensure Calgary’s rivers and watershed remain functional and that riparian areas continue to enhance the urban setting as Calgary continues to grow. These initiatives help protect river habitat and wetlands, control erosion, maintain water quality and mitigate small-scale flooding. The Panel strongly endorses these policies and The City’s participation in regional watershed plans.

> “The panel should also address winter groundwater flooding in Downtown West, Hillhurst and Sunnyside. Damage due to winter groundwater flooding has already cost property owners hundreds of thousands of dollars.” - Public input

Recommendation: Collaborate with academic and other partners to develop computer models that identify groundwater movement in Calgary in relation to flood conditions.

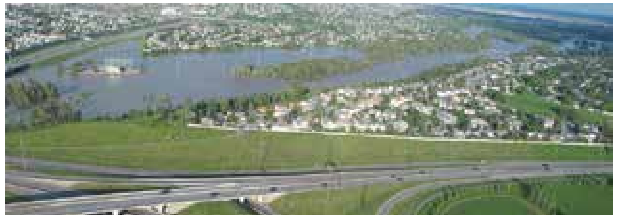
UNDERSTANDING THE INFLUENCE OF GROUNDWATER ON FLOODING

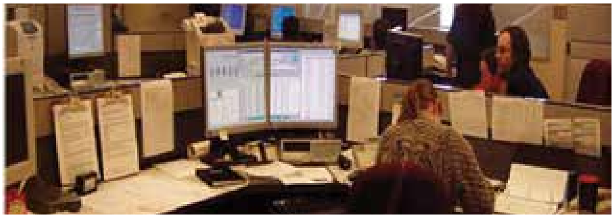
Neighbourhoods in Calgary’s low-lying areas are built over aquifers that are linked to the rivers. An aquifer is an underground layer made of permeable material such as sand or gravel that allows water to move through it, and much of Calgary’s geology in the river valleys is high permeability materials.

When the river level is high, water can move rapidly from the rivers to the aquifers, increasing groundwater levels. When the river level is low, water in the aquifers can move into the rivers. During the 2013 flood, many homes and businesses experienced flooding from groundwater and many of the costs of the flood were due to groundwater inundation.

Additional groundwater monitoring in key locations throughout the city would help inform understanding of the influence of groundwater flows during flooding and how groundwater is impacted by urban development. Installing new groundwater monitoring equipment and developing computer models would allow for a better understanding of the relationship between groundwater, surface water and flood waters. This information should be used with other modeling to improve communication between regulators and to inform the public of groundwater risks.

EVENT FORECASTING





Flood alerts, forecasts and warnings are important components of flood preparedness. Flood forecasting uses weather and river data to foresee the timing and severity of high river level conditions, so measures can be taken to ensure public safety, protect critical infrastructure, keep water treatment operational and limit impact to the environment. Near the Rocky Mountains, the weather is sometimes unpredictable and can change rapidly.

City staff and other forecasters watch for or predict key factors for potential flooding scenarios: river and reservoir levels, mountain snow conditions, precipitation and temperature patterns and soil saturation. There is much uncertainty involved in this process. The timing and severity of flooding is influenced by the intensity, duration, distribution and type of precipitation over the watershed. Direction of storm movement is a key factor in determining if and how flooding may occur.

The City of Calgary's role - *Monitoring river and weather conditions occurs year-round by a small team at The City of Calgary working with the Alberta River Forecast Centre, and takes on special importance from May to July when it focuses on flood potential. Computer models are used to predict river conditions in the watershed so that operational decisions can be made. City staff with expertise in hydrology interpret the models along with river and weather conditions. They coordinate information with the Province and TransAlta, and share it with Water Resources' Business Continuity and Emergency Management to coordinate any required action such as pathway closures and temporary barrier construction. The information is also shared with the Calgary Emergency Management Agency that uses it to make notification decisions and take other actions based on flood threat levels. Such information allowed The City to call the State of Emergency in 2013 as early as it did.*

Forecasting the 2013 flood - *The flood in June 2013 demonstrated how rapidly weather and runoff can change and how fast conditions in mountain areas can become dangerous. The event also highlighted the uncertainty in predicting how much and where rain will fall and the impacts that has on flooding. Weather forecasts had predicted 100 mm of rain – when over 300 mm fell in the Rocky Mountains and foothills. To complicate matters, several of the monitoring gauges that forecasters rely on were destroyed during the flood and observers had to physically go out and determine what was happening.*

During the public engagement process, the Panel heard that Calgarians wanted earlier warning and more time to better protect their property and prepare for evacuation. Calgarians did not realize how severe the flood was going to be and people want to have a better understanding of rapidly changing situations in the future. The reality for Calgary is that flood peak flows can reach the city within hours of when they are generated in the mountains. This leaves a relatively short time to warn and evacuate people from hazard areas regardless of monitoring and predictive models. This reality heightens the importance of advance planning and preparation.

Forecasting an event does little to prevent that event from happening. This is where flood mitigation strategies come into play.

IMPROVING PROVINCIAL AND FEDERAL FORECASTING

The City receives weather forecasting information from the Government of Alberta, Environment Canada, the U.S National Weather Service and other sources.

The Government of Alberta is undertaking a number of studies to improve flood forecasting and communications: documenting lessons learned from 2013; identifying best practices in forecasting performance measures; assessing the performance of weather models on past events; documenting the 2013 event; and determining lead time for emergency action in areas vulnerable to rapid flooding. These studies should be complete by July 2014. The new Alberta Rivers App for smartphones provides advisories and information about Alberta's lakes and rivers directly from the Alberta River Forecasting Centre.

Environment Canada is taking action to improve communication with provincial officials when a severe event is on the horizon and plans to have a national flood forecasting system running within two years. The system will combine Environment Canada's new river flow model with a prediction system to help provide earlier and more accurate warnings of disasters.

Calgarians will ultimately benefit from improvements made at the provincial and federal level and The City should ensure alignment with and uptake of any new forecasting tools and processes.

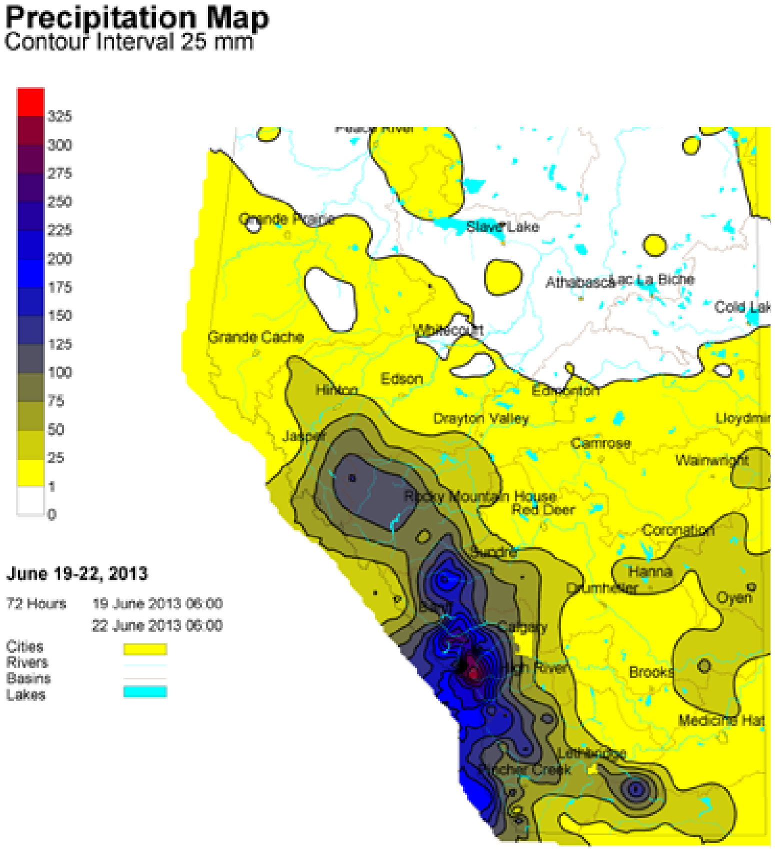


Figure 10. Alberta Environment and Sustainable Resource Development Precipitation Map (total precipitation in mm).

> “Flood mitigation needs excellent information, like […] accurate flow rates. Not something that stopped measuring water flow.”– Public input

REBUILDING AND IMPROVING MONITORING CAPABILITY

The City of Calgary works closely with Alberta Environment and Sustainable Resource Development (AESRD) River Forecast Centre, Environment Canada and TransAlta to collect and share forecasting information. Alberta’s River Forecast Centre has access to over 400 river and 600 weather stations throughout the province. These stations monitor real-time water levels, stream flows, precipitation, snowpack, temperature, wind and other data from strategic points throughout the watershed. Much of the information is available to the public online but translation of these data into flood risk predictions is not something that average citizens are likely to be able to perform. The City and TransAlta also operate stations within the watershed for their own operational needs.

The Bow River Watershed covers an area of 10,000 km^2 and weather and river conditions can vary drastically from one part of the watershed to another. This makes monitoring conditions throughout the watershed crucial to fully understand what is happening during a rainfall event, and expanding the coverage of the monitoring network would be beneficial. Several new stations have been installed since the flood of 2013, and additional upstream locations on the Bow and Elbow Rivers should be considered for new stations.

Enhanced monitoring is being explored by The City, including links to Geographical Information Systems, soil moisture, photos and runoff in the upper watershed. Specialized technology would allow better real-time forecasting to inform decisions leading up to and during extreme events. There is also an opportunity to improve the transmission of data between agencies to increase forecasting accuracy.

The flood in 2013 destroyed a number of hydrological monitoring stations and caused others to malfunction. Although most stations continued to function, this raised the issue of protecting existing and future additional stations from flood damage. Some monitoring stations have been made flood resistant during recovery efforts and several additional locations that require flood protection have been identified.

Recommendation: In partnership with Alberta Environment and Sustainable Resource Development and TransAlta, expand the network of river and weather monitoring stations upstream of Calgary and protect stations from damage during flooding.

SHARING INFORMATION FOR FASTER AND MORE ACCURATE FORECASTS

Because forecasting information is collected by several agencies, communication during emergencies is crucial to response time. Although professionals from The City, Alberta River Forecast Centre and TransAlta were in constant communication during the 2013 flood, strengthening communal knowledge can lead to better forecasting and faster warnings to the public.

A common platform for computer modeling would allow forecast data to be compared, providing increased accuracy on weather and river conditions. A platform that allows multiple models may use ensemble (group of simulations) forecasts to better understand uncertainties in predictions. Recognizing that modeling technology is constantly evolving, an adaptive approach is necessary.

The City should support research being conducted by the Province on forecasting best practices and weather forecast effectiveness. The City should also pursue additional research in all aspects of hydrological information, including research to improve scaling down regional information to the local level and examining specialized tools with a local focus.

Recommendation: Pursue a common river forecasting platform with Alberta Environment and Sustainable Resource Development and TransAlta for faster and more accurate information and alerts about future flood events.

> "As a victim of both the 2005 and 2013 floods, I think it is imperative The City develop a protocol through media, social media, etc., to notify residents of impending flood conditions. In both floods we received 3 hours notice or less which is entirely unacceptable." -Public input

ENHANCING FLOOD COMMUNICATION AND AWARENESS

After the 2013 flood, Calgarians in flood affected zones overwhelmingly expressed that they wanted earlier notification in the future to prepare themselves and their properties in the event of an evacuation. Because there is a high degree of uncertainty in forecasting and short lead time available because of the nature of the watershed and weather patterns, giving earlier warning will inevitably lead to some false alarms. The City must balance the need to predict flood risk as early as possible with the possibility of message fatigue if too many false alarms are called in an effort to maximize early warning capability. Ongoing dialogue with Calgarians about living with flood risk is important to raise awareness and encourage them to prepare each flood season. This issue is discussed in more detail in the *Managing Flood Risk* section of this report.

The City follows an internal communication process and emergency management plan where forecasters share new information as soon as possible with emergency managers and the Calgary Emergency Management Agency (CEMA), whose responsibility it is to communicate notifications and warnings to the public. The City and CEMA are currently reviewing tools and processes used to communicate with the public leading up to and during an event. In addition, The City is exploring improved tools to communicate in advance of actual flood warnings. Consistency between federal, provincial and municipal messages to the public is important to incorporate to avoid mixed messages that may cause confusion.

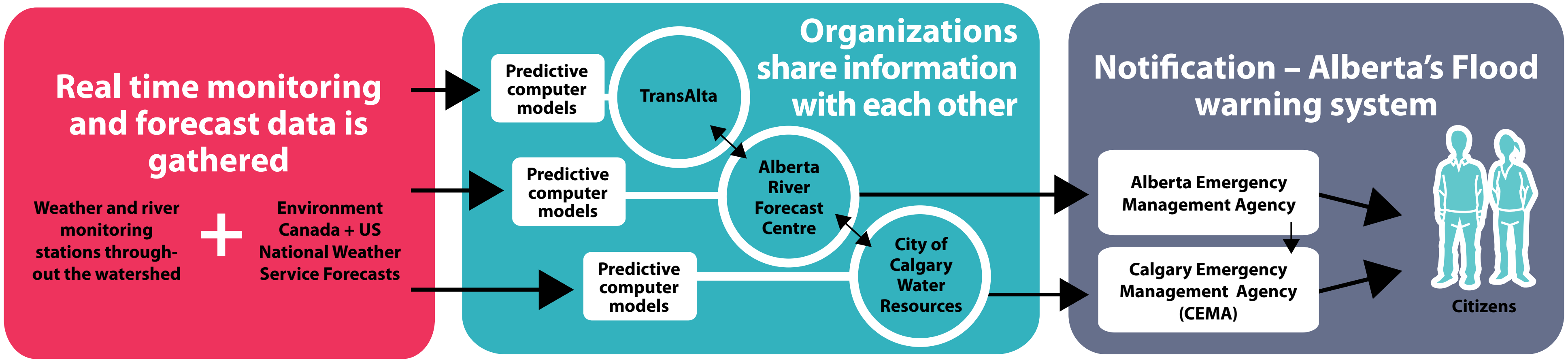


Figure 11. How organizations work together to communicate flood risk.

Frequent public updates are necessary as an event develops and should make use of social media, web pages and other electronic media. Visually communicating risks can be shown through a wide range of means including interactive maps, informative graphics, charts, flood warning lines on bridges and photos of key bridges or landmarks overlaid with projected water levels.

Recommendation: Incorporate lessons learned from the 2013 flood to enhance communication channels to keep Calgarians informed of conditions that may lead to high river levels.

Source: UK Environment Agency, 2014.

The UK's flood alert system

To give people real-time flood warnings, the United Kingdom's Environment Agency produces an interactive web-based flood alert map for England and Wales. Alerts are live 24/7 and are updated every 15 minutes with information about flood risks in any chosen area. At the street-level, a graduated system of alerts informs people what actions they need to take to protect themselves. Citizens can sign up for flood warnings by phone, text or email. The agency also provides online tools including a three day flood risk forecast, river and sea levels, a telephone hotline and advice on what to do before, during and after a flood.[xvii]

Flood messaging in Toronto

The Toronto and Region Conservation Agency (TRCA) updated its flood message terminology in 2012 to make messaging consistent with information from other agencies such as Environment Canada and the Weather Network. The terminology includes four stages: Normal, Water Conditions Statement (early warning of high flows, runoff, rain, unstable banks, etc.) Flood Watch and Flood Warning. The TRCA also uses social media, a 24-hour hotline and an extensive website to inform the public about flood preparedness.[xix]

The City can learn from these examples and others in developing more communication tools to share forecasting information with Calgarians.

STORAGE, DIVERSION AND PROTECTION

Rivers are dynamic systems with water levels and riverbeds changing over time. Floods and droughts are natural, unavoidable occurrences. Throughout Alberta and the world, structures such as dams, canals and flood barriers are constructed to manage the flow of rivers. Water control structures may be designed to:

- Store water to manage high flows and low flows, reducing the peak of flood events and storing water so it is available during low flow seasons.
- Divert water to desired locations for water supply or away from critical locations for flood protection.
- Protect locations from flooding by hardening river channels or creating flood barriers.

Until 1910, no major water control structures existed along the Bow or Elbow Rivers. The Bow River is now affected by 11 dams and six reservoirs upstream of Calgary. The only infrastructure on the Elbow is the Glenmore Dam and Reservoir in Calgary. These water control structures are operated under provincial licenses with consideration of the rights of upstream and downstream water users. They have limited flood reduction potential, but are managed to balance a number of objectives, including water supply, irrigation, power supply, water quality, habitat protection, erosion potential, recreation, and drought and flood control. The existing structures that manage the flow of water upstream of Calgary and within the city are listed in Table 2 and their locations are shown in Figure 12.

EXISTING STRUCTURES UPSTREAM OF CALGARY AND WITHIN THE CITY		PRIMARY FUNCTIONS	MANAGING ORGANIZATIONS
BOW RIVER	**UPSTREAM STORAGE** • Six reservoirs controlled by hydroelectric dams (Lake Minnewanka, Spray Lakes, Barrier Lake, Upper Kananaskis Lake, Lower Kananaskis Lake and Ghost Lake)	• Hydro-electric production	• TransAlta
	DIVERSION • Western Headworks Canal from Harvie Passage	• Irrigation supply	• Province Of Alberta
	PROTECTION • Permanent flood barriers in specific locations within the city	• Flood protection	• Province Of Alberta, City Of Calgary
	• Temporary flood barriers erected during flood events	• Flood protection	• City Of Calgary
ELBOW RIVER	**IN-CITY STORAGE** • Glenmore Reservoir controlled by Glenmore Dam	• Water supply	• City Of Calgary
	PROTECTION • Permanent flood barriers in specific locations within the city	• Flood protection	• City Of Calgary
	• Temporary flood barriers erected during flood events	• Flood protection	• City Of Calgary

Table 2. Existing structures that manage water upstream and within Calgary.

While existing facilities provided some flood mitigation, significant damage still resulted from the 2013 flood. Possibilities for additional floodwater control are listed in Table 3, along with the organizations that would be able to lead each activity. The locations of several options are also shown in Figure 12.

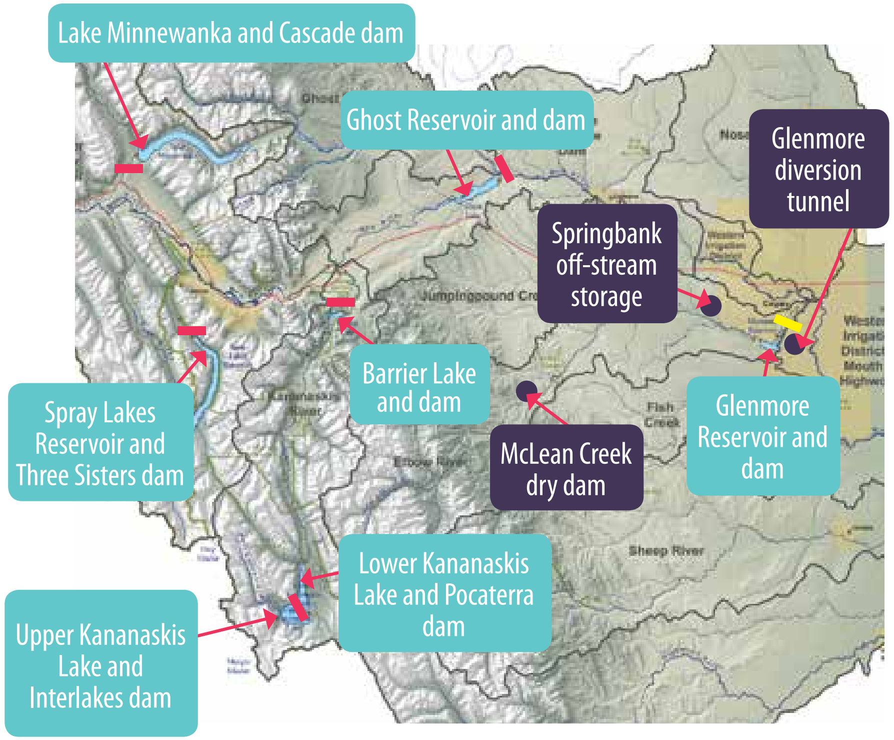


Figure 12. Water management structures in the Bow and Elbow Rivers upstream of Calgary.

OPTIONS FOR ADDITIONAL FLOODWATER CONTROL UPSTREAM OF CALGARY AND WITHIN THE CITY		LEAD ORGANIZATION
BOW RIVER	**UPSTREAM STORAGE**	
	• Operate TransAlta dams for additional flood mitigation	• TransAlta and Province of Alberta
	• Increase capacity of TransAlta reservoirs	• TransAlta and Province of Alberta
	• Store floodwaters in farmland, Crown Land, or wetlands	• Province of Alberta
	PROTECTION WITHIN CALGARY	
	• Construct or increase protection level of flood barriers	• City of Calgary
	• Design infrastructure so it does not obstruct river flooding	• City of Calgary
ELBOW RIVER	**STORAGE**	
	• Increase capacity of the Glenmore Reservoir	• City of Calgary
	• Build a dry dam in the headwaters at McLean Creek	• Province of Alberta
	• Store floodwaters in an off-stream storage site near Springbank	• Province of Alberta
	DIVERSION IN AND AROUND CALGARY	
	• Construct a flood bypass from the Elbow River to the Bow River	• The City of Calgary with the Province of Alberta
	PROTECTION WITHIN CALGARY	
	• Construct or increase protection level of flood barriers	• City of Calgary
	• Design infrastructure so it does not obstruct river flooding	• City of Calgary

Table 3. Options under investigation for water control upstream and within Calgary.

Dredging

Dredging the Glenmore Reservoir and the river channels to create more room for floodwaters was proposed following the 2013 flood.

Glenmore Reservoir

The City commissioned an independent report on the merits of dredging the Glenmore Reservoir. The report concluded that the increased capacity that could be gained by dredging would be small and provide a maximum two per cent reduction in moderate flood events (1:50) and less for larger events. Dredging the reservoir would also:

- Disturb sediment that can impact the quality of Calgary's drinking water.
- Require transport and disposal of dredged material.
- Have to be undertaken regularly as benefits are temporary.

Bow and Elbow Rivers

The river channels naturally change over time as the rivers deposit and move gravel during different flow conditions. During the 2013 flood the rivers carved out larger channels by moving gravel and eroding riverbanks. Some of that extra channel capacity will decrease gradually over time as the river deposits gravel under normal flow conditions. Areas where gravel accumulated during the flood will be monitored by The City to ensure vegetation growth does not cause new flood debris hazards. Dredging the rivers would have a negligible effect on channel capacity during floods as gravel will naturally deposit in dredged areas. Dredging the river channels would also damage aquatic habitat. The Bow and Elbow Rivers are fish-bearing rivers, protected from disturbance under the federal Fisheries Act.

Given the costs, negligible benefits and negative impacts of dredging, this option was not considered further.

Structural protection such as dams, diversions and barriers can significantly reduce the amount of water that inundates developed areas under flood conditions, as shown during the 2013 flood. However, no amount of structural protection eliminates risk in a floodplain. Physical flood protection measures inherently have limitations and additional risks associated with operations or failures. They may also provide a false sense of protection.

Although any of the options in Table 3 would reduce flood impacts, they are only advisable if further study shows that they would provide an overall benefit. Evaluating the merits of water control structures requires examining the positive and negative effects they may have on people, property, and the broader watershed during droughts, normal conditions and floods. Maintenance and long-term operational costs of physical flood protection measures must also be considered. Identifying the most effective combination of measures in the watershed is important.

Working with the Province of Alberta on upstream options - The options presented in Table 3 are at various stages of study by the Province and The City of Calgary. The Province initiated the Bow Basin Flood Mitigation and Watershed Management Project[xx] to identify and assess options for flood mitigation throughout the Bow Watershed. One of the most promising options on the Bow River in the near-term is modifying the operation of the TransAlta facilities during flood events. From the identification and analysis of many capital-works options on the Elbow River, the provincial Flood Recovery Task Force has selected the following three flood mitigation options for further consideration:

1. A dry dam on McLean Creek that would temporarily hold water and help control flow rates under flood conditions.
2. A diversion and water storage site near Springbank.
3. A diversion tunnel from the Glenmore Reservoir to the Bow River.

The Panel is supportive of flood mitigation options that are appropriate for broader watershed management as well as for buffering floods. The proposed Springbank water storage site and the dry dam would both provide additional water storage capacity upstream of Calgary, while the diversion tunnel can only manage flood waters.[xxi]

A watershed-based approach to large-scale flood mitigation works is important. The Province must continue to work with The City and other stakeholders to evaluate and implement options for upstream mitigation on the Elbow and Bow Rivers.

STORAGE

Water may be stored so it is available for later use or to slow the release of floodwaters. Water storage can be as small as a garden rain barrel or as large as a reservoir. In many parts of Calgary, urban stormwater is stored in retention ponds to slow its movement towards the river, reducing flooding and encouraging water to infiltrate into the groundwater. The same principles apply to storing and slowing floodwaters in the watersheds upstream of Calgary.

Most water storage upstream of Calgary is in large reservoirs controlled by dams. Reservoirs temporarily store floodwaters, releasing the water at slower rates than it arrives in the reservoir. This reduces peak flows and flooding downstream, and allows more time for evacuation and emergency preparation. The existing storage on the Bow and Elbow Rivers was used to buffer the 2013 flood. If not for these reservoirs, the flood would have been much more severe in Calgary.

Bow River storage - TransAlta operates dams that control water in six reservoirs upstream of Calgary (Lake Minnewanka, Spray Lake, Upper Kananaskis Lake, Lower Kananaskis Lake, Barrier Lake and Ghost Lake). These dams are designed for hydroelectric power generation and provide secondary benefits for security of municipal and irrigation water supply, recreation and, to a limited extent, flood mitigation.

TransAlta estimates that the floodwater stored in these reservoirs reduced the peak flood on the Bow River by 15 to 20 percent in Calgary during the 2013 flood. This kept flood levels in Calgary at approximately equivalent to the 1:100 flood levels. Unfortunately, this flood level still caused significant riverbank erosion through the city and some overland flooding.

The most promising option for additional flood storage on the Bow River, as identified by the Bow Basin Flood Mitigation and Watershed Management Project, is through modifications to the operation of the existing TransAlta system during floods. TransAlta and the Government of Alberta are discussing operational changes and possible reservoir expansions to mitigate future floods while maintaining water supplies for electricity generation and municipal, agricultural and industrial uses. Other options for storing water upstream of Calgary, either in wetlands or off-stream areas such as farmland or Crown Land, should also being explored further by the Province.

Recommendation: Continue to cooperate with TransAlta and the Province to increase flood storage on the Bow River through existing TransAlta facilities.

Elbow River storage - The Elbow River was dammed in 1932 to create the Glenmore Reservoir. The Glenmore Reservoir and dam are operated by The City of Calgary; they are used primarily for drinking water supply, and secondarily for flood mitigation and recreation. The dam operational protocol includes lowering the water level in the reservoir as a precautionary measure during the May to July flood season. When a flood is forecast, the water in the reservoir may be brought down to the lowest level that still allows the treatment plant to produce potable water, maximizing the volume of floodwaters that can be captured to reduce peak flow downstream on the Elbow River. The amount of floodwater the reservoir can store is limited by the size of the reservoir and the need to ensure the availability and quality of drinking water supply for the city.

Floodwater storage during the 2013 flood

Leading up to the 2013 flood The City lowered the level of the Glenmore reservoir by approximately 3.5 metres. This created room to capture the initial, very high peak flood flow.

The peak flow into the reservoir was approximately a 1:500 flood, while the flow out of the reservoir was approximately a 1:100 flood (See Figure 13).

As a result, there was extensive flooding in the neighbourhoods along the Elbow River and a large portion of the downtown core.

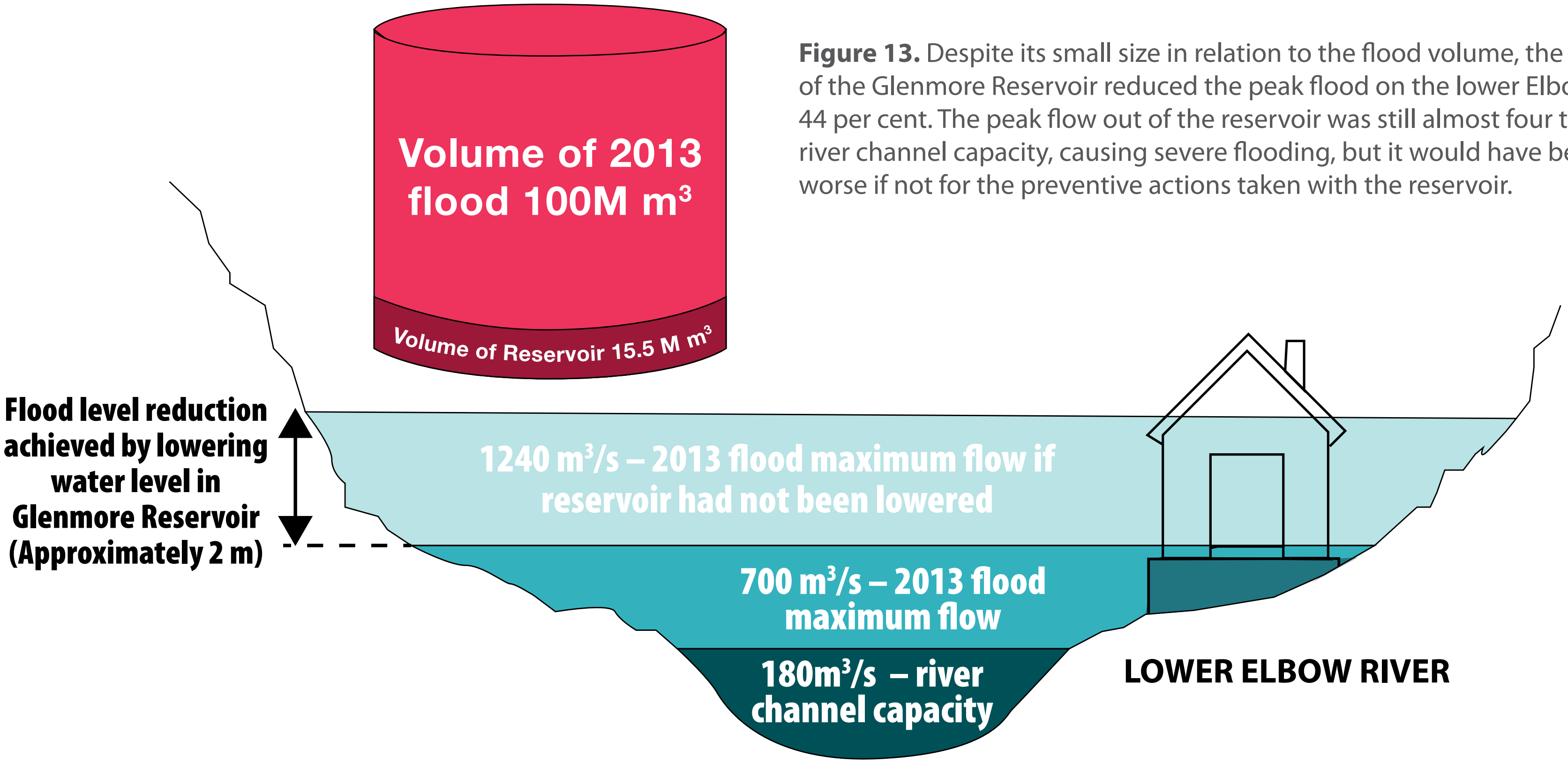


Figure 13. Despite its small size in relation to the flood volume, the operation of the Glenmore Reservoir reduced the peak flood on the lower Elbow River by 44 per cent. The peak flow out of the reservoir was still almost four times the river channel capacity, causing severe flooding, but it would have been much worse if not for the preventive actions taken with the reservoir.

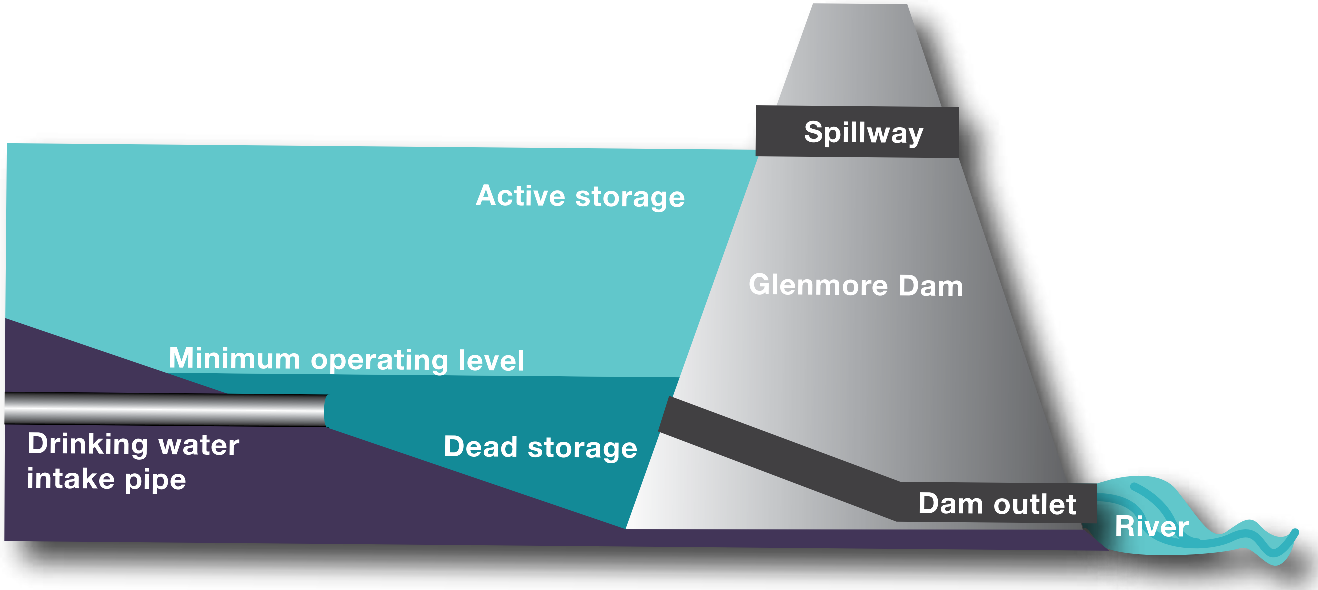


Figure 14. The water level in the Glenmore Reservoir has to stay above the drinking water intake to maintain water supply for Calgary. Water below that level is "dead storage" as it cannot be released. Dredging the deepest part of the reservoir only adds to the "dead storage" volume and does not provide any additional flood mitigation capacity.

The available storage in Glenmore Reservoir greatly reduced flooding downstream of the dam. Additional storage capacity in the Elbow River Watershed would increase the amount of floodwaters that could be stored for short durations during future floods. Approximately 100 million cubic metres of storage would be needed in the watershed to completely buffer a flood the size of the 2013 event within Calgary. This is equivalent to approximately five more Glenmore Reservoirs, an option that is not plausible within Calgary.

While increasing the capacity of the Glenmore Reservoir cannot provide enough additional storage to buffer the 2013 flood on its own, it could be one of a combination of projects to effectively mitigate floods on the Elbow River and would provide additional water supply storage for Calgary. Increasing the reservoir volume would raise water levels in the reservoir, increase the footprint of the reservoir, and affect surrounding infrastructure and development. The potential to increase storage in the Glenmore Reservoir through raising the height of the dam by small or large increments is being investigated by consultants retained by The City.

> "Anything to expand the capacity of the Glenmore Reservoir should be pursued." - Public input

Recommendation: Increase the operating water storage capacity of the Glenmore Reservoir on the Elbow River through modifications to the Glenmore Dam.

> "Begin the process of building the 58th SW tunnel for water diversion immediately. It is proven technology and, whatever it costs, it is a fraction of the damage, loss of business, and social impacts of weather events like the recent one."
> – Public input

DIVERSION

Flood waters can be diverted from their natural course to split through multiple channels, reducing the water flowing through the natural channel. The only water diversion within Calgary is the Western Irrigation District (WID) canal system which diverts water from the Bow River for irrigation supply downstream. Water is diverted by the weir at Harvie Passage in Calgary through the Western Headworks Canal to Chestermere Lake, then to a canal system to farmland and water storage sites.

The WID canal system was not designed to carry floodwaters and its capacity is only one to two per cent of the 2013 flood flow. The canal system does not provide the opportunity to divert significant flood volumes. The Harvie Passage weir was damaged during the flood and will be rebuilt in 2015. A redesign should also address safety issues for recreational users identified before the flood. No practical options have been identified to divert floodwaters from the Bow River.

Diverting floodwaters on the Elbow River

Since the Glenmore Dam was completed in 1932, floods have overtopped the dam and caused significant local flooding downstream twice, in 2005 and 2013. The Government of Alberta's Flood Mitigation Advisory Panel recommended investigating the construction of a large tunnel to divert floodwaters from the Elbow River at Glenmore Reservoir to the Bow River. This would protect communities downstream of the reservoir and parts of downtown Calgary. The Province commissioned a preliminary report that outlined the concept of a five kilometre long tunnel beneath either 58 Avenue South or Heritage Drive. The preliminary cost estimate was $200 to $290 million. A consultant for The City was retained to conduct a more detailed feasibility study for the diversion tunnel, reporting the following:

- A tunnel diameter of 9 meters would be capable of preventing flooding on the lower Elbow River during a 1:100 flood event, equal to the actual 2013 flood.
- The estimated cost of construction is $457 million.
- The optimal route of the diversion is under Heritage Drive because the intake design is simpler and the bedrock conditions are more consistent for tunnelling than beneath 58 Avenue South.

The consultant report also details the geotechnical conditions, entry and exit hydraulics, energy dissipation at the outlet into the Bow River, potential impacts on downstream flows, and social, environmental and economic costs and benefits.

Another possibility examined by the Panel for an Elbow River diversion is an open channel or tunnel to Fish Creek, diverting water either from the Glenmore Reservoir or the Elbow River before it enters Calgary. The Fish Creek valley within the city has high escarpments providing the possibility of constructing a dry dam that would temporarily contain diverted floodwaters, controlling outflow to the Bow River. This option would provide additional water storage which is not possible with the diversion tunnel directly to the Bow River. This route would, however, be a longer diversion than the direct tunnel from Glenmore Reservoir to the Bow River, and would heavily impact Fish Creek. An investigation of the merits and disadvantages of this diversion option is being undertaken by The City.

The two diversion alignments studied

A diversion from the Elbow to the Bow River needs to be evaluated alongside the other two large-scale capital-works projects being considered by the Province on the Elbow River: the off-stream diversion and storage site at Springbank and at the dry dam at McLean Creek. Given that these two projects are presently estimated to cost under $200 million each, the diversion to the Bow River is the most expensive option. The selection of capital works projects to undertake should consider, also which works will be most appropriate for broader watershed management, including both flood mitigation and drought response. A combination of civil works, new flood barriers and removing buildings from the floodway could be complementary parts of an overall plan.

An integrated analysis will be needed to identify the best combination of flood mitigation measures on the Elbow River. The analysis must consider initial capital cost, total cost of ownership, reliability, environmental impacts, stakeholder interests and land accessibility. Large diversion projects inherently present many risks that must also be included in a full evaluation. Examples include:

- Agreements with federal, provincial and First Nation governments.
- Disruption to local communities during construction.
- Potential relocation of existing infrastructure.
- Potential impacts on downstream communities and downstream infrastructure.
- Potential delays and extra costs from regulatory requirements, procurement processes and financing approvals.
- Construction and tunneling risks, including geotechnical variability, equipment failure and weather.

Recommendation: In partnership with the Province, compare the three major capital works options for mitigating floods on the Elbow River and identify the optimal investment plan:

i. A diversion from the Elbow River to the Bow River in accordance with the conclusions of the feasibility studies.

ii. The Springbank off-stream diversion and storage site.

iii. The McLean Creek dry dam.

Large-scale water diversions

source:
sayangwak.wordpress.com

The Kuala Lumpur Stormwater Management and Road Tunnel "SMART" is a 9.7 km tunnel that carries water during flash floods and serves as a roadway when not carrying flood waters. The tunnel protects the centre of Kuala Lumpur from river floods by diversion from one river to another.[xxii]

The Waller Creek Flood Control Tunnel Project is a 1.6 kilometre, eight metre diameter stormwater bypass tunnel protecting much of downtown Austin, Texas. Currently under construction, the estimated cost is approximately $150 million.[xxiii]

The Niagara Tunnel is 12.7 metres wide, 10.2 kilometres long and cost approximately $1.5 billion. It was completed in 2013 and diverts water from the Niagara River to a hydroelectric plant for power generation.[xxiv]

The Red River Floodway was expanded, starting in 2005, and now protects Winnipeg against a 1:700 flood. The expansion cost of $665 million and was shared by Canada and Manitoba. It is estimated that this channel has prevented over $40 billion in damages since it was first built in 1968.[xxv]

> "Natural streams do a better job of containing rising water levels. I'm afraid that all our ideas are about building more dams and concrete diversion channels." – Public input

PROTECTION

Permanent and temporary barriers provide some protection from floods in Calgary. In 2013 they prevented and limited flooding in many parts of Calgary and yet they were overtopped within several communities.

Permanent barriers - Permanent flood barriers have been constructed along stretches of the Bow River through Calgary and isolated reaches of the lower Elbow River. Most flood barriers in the city were originally designed to protect against flooding caused by ice jams. Since the TransAlta facilities were constructed during the early and mid 1900s and began regulating water flow in the Bow, ice flooding risk has been greatly reduced and spring floods are the more common river flood events in Calgary with the exception of a few select reaches.

The City designs flood protection barriers in general to a 1:100 flood level plus an additional 0.5 metres of elevation to account for uncertainty in predicting actual flows. For each site where a barrier is constructed or raised, The City undertakes a social, environmental and economic assessment to identify the appropriate height. The highest level of protection constructed within the city is designed to a 1:100 flood level plus 1.0 metres. Riverbanks that were damaged during the 2013 flood are being repaired with additional height (to 1:100 flood plus 0.5 metres) where possible.

Communities behind flood barriers live with the risk that the barrier could be overtopped in a flood larger than the barrier designed, because flooding could occur through groundwater upwelling or storm water back-up during large river floods. Riverside neighbourhoods that are being redeveloped, such as Quarry Park and East Village, have been required to raise the ground with fill to reduce the need for river flood barriers for protection.

Areas where private property stretches to the riverside, primarily along the lower Elbow River, are generally not protected by permanent flood barriers. Often the density of development in these locations makes barrier construction problematic. Some residents have built their own retaining walls or landscaping features to mitigate flood risk to their personal property. These require a permit and oversight from The City to ensure they are structurally sound and will not adversely affect neighbouring properties.

Temporary barriers - The City has detailed emergency plans for the location and construction methods of temporary flood barriers in the event of floods of various magnitudes up to a 1:100 flood. The first priority for temporary barrier construction is protecting public safety and second is protecting critical infrastructure. These are followed by protecting private property and the environment. Temporary flood barriers are not feasible in some areas along the lower Elbow River, because they would be required along lengthy stretches and private riverside property is inaccessible for rapid barrier construction. The City continues to study where additional temporary barriers would be useful, and the most appropriate construction materials and methods for these barriers.

Improving flood protection - Calgary’s flood protection can be increased through increasing the level of protection from flood barriers, and modifying structures that constrain floodwaters.

A cost-benefit analysis is currently being performed to assess the feasibility of increasing the protection level provided by permanent barriers across the city. The results of this analysis may identify areas that economically should be protected to higher standards. The recommended assessment of flood protection levels across Calgary (see *Managing Flood Risk* section) may also identify areas that should be protected to a level higher than the 1:100 flood.

Recommendation: Construct additional or higher flood barriers in key locations throughout the city and update temporary flood barrier plans to protect against higher flood levels.

At points along the Bow and Elbow Rivers the river channel is constricted by structures such as bike paths and bridges. Floodwaters are forced around or above these structures, resulting in higher floodwater levels locally. Several pedestrian bridges over the Elbow River in Calgary are being redesigned so they do not constrict the river channel and allow more space for the river to flood.

Recommendation: Prepare a time-phased plan to modify structures that constrain river flow during flood events, such as pathways and bridges.

Examples of temporary flood barriers

There are many types of temporary flood barriers appropriate for different locations and flood scenarios.

Earthen barriers made with sandbags and tubes that may be filled with water, mud slurry or concrete are common around much of the world and used by The City of Calgary as needed.

Modular barriers with waterproof board or steel pieces that can slot into place are also used by some municipalities and property-owners in other cities, notably in towns in the United Kingdom where flooding is a regular threat.

Hydraulically actuated flood walls that can be raised during flood events are used by towns in Germany, the UK and Japan to protect short river reaches, such as roadways between riverside buildings.

The City of Calgary uses water-filled tubes as temporary flood barriers

INFRASTRUCTURE AND PROPERTY RESILIENCY

Infrastructure is necessary to provide essential and non-essential services and can be categorized as either public or private. The City's role is distinct with regards to building resiliency into public and private infrastructure. Policy and planning changes can be used to build resiliency into City-owned and managed public infrastructure. Building resiliency into utility and communication infrastructure involves working in partnership with the private sector.

Public infrastructure *is owned and operated by provincial or municipal government and includes hospitals, schools, municipal buildings, police and fire stations, roads, bridges, light rail transit (LRT) water and wastewater systems.*

Private infrastructure *is owned and/or operated by private companies and includes communication and energy networks.*

Private property *includes houses, condominiums, businesses, commercial buildings and private industrial areas.*

PUBLIC INFRASTRUCTURE

The Province has recently created flood risk management guidelines for locating new facilities that are funded by Alberta Infrastructure.[xxvi] The guidelines categorize facilities based on their function, identifying those that should be located on sites that are less vulnerable to flooding. The guidelines outline three flood protection levels:

I. 1:1000 flood for "lifeline facilities" that are critical for saving and avoiding loss of human life during emergencies, endanger human life or the environment if compromised and that house irreplaceable items. These include hospitals, hazardous waste disposal sites, museums and communication centres.

II. 1:500 flood for other facilities critical for maintaining and restoring public order. These include courthouses, schools, correctional facilities, airports and seniors residences.

III. 1:100 for all other facilities.

While the 1:100 flood hazard mapping informs the development of public infrastructure in Calgary there are no standards or guidelines for infrastructure that do not fall under the provincial guidelines. While public development is avoided in the floodway some exceptions related to certain land uses are made, such as the RiverWalk promenade and pathway along the Bow River downtown.

Following the 2005 flood, Calgary initiated numerous projects to improve the flood-resiliency of specific City infrastructure. New operating guidelines at the Glenmore Reservoir increased the volume of floodwater that the reservoir was able to store. Investments in water treatment following an assessment conducted in partnership with the Public Infrastructure Engineering Vulnerability Committee (PIEVC) of Engineers Canada[xxvii] allowed The City to continue providing high quality drinking water throughout the 2013 flood. A flood wall recently built in Inglewood significantly reduced the impact of flood for that community. The impacts of the 2013 flood would have been much worse if it were not for the initiation of flood-resiliency efforts that followed the 2005 flood.

Impacts to public infrastructure during the 2013 flood - Despite additional flood resiliency initiatives taken by The City since 2005, considerable public infrastructure in the floodplain suffered damage in 2013, requiring extensive repairs and impairing vital services to Calgarians. Specific impacts included:

- Approximately $445 million in damage to public infrastructure.
- Twenty bridges closed, 50 bus routes canceled or detoured and 16 LRT stations closed.
- Thirty parks flooded.
- The Bonnybrook Wastewater Treatment Plant was completely inundated with floodwaters and discharged untreated wastewater to the Bow River.
- Disruption to City services while the Municipal Building was inaccessible.
- Extensive damage to St. Mary's, Rideau Park and Elbow Park schools.

Many of the recovery projects to fix damaged infrastructure have included capital measures not just to restore facilities but also to improve their resiliency so the impacts of a future event are lessened. For example:

- Riverbanks are being engineered to better withstand the effects of erosion.
- Several pedestrian bridges over the Elbow River are being rebuilt to be more resilient to future floods.
- Mechanical systems have been relocated above areas susceptible to flooding in restored parks facilities.
- Utility lines damaged from erosion have been relocated below anticipated depths of flood erosion.

The Centre Street bridge was washed out by Bow River flood in 1910.

Additional resiliency plans include flood protection measures for Bonnybrook Wastewater Treatment Plant, and riverbank stabilization and community drainage projects for Sunnyside Community.

The City is supporting civic partners, including the Calgary Zoo, Calgary Stampede, Talisman Centre and the Telus Convention Centre, to undertake projects to protect their facilities and operations from future floods. The Calgary Zoo is considering a flood barrier designed to protect to a 1:100 flood level, and to manage both overland and groundwater flooding. Over the last 15 years, the Calgary Stampede has been planning and constructing flood barriers to protect portions of their site and facilities. Additional barriers and systems are now under construction.

Both the Calgary Zoo and Stampede have been using flood mapping information over the last few decades to ensure that new facilities are more resilient to impacts of high water events. Federal, provincial and municipal processes are in place to ensure that for any flood protection concepts, the implications on the aquatic or riparian environment, water quality, water levels or erosion potential are addressed.

Improving the resilience of public infrastructure

For public infrastructure that does not fall under provincial flood protection guidelines The City may consider identifying graduated levels of tolerable flood risk depending on the function of specific types of infrastructure. The City should also review how the 1:100 flood level is used throughout City planning and operations and consider whether there should be firm design standards in place for any specific situations, rather than the 1:100 flood guideline. At minimum, The City should ensure that public development sets a good example for private development by meeting stringent flood protection standards in the flood fringe and avoiding building new structures in the floodway.

Recommendation: Create graduated flood protection level requirements for City infrastructure.

Improving the resiliency of infrastructure and property can be a costly and time-intensive undertaking. It is important that flood-resiliency projects are selected based on best available information. The City has a geographic information system (GIS) that includes layers of information that support analysis of flood risks, flood barrier planning and emergency preparation planning. Information related to flood risk in the existing GIS databases includes:

- Flood hazard maps for various magnitudes of flood events.
- Critical information specifics, such as value of assets and replacement schedules.
- Elevation of roads with respect to 1:100 flood levels.
- Critical transportation routes for access and egress throughout the city.
- Hospitals, schools, long-term-care facilities and other facilities that house vulnerable populations.
- Numbers of residential units in specific buildings and neighbourhoods.

This database should be expanded to include information on flood extent, causes of flooding and damages sustained during the 2013 flood. It can then be used to create a priority action list for future flood resiliency investments, such as critical infrastructure that deserves focused risk assessments. The GIS tool and priority action list should be integrated into flood resiliency planning, as per recommendations in the *Implementation* and the *Managing Flood Risk* section of this report.

Part of improving the resilience of public infrastructure may include implementing the PIEVC Protocol to assess climate vulnerability and recommend modifications to City systems as was done to improve the resilience of The City's water supply system. The PIEVC protocol helps municipalities identify and plan for climate-driven risks to infrastructure. Further assessments should be conducted for different infrastructure types including the wastewater treatment plant that flooded in 2013.

Recommendation: Maintain a comprehensive flood risk database integrated with existing geographic information systems (GIS).

ENMAX substation #32 surrounded by floodwaters.

PRIVATE INFRASTRUCTURE

ENMAX is the electrical distribution utility serving Calgary. ENMAX uses The City's flood inundation mapping in their infrastructure design considerations and flood mitigation plans. They review, revise and exercise their flood preparedness plan on an annual basis. They also have mutual assistance agreements in place with their counterparts to respond to emergency events. During the 2013 flood this led to ENMAX receiving help from EPCOR in Edmonton.

Impacts to private infrastructure during the 2013 flood - To protect public safety and to prevent significant damage, the Calgary Emergency Management Agency (CEMA) coordinated staged shut-offs of electricity and gas in advance of floodwaters reaching areas during the flood. Power outages extended into areas not affected by surface flooding because of the limited capability of the electrical distribution network to isolate outages. Larger areas needed to be evacuated than were actually impacted by the floodwater due to these power outages. Power outages and fuel shortages in the city resulted in the shut-down of sump pumps and back-up generators contributing to flooding in buildings that were not directly impacted by surface flooding.

Approximately 35,000 ENMAX customers were without power for varying periods of time. ENMAX substation #32, which provides critical power supply to the new hospital in south Calgary, had 300 mm of flooding and was threatened by severe bank erosion. Access to the substation was cut off. Four river crossing lines from this substation were lost during the flood. CEMA arranged for the Canadian Forces and emergency response volunteers to help with riverbank stabilization at the substation.

Improving the resilience of private infrastructure - Many of the recovery projects to repair damaged infrastructure have included measures to improve resiliency. For example, redundancy has been built into power supply and communication networks for critical operations. Additional resiliency plans include specific projects for improving the resilience of ENMAX's power supply network, such as hardening substations and other electrical infrastructure that was threatened in 2013.

The critical nature of energy supply in the case of emergencies necessitates working closely with utility providers to continue to improve resilience.

> "I believe it is important to manage how/if electricity is cut off in affected areas. Our building did not directly flood, however the parkade experienced backup (more than an entire level was flooded). The reason for the flooding was that the sump pumps were not functioning because the power was shut off." – Public input

Opportunities to improve the resilience of Calgary's energy supply include:

- Making existing infrastructure more robust against floods.
- Adding a more modular electrical supply system that allows electricity to be cut-off at the level of specific neighbourhoods.
- Installing smart meters in flood-prone areas so that disconnections and reconnections can be done remotely at the household level.
- Enhancing the capability to effect more localized disconnections and re-connections of electricity supply downtown.
- Improving the resilience of the Downtown District Energy Centre.
- Providing ENMAX and City staff with enhanced information system tools to improve the speed at which re-connections can be made.
- Enhancing ENMAX's ability to share geospatial data with CEMA on the status of power re-connection.

With respect to all of the above-mentioned opportunities, ENMAX has applied to the Government of Alberta Flood Mitigation Secretariat for implementation funding.

Opportunities to improve resilience in the communication sector include:

- Making existing infrastructure more robust against floods.
- Expanding CEMA's membership to include additional communication providers to build resiliency throughout the sector.

Recommendation: Strengthen partnerships with utility providers to improve resiliency of their infrastructure and operations, with first priority to energy supply and communication networks.

PRIVATE PROPERTY

Many communities in Calgary were established before there were criteria for locating development outside of the floodway or designing properties in the floodplain for flood-resilience. As a result, much private development in the floodplain is vulnerably located and inadequately built to withstand floods and allow for a quick, cost-effective recovery.

In 1985 The City updated the Land Use Bylaw, forbidding new development in the floodway and putting requirements in place for development in the flood fringe. The City is working to remove grandfathering language from the Land Use Bylaw so all existing development will have to meet flood protection standards when re-developments are planned. Outside of the official flood hazard areas there are no requirements for flood protection of private property.

The City's Land Use Bylaw - *Development in the floodway and flood fringe is governed by the Land Use Bylaw. No new structures are permitted in the floodway but existing homes can be replaced using the same footprint as grandfathered properties that were in place prior to 1985. Flood fringe development specifies set back distances from the floodway and edge of rivers and creeks.*

"Unless otherwise referenced in subsection (2), all buildings constructed in the flood fringe after September 9, 1985 must be designed in the following manner:

(a) to prevent structural damage by floodwaters

(b) the first floor of all buildings must be constructed at or above the designated flood level

(c) all electrical and mechanical equipment within a building shall be located at or above the designated flood level"

Impacts to private property during the 2013 flood

During the 2013 flood, properties were flooded both within and outside of the official flood hazard areas causing extensive damage. Flooding was caused by surface water, groundwater and backflow through sanitary sewers and storm sewers. Buildings constructed prior to 1985 and covered by the grandfathering clause of the Land Use Bylaw sustained the most extensive damage.

Much of the damage to commercial buildings and condominiums resulted from the flooding of underground structures containing critical building systems, such as electrical vaults, elevator shafts and parking garages. In many cases simple flood protection measures could have avoided significant losses.

In addition to direct property damage, the flooding of private property resulted in broader losses, such as lost work time, financial stress and emotional trauma. Some Calgarians were out of their building for months as a result of damage. Businesses lost weeks if not months of productivity because their offices or shops were shut.

Erlton flood resilient development - *Part of the Erlton neighbourhood was designed to sustain minimal damage during flood events up to the 1:100 flood. Buildings were constructed with elevated main floors. While the streets and garages in this development were inundated with water, repairs were much less expensive than in developments not designed for flood resilience.*

Improving the resilience of private property

In many cases there are basic resilience measures that could drastically reduce impacts of future floods, such as raising electrical equipment above the 1:100 flood level.

It may be appropriate to require flood protection in areas outside of the official flood hazard area that sustained damage from the 2013 flood or can otherwise be identified as being in a flood risk area. The City should consider implementing stricter design standards for private property in the flood hazard area or graduated flood protection requirements according to graduated flood maps.

Recommendation: Expand the review of the Land Use Bylaw and other development regulations to update flood resiliency requirements for private property in flood risk areas.

"While volunteering to help clean up flood affected homes, of the 10 houses I worked on, 9 had only basement flood damage. Only 1 house had some water damage to the main floor as well as the basement. If that ratio is a truism, if we had no basements in the flood fringe, we would have 90% less damage." – Public input

Green Calgary in partnership with Green Communities Canada offers home visits to help homeowners identify ways to reduce damage from storm water and floodwaters on their properties. The City should initiate additional programs that would further support building-owners to implement flood resiliency measures, such as:

- An incentive program that provides home improvement grants and loans for flood resilience products.
- Collaborating with the insurance industry and emergency management agencies to create a home flood resilience audit program, similar to a home energy audit program.
- Workshops or seminars in collaboration with the insurance industry that support community and business organizations to identify risk management strategies.

> "Placing utilities [in office and apartment high rises] above ground level would considerably reduce the time to re-occupation, even if the parking is unusable. City Building code should be updated accordingly, and where possible, applied retroactively." – Public input

Recommendation: Develop programs that support building-owners to implement flood resiliency measures.

CHANGING CLIMATE

After Alberta's 2013 floods, many asked the question: was climate change to blame? The answer is not simple. Extreme weather events in the region like the 2013 flood are rare and there are insufficient historical data on which to base predictions in their frequency or intensity.[xxix] Regardless of the inevitable uncertainty about climate change, we know that extreme weather events have happened in the past and we can be sure they will happen again in the future. We cannot know exactly when future extreme weather will occur.

The Intergovernmental Panel on Climate Change's latest Assessment Report concludes that the global climate system is warming, with increases in average air and ocean temperatures, melting of snow and ice, and rising global average sea level.[xxx] In Canada, an average temperature increase of 1.3°C has been observed between 1950 and 2000. But what does this mean at the local level?

The Canadian prairies have one of the world's most variable climates. Changes in the global climate system are expected to bring more frequent and intense weather events to the prairie region. The climate and weather is expected to become more unpredictable with more frequent droughts and flooding from intense rainfalls and rapid snow melt.[xxxi]

The Water Survey of Canada uses historical river flow data to calculate the size of the 1:100 flood.

Each year, more data are collected and can be used to refine the estimate of the size of the 1:100 flood.

As the climate is changing, large floods could become more common.

This means that the size of the 1:100 flood may be larger in the future than it is today.

ADAPTING TO A CHANGING CLIMATE

Increasingly unpredictable weather and climate patterns in Calgary may impact The City's ability to make well-informed decisions regarding service delivery and infrastructure. Flood mitigation work must be done with a view to several possible scenarios to manage this uncertainty – applying adaptability to design standards and mitigation measures as part of a comprehensive approach to climate adaptation. The City must consider the potential for droughts and other climatic conditions and severe localized weather events (such as hail, thunderstorms, and high winds) in its planning. Drought events can be more costly than flood events when broader impacts are measured, for example, agricultural losses. Robust and flexible adaptation options are needed. The challenge is to put in place design standards for infrastructure that will be built to last 50 to 100 years. What will that infrastructure have to withstand and how might operations need to change?

Recommendation: Develop a comprehensive climate adaptation plan and implementation tools to reduce The City's infrastructure and operational vulnerabilities.

City of Calgary water treatment system vulnerability - *In partnership with Canada's Public Infrastructure Engineering Vulnerability Committee (PIEVC), in 2011 The City of Calgary assessed the potential vulnerability of its water supply infrastructure to climate change. The vulnerabilities seen as the highest priorities were those associated with extreme events such as flooding and drought. Operation and management plans are in place to reduce risk of some negative climate-infrastructure impacts. It is likely the climate changes will be gradual so adaptation can be incorporated into The City's long-range plans.*

Resiliency of flood control dams in Toronto

A 2010 vulnerability study examined current and future climate change impacts on two Toronto flood control dams and reservoirs. The assessment, taken up to the 2050 time horizon, examined the impacts of rainfall on performance of the dams to determine if any engineering solutions were needed. The report found that the current infrastructure is resilient to anticipated severe weather events allowing the city to prioritize infrastructure maintenance.[xxxii]

Examining infrastructure vulnerability to flood and other extreme weather should be part of a comprehensive climate adaptation plan for The City. As part of the plan, The City must evaluate the highest infrastructure vulnerabilities to climate change impacts and then prioritize interventions to improve resilience and incorporate these into existing asset replacement plans. Flood mitigation in public and private infrastructure is discussed in detail in the *Infrastructure and Property Resiliency* section.

THE LOCAL CLIMATE

Calgary has a prairie type climate, influenced by the city's proximity to the Rocky Mountains making the weather quite variable and unpredictable. The climate is typically sunny and dry, with cold winters and most of Calgary's precipitation occurring in the form of rainfall in late spring and early summer.

The understanding of variability in Calgary's future climate and weather patterns has focused mostly on annual averages and long-term changes. Understanding the types and frequencies of extreme events expected as a result of climate change at the local level requires researching weather and flooding events and how they are connected. Translating regional predictions into more local conditions is not yet well developed.

The impacts of climate change on spring flooding in the Elbow River Watershed were examined in 2007; results showed that annual average temperatures were increasing. The eastern portion of the watershed showed significant decreases in annual snowfall, while the western portion near the foothills showed increases in snowfall. Modeling showed that spring time flooding from expected increases in precipitation may nearly double flood peaks in the future.[xxxiii] However, it is important to note that even though trends in average snowfall and accumulated snow or snowpack conditions are decreasing, the trends in extreme snow conditions can be different.

The South Saskatchewan River Basin Adaptation to Climate Variability Project commissioned an evaluation of potential climate change impacts in the Bow River Basin.[xxxiv] As part of the project The City was involved in developing the Bow River Operational Model (BROM), which examined how changes in climate could impact flows and functions of the Bow River. This approach and others should be used to give the best simulations for the Bow Watershed.

Watershed-scale climate modeling provides information for The City and regional stakeholders in managing the uncertainties in projected changes in flood magnitudes and seasonality, expected changes in extreme precipitation and impacts on other water management issues such as drought. A better understanding of historical events and future scenarios can inform flood risk assessments, flood hazard maps, structural and land-use design standards, as well as contribute to flood and drought mitigation measures. This gives decision makers a tool to address vulnerabilities and direct resources where needs are highest. If The City pursues local climate models, other orders of government should be consulted.

> "Calgary is a world class city and the downtown areas need protecting. The city cannot afford to have its business centre flooded again and it would be short sighted not to proceed with this preventative work. The floods will become more frequent in the coming years due to climate change." – Public input

Recommendation: Develop a suite of watershed-scale climate models to capture various weather event scenarios, with input from regional partners, academic institutions and other levels of government.

Climate resiliency models for cities - *In British Columbia, the Pacific Climate Impacts Consortium developed regional scenarios for the Georgia Basin on climate variables such as: annual heating and cooling days, hydrological models and the length of time between events of a certain size or magnitude. Researchers used eight regional climate models to project changes in extremes. The information was used by the City of Vancouver to inform its climate change adaptation strategy.*[xxxv]

IMPLEMENTATION

The result of the Panel's investigation is a wide-ranging report that brings forward the most effective recommendations possible based on broad engagement and the best information that could be gathered in the months available. The timeframe did not allow the Panel to undertake new research, extensive design or modeling or detailed evaluation of alternatives. This work remains to be done and will be turned over to City Administration. To guide this work, The City should develop a vision and principles to direct flood risk management in the city and report annually on activities undertaken to improve resiliency and how well they are working.

Recommendation: Establish a permanent team within The City to oversee flood preparedness and resilience.

Recommendation: Provide an annual update to City Council on progress related to the recommendations from the Expert Management Panel on River Flood Mitigation.

The Expert Management Panel reviewed all recommendations qualitatively, considering potential economic, environmental and social impacts. The City should further assess flood mitigation options for their relative life-cycle costs and benefits to select options that best serve the public good and make efficient use of public funds.

Capital project options are at various stages of study by The City and the Province. More study would better quantify the impacts and should consider regional water management objectives. The City must consider combinations of measures yielding optimum results, as some measures are complementary, and some measures, if implemented, may reduce the need for others. Implementation decisions should be based on a thorough assessment across all mitigation options.

Recommendation: Evaluate social, economic and environmental impacts of flood mitigation options.

What The City does may influence what the Province is considering upstream of Calgary and vice versa. Many of the structural opportunities for reducing floodwaters in Calgary are upstream of the city; investigating or pursuing these options requires coordination with the Province, TransAlta, First Nations and private property owners.

Recommendation: Connect with the provincial body overseeing flood protection and loss reduction and support the Province's continuing analysis of flood mitigation options and implementation of appropriate measures throughout the Bow and Elbow watersheds.

The City can learn from other communities' efforts to improve their resiliency to flood events, and share lessons learned on what worked well during the 2013 flood and where improvements are being made or could be made. There are numerous events related to floods hosted by organizations such as cities, professional organizations and non-governmental organizations, but there is no regular event that brings together professionals from across Canada with a focus on municipal flood resiliency. This presents an opportunity for Calgary to initiate a regular national dialogue on these issues.

Recommendation: Host a national flood risk management workshop to share best practices and develop an ongoing networking group.

NEXT STEPS

This report is one step of many towards resiliency to floods and other disruptive events in Calgary. Implementing these recommendations requires a collaborative and coordinated approach between The City, the Province and other parties. The way forward will require investment – municipal, provincial, and federal. The pace of these investments must be balanced against the risk and reward achieved from each action.

Some of the recommendations in this report are contingent on the implementation of others and decisions on these may cause priorities to change. Even with dedicated efforts, flood resilience is not something that can be achieved overnight. Resilience requires continually learning and adapting as situations change. The city will grow, the watershed and climate will change, and flood risks will evolve. Calgary's flood mitigation strategy must evolve as well.

"I hope that our leaders will not shy away from making long-term solutions possible because they fear the short-term reactions of citizens." – Public input

GLOSSARY

1:100 or 100 year flood – A flood whose magnitude has a one per cent chance of occurring in any year. It is also sometimes referred to as the one per cent flood, since the probability that it will be exceeded in any given year is one per cent.

Aquifer – A subsurface formation that is permeable enough to store or conduct groundwater to wells and springs. An aquifer can be adjacent to and hydraulically connected to water bodies such as rivers and lakes.

Basin – The drainage area of a stream, river or lake. Also known as a watershed.

Climate adaptation – Anticipating the effects of climate change and taking appropriate action to prevent or minimize the damage they may cause.

Climate scenario – A simplified representation of the future climate, typically constructed for use as input to climate change impact models.

Dry dam – A dam constructed for the purpose of flood control, allowing water to flow past under normal conditions, and temporarily holding back floodwaters, releasing them over a period of time.

Ecosystem approach – A strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in a way that is balanced and equitable to future generations. It requires adaptive management to deal with the complex and dynamic nature of ecosystems and the absence of complete knowledge or understanding of their functioning.

Ensemble forecasts – A group of model simulations used for weather or climate projections. Variation of the results across the ensemble gives an estimate of uncertainty. Multi-model ensembles with simulations by several models include the impact of model differences.

Flood barrier – A permanent earthen embankment or wall, or a temporary wall constructed of sand bags or other materials, erected to provide protection from floods.

Flood fringe – The portion of the flood hazard area outside of the floodway. Water in the flood fringe is generally shallower and flows more slowly than in the floodway.

Flood hazard area – The area that is affected by a 1:100 flood, as indicated by official provincial flood hazard maps. The flood hazard area is typically divided into floodway and flood fringe zones and may also include areas of overland flow.

Flood hazard map – An official map published by the Government of Alberta that indicates the areas likely to be affected by surface water during a 1:100 flood event.

Floodplain – The area of land adjacent to a river that stretches to the base of the enclosing valley walls and experiences flooding during periods of high river flow.

Flood protection level – Flood magnitude (e.g. 1:100 flood) that infrastructure such as flood barriers are designed to withstand.

Floodway – The portion of the flood hazard area where flows are deepest, fastest and most destructive. The floodway typically includes the main channel of a stream and a portion of the adjacent area.

Hydrology – The scientific study of the properties, distribution and circulation of water on and below the earth's surface and in the atmosphere.

Model – A physical or mathematical representation of a process that can be used to predict some aspect of the process.

Overland flooding – Flooding of a property by water that enters the property from the surface, typically through doors or windows.

Overland flow area – Part of the official flood hazard area and typically considered special areas of the flood fringe.

Peak flow – The highest rate of water moving through a river during a specific event or period of time. The water level in the river is highest during peak flow. Also known as maximum flow.

Reservoir – A storage place for water created by construction of a dam in a river valley, and from which the water may be withdrawn for such purposes as irrigation, power generation or water supply.

Resilience – The ability of a social or ecological system to absorb disturbances while retaining the same ways of functioning and the capacity to adapt to stress and change.

Riparian zone or riparian area – Transition zones between the water and land. Riparian zones play an important role in protecting the river; they prevent excessive erosion, act as natural floodplains, provide river bank stabilization and also offer aesthetic, economic and recreational benefits.

Risk – The likelihood that an event will occur that causes harm.

Watershed – An area of land where waters flowing from different rivers, streams, lakes and wetlands, is conveyed to the same outlet. Other terms that are used to describe a watershed are drainage basin, catchment basin, catchment area, and river basin. Large watersheds may contain several smaller sub-watersheds that drain to the same outlet.

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Flood Mitigation Options Assessment Summary

A City of Calgary Summary

Full report prepared by IBI Group and Golder Associates

December 15, 2017

Introduction

Calgary was built at the confluence of two mountain rivers, making it vulnerable to river flooding. The downtown economic core, the beltline areas and other communities are at risk of being flooded by the Bow and Elbow rivers every year. These vital areas include government buildings, social and health services, historic communities, commercial and industrial areas, major tourist attractions and recreation facilities (Figure 1).

The 2013 floods in Southern Alberta were one of Canada's most costly natural disasters, resulting in loss of life as well as significant property damage, personal impact and social and economic disruption. The 2013 flood event emphasized the need to address flood risk in Calgary, protect public safety and reduce future social, environmental, and economic flood damages to our city. This imperative drove the recommendation for The City to gain a better understanding of Calgary's flood risk and the changing dynamics of the floodplain, and develop evidence-based strategies to reduce flood risk.

The Flood Mitigations Options Assessment, completed for The City by IBI Group and Golder Associates Ltd. in 2017, is an important step towards achieving these goals. The study undertook four key steps:

1. Develop a detailed computer model to calculate the risk of flood damages within the city (Damage Model).
2. Assess the risk of flood damages under a number of scenarios with potential mitigation options in place (Scenario Analysis).
3. Compare mitigation scenarios using a framework that considers cost, benefit and social-environmental sustainability (Sustainability Assessment).
4. Provide recommendations for reducing potential river flood damages though structural and non-structural measures (Recommendations).

The purpose of this document is to provide an overview of key findings from the study.

"Flood Mitigation remains a top priority for The City of Calgary."
(Utilities and Corporate ServicesCommittee, April 2017)

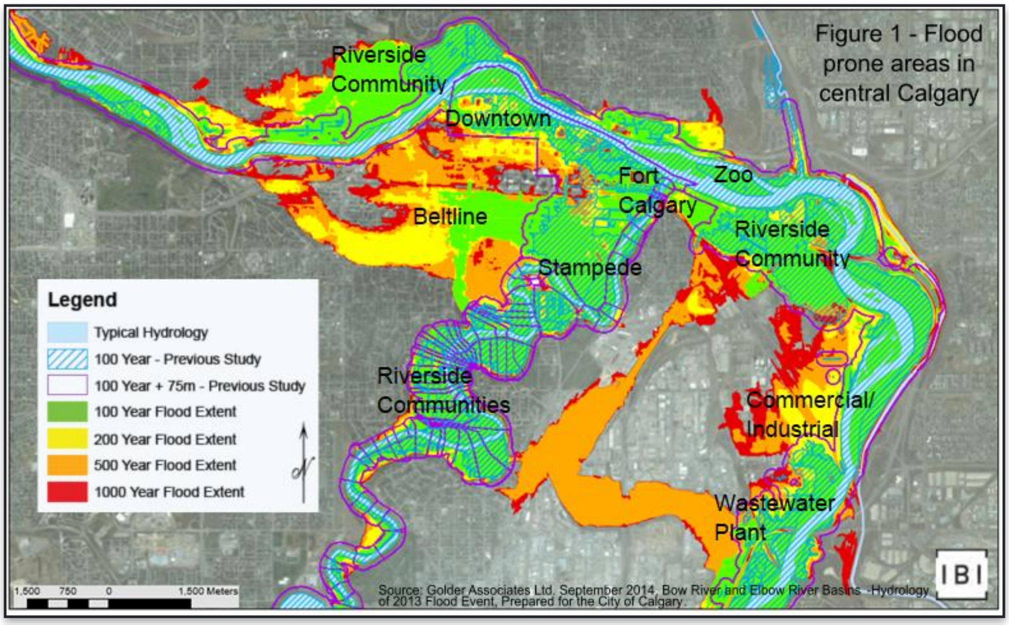


Figure 1 - Flood prone areas in central Calgary

Source: Golder Associates Ltd. September 2014. Bow River and Elbow River Basins -Hydrology of 2013 Flood Event, Prepared for the City of Calgary.

The Flood Damage Model

Understanding the impacts of flooding is a crucial part of mitigating against the hazard. One way to understand the impacts is to create a flood damage model. In general, a flood damage model calculates the depth of flood water at every property for various sized flood events. It then calculates the estimated damage based on the flood depth, current land use and infrastructure on that property. Where possible, The City's model also calculates a financial value for environmental and social impacts of flooding, which provides a more holistic evaluation of flood impacts.

The City's flood damage model is an updated version of a model previously created by IBI Group and Golder Associates for the Province of Alberta (AEP, 2014). The area considered in this study (Figure 2) encompasses all of the flood prone areas within the city limits on the Bow and Elbow Rivers, up to a 1:1000 year flood.

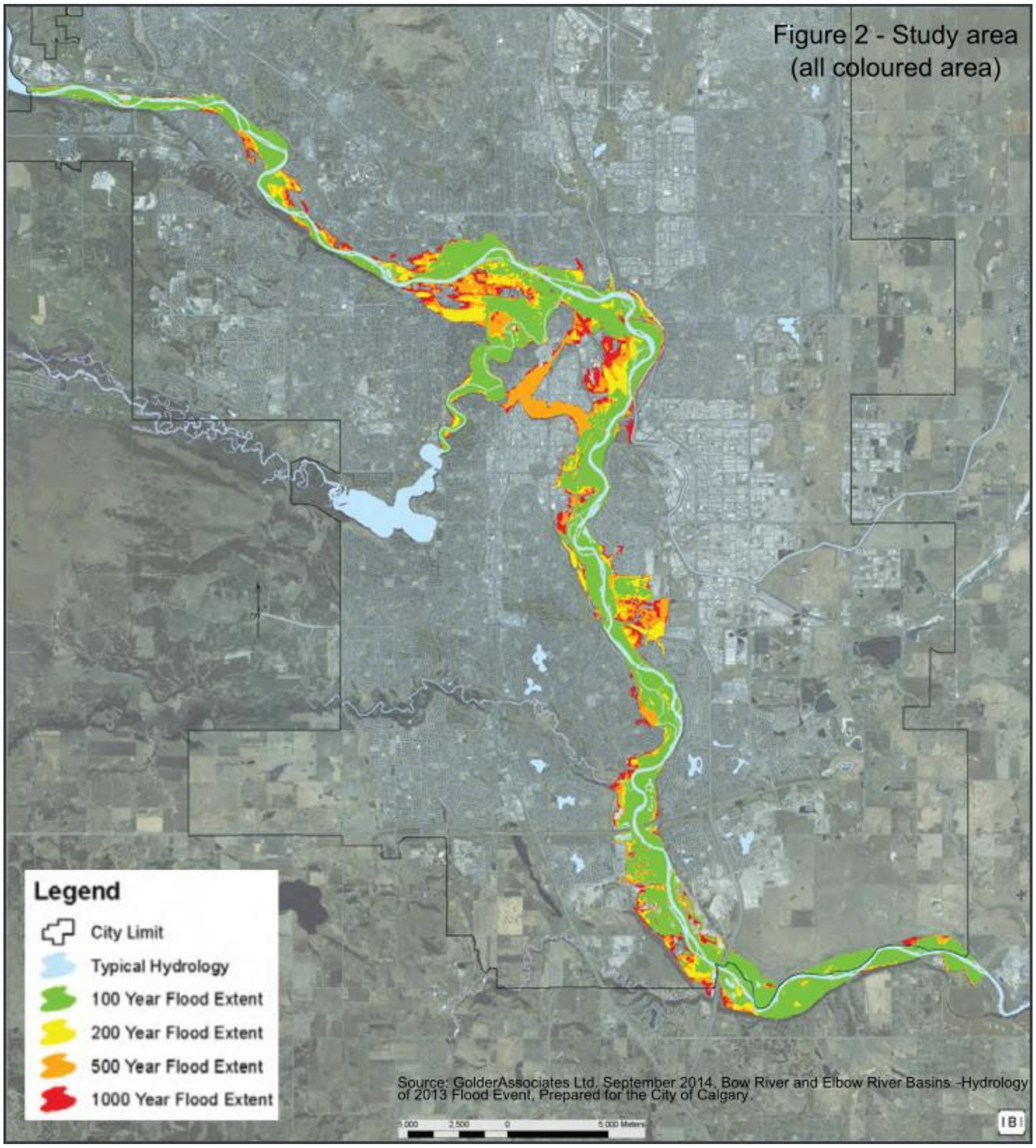


Figure 2 - Study area (all coloured area)

Source: GolderAssociates Ltd. September 2014, Bow River and Elbow River Basins -Hydrology of 2013 Flood Event, Prepared for the City of Calgary.

A 1:100 year flood has a 1% chance of occurring in a given year, and a flow rate of 2820 m^3/s on the Bow River downstream of the Elbow confluence.

A 1:200 year flood has a 0.5% chance of occurring in a given year, and a flow rate of 3520 m^3/s on the Bow River downstream of the Elbow confluence.

A 1:500 year flood has a 0.25% chance of occurring in a given year, and a flow rate of 4600 m^3/s on the Bow River downstream of the Elbow confluence.

A 1:1000 year flood has a 0.1% chance of occurring in a given year, and a flow rate of 5600 m^3/s on the Bow River downstream of the Elbow confluence.

Scenario Analysis

The study used the flood damage model to assess the flood risk in Calgary with and without mitigation. Without mitigation measures, such as those put in place since 2013, the average cost of flooding in Calgary would be nearly $170 Million per year. This value is the cost of damages from all floods that could happen (large and small), averaged out as annual payments. This amount is called the "average annual damages" (AAD).

With the existing mitigation in Calgary, including the projects currently under construction in 2017 (e.g., the flood barrier in West Eau Claire/downtown and upgraded gates on Glenmore Dam), the average annual damages have been reduced by 30% to $115 Million per year. This significant reduction in flood risk has been a notable achievement for our city, with support from citizens and The Province.

The remaining risk of $115 Million per year is still high. The study also explored a number of mitigation scenarios to further reduce potential flood damages. Each scenario is a plausible combination of options that can prevent flooding in communities, or remove buildings and people from harm's way. The process for selecting mitigation scenarios for consideration involved an initial screening of options, taking into account local feasibility, functional reliability, financial efficiency, and environmental and social impact.

The resulting options considered for mitigation scenarios included:

- Watershed-level structural flood mitigation measures – new reservoirs and refined operations of existing reservoirs upstream of Calgary on the Bow and Elbow Rivers.
- Community-level structural mitigation – new flood barriers within Calgary, and
- Property-level and land use policy-based mitigation measures.

The results of this analysis include calculation of a cost-benefit ratio for each scenario, and the "residual" average annual damages that large floods could still cause, even with the proposed mitigation measures in place. The following table shows the results of the analysis. A full description of each of scenario is provided in the full report.

The technical information used for each measure, such as size, location and conceptual cost, was based on other technical studies, such as The City's Permanent Flood Barrier Protection Assessment (2017), and The Province's Bow River Working Group (report submitted in 2017), of which The City has been an active member. A protection level to the 1:200 year flood (which has a 0.5% chance of occuring in any year) was selected for the assessment, to evaluate the feasibility of protecting beyond the current provincial standard and to address future climate uncertainty.

The City's ongoing improvements to forecasting and emergency response were included in all scenarios.

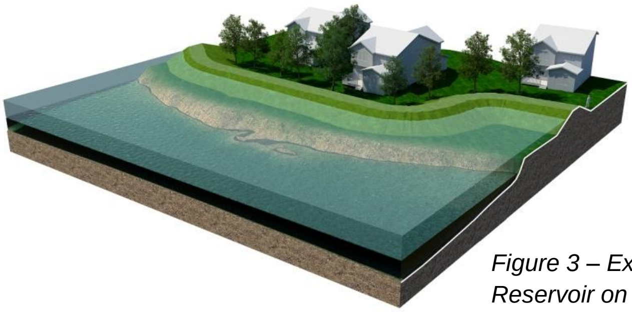


Figure 3 – Existing Glenmore Reservoir on the Elbow River (left) and conceptual flood barrier in a residential community (right).

Summary of Scenario Analysis

All scenarios include the flood protection provided by:

- Glenmore Dam, including the upgraded gates.
- TransAlta agreement with The Province to operate reservoirs in the Bow River system for flood mitigation.
- Existing and under-design barriers as of 2016 (e.g., Stampede, Zoo, West Eau Claire, Heritage Drive & Glendeer Circle, Centre Street Bridge, Bonnybrook, Deane House).
- Existing stormwater outfall gates and stormwater management plans.
- Existing flood forecasting and emergency response plans (including temporary flood barriers).

Scenario	**Capital Cost**	**Benefit-Cost Ratio***	**Residual Average Annual Damages (AAD) – per year**
Existing (Baseline) – does not include the TransAlta operational agreement	N/A	N/A	$115 million
1**) Springbank Off-Stream Reservoir** (SR1) on the Elbow River	$510 million	3.22	$45.2 million
2) **Springbank Off-Stream Reservoir** (SR1) on the Elbow River and a new **reservoir on the Bow River**	$1.41 billion	1.35	$31.8 million
3) **Elbow River barriers** below the Glenmore Dam and a **Bow River reservoir**. Total length of the barriers is estimated at 14.6 km.	$1.80 billion	1.06	$44.7 million
3a) **Scenario 3 plus groundwater controls** included with the barriers.	$1.96 billion	1.08	$38.2 million
4) **Springbank Off-Stream Reservoir** (SR1) **and Bow River barriers** (no upstream reservoir on the Bow). Total length of the barriers is estimated at 30 km.	$900 million	2.53	$34.6 million
4a) **Scenario 4 plus groundwater controls** included with the barriers.	$1.13 billion	2.09	$28.8 million
5) **Elbow River barriers** below the Glenmore Dam and **Bow River barriers** (no upstream reservoirs). Total length of barriers is estimated at 44 km.	$1.32 billion	1.69	$45.6 million
5a) **Scenario 5 plus groundwater controls** for barriers.	$1.75 billion	1.55	$31.9 million
6) **Buyouts** of all residential properties in the 1:200 year floodway (980 properties)	$1.81 billion	0.47	$88.8 million
7) **Upstream reservoirs on the Bow and Elbow Rivers with 1:25 barriers** for Downtown, Sunnyside and Bowness on the Bow River. Total length of the barriers is estimated at 4.5 km.	$1.45 billion	1.33	$31.5 million
7a) **Scenario 7 without reservoir on the Bow.**	$547 million	3.07	$43 million

Scenario	**Capital Cost**	**Benefit-Cost Ratio***	**Residual Average Annual Damages (AAD) – per year**
8) **Scenario 7 plus groundwater control** for Sunnyside and a 1:200 level barrier for the downtown core.	$1.47 billion	1.32	$31 million
8a) **Scenario 8 without upstream reservoir on the Bow.**	$569 million	3.02	$43 million
9) **Scenario 8a with higher barriers** (1:100 for Bowness/Sunnyside and 1:200 for Inglewood/Downtown).	$658 million	2.84	$38.6 million

**Note: The benefit-cost ratio does not reflect the benefit/cost of individual measures, but of all the measures included in the scenario working together. The benefit-cost ratio is all benefits over the life of the project (100 years was used in the analysis) divided by all costs over the life of the project (100 years).*

Benefit-cost ration (B/C Ratio) = Benefits / Costs. If the B/C Ratio is greater than 1, the scenario is cost-beneficial. If benefits equal costs, the B/C Ratio = 1, and the project will "break even". If benefits are less than the costs, the B/C Ratio is less than 1.

Sustainability Assessment

In addition to technical analysis using the flood damage model, a sustainability assessment was conducted for each mitigation scenario.

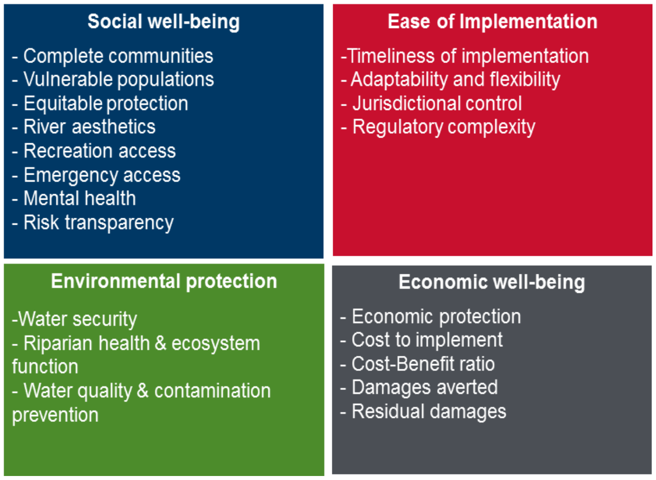
Mitigation scenarios were evaluated through technical analysis, sustainability assessment and public engagement.

Each flood mitigation scenario was evaluated in the areas of social well-being, environmental protection, economic well-being and ease of implementation (Figure 4). Each theme area was equally weighted. The criteria within each area, their assigned individual weightings, and the scores for each mitigation scenario were determined based on:

- Feedback from public engagement.
- Subject matter expertise from across *several City departments.*
- *IBI Group and Golder's expertise.*
- *The City's Triple Bottom Line Policy, Sustainability Direction, Sustainability Appraisal Tool* and watershed goals, and
- Best practices in sustainability analyses.

Significant community and stakeholder engagement work was undertaken to inform the study (e.g. development of the sustainability criteria, scenario evaluation) and the direction of The City's future mitigation work. Public engagement activites included:

- Community Advisory Group (flood-affected and non-flood-affected citizens who met throughout the duration of the project).
- Telephone survey (randomized third-party) on values around the river, flooding, mitigation and development, and
- Public booths, workshops and open houses (11 events city-wide).



Social well-being

- Complete communities
- Vulnerable populations
- Equitable protection
- River aesthetics
- Recreation access
- Emergency access
- Mental health
- Risk transparency

Ease of Implementation

-Timeliness of implementation
- Adaptability and flexibility
- Jurisdictional control
- Regulatory complexity

Environmental protection

-Water security
- Riparian health & ecosystem function
- Water quality & contamination prevention

Economic well-being

- Economic protection
- Cost to implement
- Cost-Benefit ratio
- Damages averted
- Residual damages

Figure 4 – Flood mitigation scenario sustainability assessment criteria

At the end of the study, The City also reconvened with the Expert Management Panel on River Flood Mitigation, established after the 2013 flood, to gather their perspectives on how the assessment's recommended approach aligned with the Panel's original vision and recommendations.

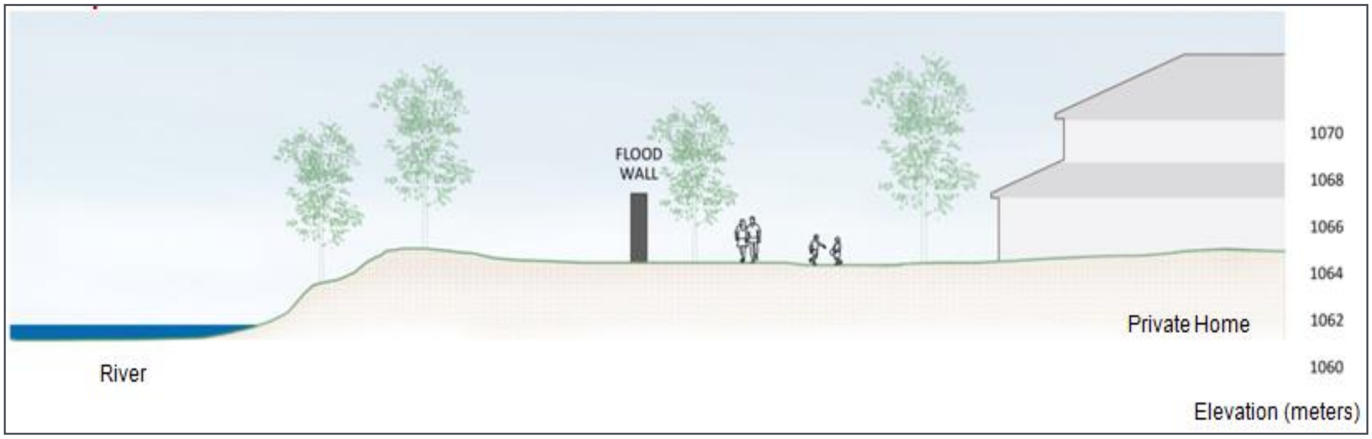


Figure 5 – Social and environmental impacts of 1:200 year flood barriers (illustrated here) were evaluated.

Results and Recommendations

The assessment provided a multi-faceted and robust evaluation of the opportunities and challenges associated with each potential mitigation scenario. Under the Sustainability Assessment, upstream mitigation (reservoirs) scored highest due to:

- Potential climate adaptability and water security benefits.
- Geographical extent and equitability of protection along the entire river downstream of the reservoir, and
- Lower level of community disruptions compared to large barriers.

The study identified that because community-level flood barrier projects are within The City's jurisdiction, they can be constructed more quickly than watershed-scale projects such as reservoirs, which is a benefit.

The study also highlighted the drawbacks of each mitigation measure. Every mitigation measure is designed to protect against a certain sized flood, and can be overtopped by rare larger events. Dams and reservoirs cause significant environmental impacts, take years to plan and construct, and have a small chance of catastrophic dam failure, although this is mitigated through rigourous dam safety legislation in Alberta. Barriers (such as illustrated in Figure 5) lack any protection benefits for events larger than the design flood, are aestheticly and environmentally intrusive; may not protect against groundwater flooding, and cannot provide opportunities for drought management, energy generation, or recreation.

To address the deficiencies of each individual measure, and to provide adaptability for future climate uncertainty, multiple or redundant defences can be used to create a layered approach for increased resiliency. Scenarios that included upstream reservoirs and complementary low-height barriers scored higher than fortification of the rivers by barriers alone or upstream reservoirs alone. This aligns with concepts of integrated watershed management and integrated flood risk management, which aim to manage the watershed as a holistic system and create climate adaptable resilience.

The mitigation scenario including upstream reservoirs on the Bow and the Elbow, small barriers at specific locations along the Bow (to achieve equivalent level of protection) and complementary non-structural measures had among the lowest residual average annual damages, and a robust #1 ranking for sustainability.

Scenario 1
The study results showed that the Springbank Reservoir (SR1) on the Elbow River removes a significant portion of flood risk, as does the current 5-year agreement between the Government of Alberta and TransAlta to operate the Ghost Reservoir on the Bow River for flood mitigation. Together, these measures reduce the city-wide flood risk by another 30%. This scenario has a very high benefit-cost ratio of 3.2. It does, however, leave a high residual risk ($45.2 Million per year), largely on the Bow River, as the level of protection provided in this scenario is not as high on the Bow as the Elbow.

Scenario 2
To further reduce risk on the Bow, the potential mitigation benefits from an additional (new) reservoir on the Bow River was modelled upstream of Calgary. This change increases the capital cost significantly, but lowers the residual annual average flood damages to $31.8 Million per year.

Scenarios 3, 3a, 4, 4a, 5 and 5a
These scenarios investigated mitigating flooding using barriers on each river without having an upstream reservoir to provide additional mitigation. Residual average annual flood damages were between $28.8 and 45.6 Million per year. The costs, however, were similar or higher than building reservoirs. This is due to the amount of private land that would have to be aquired along the river to accommodate barriers large enough to mitigate against flooding because upstream reservoirs are not in place. Scenarios involving large flood barriers scored low on the sustainability analysis, however, largely due to the social and environmental impacts of constructing large permanent barriers, in a few cases up to 6m high, along the rivers.

Scenario 6
Buyouts of properties in a hypothetical floodway based on a 200-year flood were assessed as a mitigation solution. The results showed this measure is one of the most costly, even though it did not provided mitigation to all properties at risk of flood damage. While the study acknowledged flood damages would be completely eliminated for the bought-out properties, the high cost of purchasing the properties made it the only scenario that was not cost-beneficial. Further discussion on property buy-out is included in the following section.

Scenarios 7, 7a, 8, 8a and 9
After reviewing public input and the results of the first six scenarios, Scenarios 7, 7a, 8, 8a and 9 were developed to assess combinations of reservoirs and barriers on the Bow River. Because a new reservoir on the Bow River would likely still not provide enough flood water storage to mitigate a 2013-sized flood event, and because of the long timeframe to explore and build such a reservoir, complementary barriers were modelled along the Bow. These barriers were modelled in locations where extra measures are required in addition to a reservoir, to achieve equivalent levels of protection to that committed to on the Elbow River.

While the addition of these barriers increase the cost of these scenarios, it also increases benefits correspondingly, and increases the equitability of protection for all at-risk Calgary communities. These scenarios were ranked the highest out of all of the options.

Non-Structural Options

In addition to structural mitigation measures such as reservoirs and flood barriers, the study also evaluated potential non-structural measures that can reduce future flood damages in Calgary. It identified feasible measures and generalized costs and benefits. The measures identified form a basis for The City's ongoing work exploring policy and land use based flood resiliency measures.

Contingency Measures

These measures include forecasting and warning systems, keeping citizens educated and updated, emergency response planning and enhanced connections and partnerships. These methods are highlighted as being essential, flexible and low-cost.

Land Use Regulations

The study acknowledges that while not developing in a floodplain eliminates flood damages, historic development patterns have led to a complex relationship between cities and floodplains, and the social and economic value of development in floodplains is significant.

The study identified basement damages as a significant risk, even with current or stricter building flood proofing regulations. Over time, basement damages could be reduced by implementing regulations that eliminate development of below grade space, prohibiting habitable space (such as bedrooms or suites) in basements, and requiring sump pumps and sewer backflow preventers in all flood prone areas.

Further investigation of the costs and benefits associated with specific potential land use regulation changes is recommended.

Property Level Mitigation/Floodproofing

Property level mitigation is described by the researchers as being cost-effective and keeps flood readiness front of mind for citizens. The emphasized options include incentives for sump pumps and backflow preventer valves. Other options include higher elevation of main floors, basement removal or finishing basements with materials that are easy to clean after floods, and property-level flood protection such as berms and flood gates for commercial and larger buildings.

Exploration of property level mitigation is recommended in combination with structural measures, and can significantly reduce private property damage from groundwater, sewer back-up and overland flooding. Public engagement demonstrated an interest from Calgarians for more public education on reducing flood risk and financial incentives for private property owners to flood proof homes and other buildings. The Assessment recommended that The City explore the development of an incentive program for property level measures with a supporting education program.

Flood Insurance

The study suggests that flood insurance should not be relied on to achieve acceptable levels of protection. The costs and levels of risk involved suggest that premiums for unmitigated homes are not viable for most property owners. Insurance is a tool to redistribute the financial risk of flooding, not prevent flood damages.

What about buying out properties at risk?

Property ownership and development within Calgary's floodplain is diverse, spanning many land uses and demographics. The cost of buying out all properties at flood risk in Calgary and converting them to parkland is extrodinarily high (over $2 Billion) – far more costly than any other mitigation option assessed.

Not all properties have to be bought out to reduce future flood damages. Buying out select properties, however, leaves many other properties still in need of protection. The fincanical and social implications of buying properties must be considered very carefully.

There are also ways to alter how Calgary develops that can decrease flood risk – for example, restricting land uses that would be at most risk during a flood, and protecting high-value riparian areas. The City is exploring or already implementing such options.

Currently in Calgary, no new development is allowed in the floodway, and development in the flood fringe must be flood-proofed. The City continues to investigate the costs and benefits of removing or further restricting development in Calgary's floodplain.

What's Next:
The City's River Flood Mitigation Strategy

Based on the results of this study and other work undertaken since 2013, The City recommended an informed flood resiliency and mitigation strategy, which was approved by Council in April 2017. Subsequently, an implementation plan was approved by Council in June 2017 that outlined a combination of watershed and community level mitigation that allows flexibility and adaptability in managing flood risk.

The recommended scenario is Scenario 8, which has the lowest residual average annual flood damages, and provides the most timely and equitable protection to communities at risk of flooding from the Bow and Elbow Rivers.

Recommended Scenario: #8

- Upstream reservoirs on the Bow River (upstream of Calgary) and Elbow River (SR1).
- Low-height barriers for Sunnyside, Bowness and Pearce Estates on the Bow River.
- 1:200 barrier for the downtown core.

While The City of Calgary can implement some mitigation measures within its jurisdiction, it is essential that upstream mitigation is built to provide the level of protection needed for Calgary. The City will continue to support and advocate for upstream mitigation on both the Elbow and Bow Rivers.

As approved by Council, work is already underway to fund, design and construct barriers to complement a potential new reservoir on the Bow River that would achieve equitable protection for all at-risk communities across the city.

The City has implemented several lessons-learned from the 2013 flood, and continues to improve forecasting, emergency response, citizen education and communication, and preparedness for citizens, businesses and city departments.

Other non-structural solutions, such as policy, regulations, education, incentives and selective property buyouts are being explored to complement structural measures and provide further flood resiliency for Calgary.

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Government of Alberta. Springbank Off-stream Reservoir. http://www.transportation.alberta.ca/sr1.htm

The full Flood Mitigation Options Assessment report can be requested by contacting 311.

For more information on flooding in Calgary, resiliency and mitigation,
please visit www.calgary.ca/floodinfo or contact 311.

Calgary

The Riparian Action Program:

A blueprint for resilience

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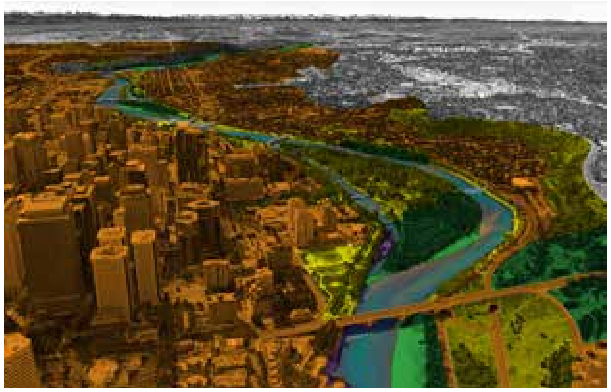

The areas that border our creeks and rivers are highly valued landscapes and critical pieces of 'green infrastructure' that provide multiple, free, and self-sustaining services. The front cover illustration highlights the multiple uses of riparian lands located within the downtown core.

🟧 Developed
🟩 Conservation
🟪 Flood and erosion control
🟥 Restoration
🟨 Recreation

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Foreword

Statement of purpose

Water utilities around the world are seeking new solutions to urban infrastructure issues and have recognized the importance of "green infrastructure" to protect, restore and mimic nature's water cycle. Green water infrastructure harnesses the power of natural design to provide multiple services, often free and self-sustaining, rather than building costly drainage and flood mitigation infrastructure.

The areas that border our creeks and rivers—riparian areas—are the foundation of The City of Calgary's integrated approach to watershed protection and management. The Riparian Action Program also takes a systems approach to program design based on the unifying vision and strategies established in the 2013 Riparian Strategy. It sets out a 10-year program focused on three areas and outcomes:

Program area	Outcome
Land use planning	Further loss of riparian areas is minimized
Health restoration	City-wide riparian health is improved
Education and outreach	Stakeholders and citizens value riparian areas

The following document characterizes riparian landscapes, organizes areas of work across The Corporation and brings emphasis to the importance of riparian landscapes as green infrastructure critical to integrated watershed management.

It is also a complementary companion piece to flood resiliency and mitigation. Many of the priority actions found here are equally critical to realizing the recommendations outlined within The City's **Report from the Expert Management Panel on River Flood Mitigation**, as well as other regional watershed management planning initiatives.

How to use this document

The Riparian Action Program is intended to be a working document and unfolds over three chapters. Chapter One discusses Calgary's riparian areas, including riparian ecosystem services, the health of Calgary's riparian areas, recent work to map and categorize these landscapes and citizen research. Chapter Two covers the main content of the program and outlines three areas of action and recommended outcomes and indicators. Chapter Three includes a series of watershed maps that provide an overview of riparian land uses in Calgary and identifies priority restoration projects.

Specific information and implementation tools designed for planners, engineers and practitioners are included in Supplements 1 to 4. Supplements include detailed information on land-use planning, restoration, monitoring protocols and engagement planning. Finally, detailed work plans for each program area are included in an Appendix.

Who should use this plan and how to make best use of it

The document should be used by planners, engineers, practitioners and watershed stewards within The Corporation and the community for direction and ideas on how to protect and restore riparian landscapes within Calgary. It is intended to help practitioners and citizens actively engage and align their work across Calgary's watersheds. It is hoped that this document will also help watershed stewards identify potential project partners.

This document may also assist with resourcing riparian protection and restoration projects, as proposals linked to this plan will be contributing to watershed goals. A number of resources, contacts and existing projects are detailed throughout.

> 83 per cent of Calgarians say that river areas are important to them personally.
>
> **Ipsos Public Affairs (2016b)**

The legacy of Calgary's river parks and stewardship

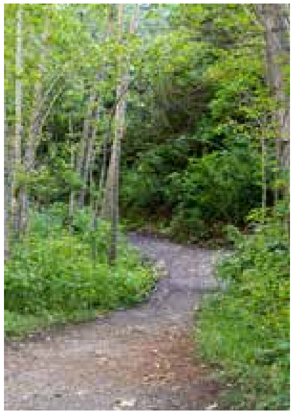
Bowness Park: In 1912, developer John Hextall, donated Bowness Park area to The City in return for an extension of a streetcar line to his adjacent subdivision.

Lawrey Gardens: In the 1930s and 1940s, ice jam floods regularly impacted Calgary's riverside communities, including the working class neighbourhood of Lawrey Gardens, three miles west of downtown. To reduce flood risk, private residential lots in Lawrey Gardens were purchased by The City of Calgary with provincial assistance in the 1950s.

Bow Riverfront Park system near downtown: In the 1960s, the south bank of the Bow River alongside downtown Calgary was almost converted into a highway freeway and railway corridor. The public riverfront park system today that provides such an amenity next to downtown's skyscrapers was only made possible by a coalition between the organized women's movement, urban elites, philanthropists, and the planning department.

Pearce Estate Park: William Pearce, an early settler and the federal government's land commissioner, willed his property on the west bank of the Bow River in Inglewood to The City.

Sources: Armstrong, Evenden, and Nelles (2014); Nelles (2005)



"We have a clean river flowing through our city, this is so precious"

Riparian Landowner
Ipsos Public Affairs
(2016a)

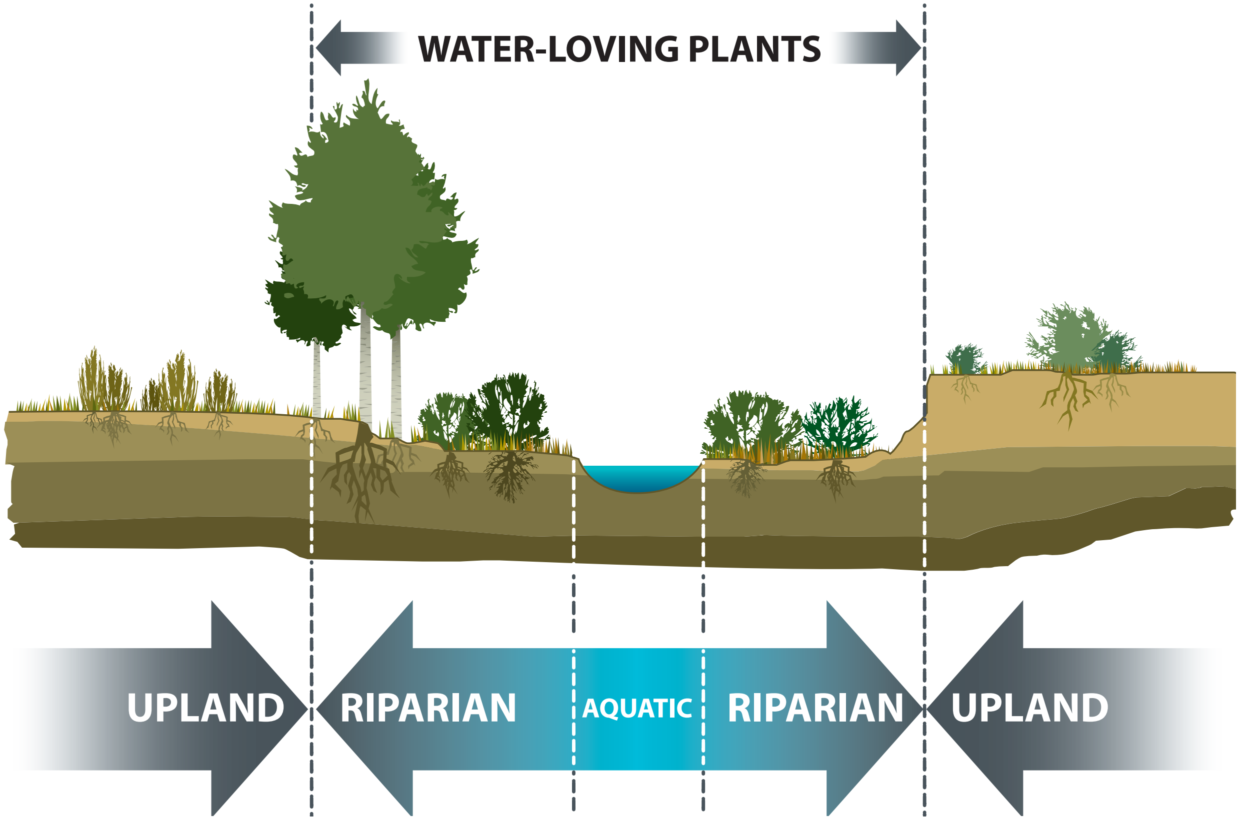
Green water infrastructure harnesses the power of natural design to provide multiple services, often free and self-sustaining, rather than building costly drainage and flood mitigation infrastructure.

Introduction: Building a blueprint for resilience

Riparian areas are central to watershed and community resilience

Riparian areas unfold like ribbons across our watershed, encompassing landscapes where land and water interact. They border rivers, creeks and wetlands and extend across the floodplain, down into the groundwater and upwards to include plants and trees (see Figure 1). These areas are unique ecosystems largely defined by the complex interactions that happen when land meets water. Along the water's edge, higher-than-average levels of nutrient exchange give rise to rich soils that store water and support a diversity of plant and animal life. This natural diversity sustains many ecological, social and economic benefits that we depend on, including clean drinking water, resilience to flood and drought, plant and animal life, recreational opportunities and experiences of nature within our urban environment.

Figure 1. Riparian areas border rivers, creeks, stream and wetlands (adapted from Fitch et al., 2001)



Resilience is the capacity to endure and recover from disruptive events. Resilience requires appropriate action before, during and after an event to minimize negative effects. A more resilient city suffers less impact when disasters occur and recovers more quickly.

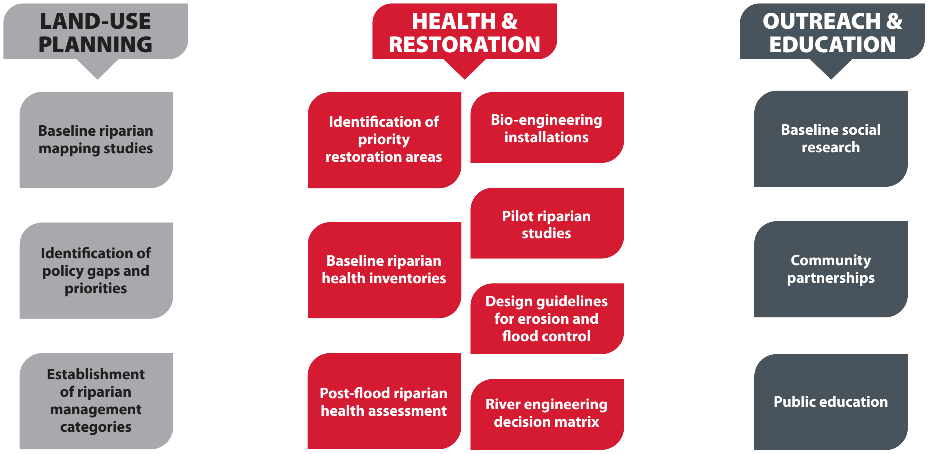
The Latin root of the word riparian is “ripa,” meaning bank.

Within the past 10 years, The City of Calgary has focused on understanding the function of riparian areas within our watershed and on better understanding their connection to the resilience of our community after a flood. In particular, since the 2013 flood, our focus on better riparian management has become an urgent priority. Protecting these landscapes now will directly improve public safety in the near term and increase our watershed and community resilience in the long term. Healthy, intact riparian areas also improve overall drainage and minimize demands on our stormwater infrastructure.

Our commitment to riparian protection and management

The Riparian Action Program addresses multiple business priorities—including stormwater management, flood mitigation, biodiversity and climate change adaptation—while directly improving the quality of life for citizens and improving the resilience of our infrastructure and communities. While Water Resources has already undertaken many actions over the past decade to protect and restore riparian areas (see Figure 2). The Riparian Action Program aims to better co-ordinate and focus municipal and community efforts.

Figure 2. Actions undertaken to improve riparian areas



Program management and governance

Water is a public resource, and there is considerable legislation, policy and planning that already provides direction for riparian-area governance. In fact, the complexity of the Riparian Action Program is due to the broad number of interests that play a role in how we plan for and manage these areas. Currently, the management of riparian areas extends across federal and provincial governments, as well as across multiple municipal business units. Responsibility also extends outwards to partnering organizations, consultants, developers, private landowners and citizens.

It takes a community

Riparian protection is already an important part of how The City manages water and natural resources. The creation and implementation of the Riparian Action Program is made possible by the contributions of numerous City business units and departments., as well as community partners who have shared their expertise, guidance and support, including:

- City of Calgary: Water Utilities, Calgary Parks, Planning and Development
- Cows and Fish: The Alberta Riparian Habitat Management Society
- Calgary River Valleys
- Bow River Basin Council
- Government of Alberta

Due to the critical influence riparian landscapes play in the business of delivering and managing municipal water management priorities, Water Resources will oversee and lead riparian programming within The Corporation and Calgary's municipal boundaries. In the very near future, it is recommended that dedicated resources be established within Water Resources to oversee and deliver on programming identified within this document. It is also recommended that Water Resources provide annual Riparian Action Program progress updates to City Council.

Alignment with flood program and other corporate plans, policies and projects

The Riparian Action Program aligns with numerous provincial and municipal plans, policies and projects. Most notably, it is key to realizing the **Municipal Development Plan's** (MDP) goal of "Greening the City" and specific MDP objectives related to green infrastructure, watershed protection and ecological networks. It also provides a visible line of sight to MDP policies related to riparian protection that have long been approved, though not always consistently applied.

Many of the priority actions found here are equally critical to realizing the recommendations outlined in The City's **Report from the Expert Management Panel on River Flood Mitigation**. While the program focuses specifically on the natural riparian areas that border river, streams and creeks, it complements work related to wetlands and other watershed management programs. Other key areas of corporate alignment include the **Biodiversity Strategic Plan** (2015), the **Action Plan** 2015-2018 and a range of regional watershed management planning initiatives, including the provincial **Water for Life** strategy, regional and sub-regional plans like the **South Saskatchewan Regional Plan** and the **Bow River Basin Watershed Management Plan.**[1] See Figure 3.

Figure 3. Alignment of the Riparian Action Program with other corporate initiatives

Riparian Action Program

10-year program to restore and protect riparian areas.

MDP

60-year strategy and policy framework for "Greening the city."

Flood Resiliency and Mitigation Plan

4-year plan.

Drainage Financial Plan

12-year action plan.

Corporate Action Plan

4-year budget cycle and plan.

Responsible planning and management of riparian areas will benefit Calgarians by providing cleaner water and improved drainage that supports recovery after climatic events, including flood and drought. As well, riparian areas improve public safety, minimize long-term costs to citizens, enhance the spatial quality of our river valleys and creek systems and protect critical environmental assets.

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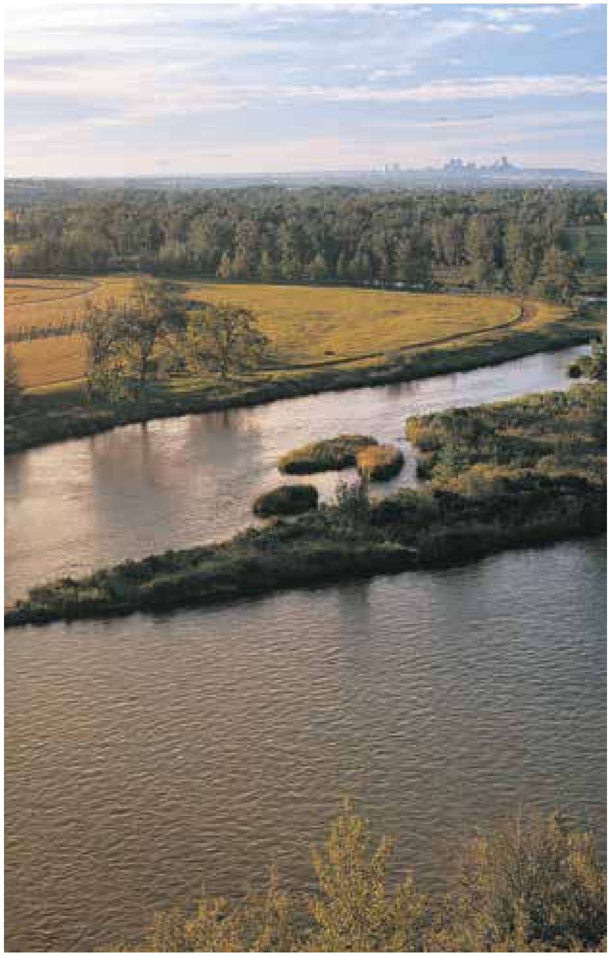
[1] See Supplement Two of the Riparian Strategy (City of Calgary, 2013) for a complete overview of legislation, policy and plans pertaining to Calgary's riparian areas.

Riparian areas are the foundation of a new approach to integrated watershed management.



Riparian areas sustain our creeks and rivers.

Chapter 1. Riparian Areas in Calgary

Calgary's historical roots are at the confluence of the Bow and the Elbow rivers, a naturally occurring ford that has been the centre of life and activity in this region for millennia. Like many places around the world, as our city has expanded, our natural riparian landscapes have disappeared. Today, Calgary's riparian areas are marked by human intervention, and remaining natural open spaces that border our creeks and rivers often face pressures from recreation and development.

The City has undertaken significant work in partnership with riparian experts to better understand and characterize Calgary's riparian areas, including:

- Recognizing riparian ecosystem services.
- Assessing the health of riparian areas.
- Mapping riparian areas within the city.
- Creating riparian management categories.
- Conducting citizen and stakeholder research.

The work discussed within this section represents nearly 10 years of accumulated research and data focused on Calgary's riparian areas. This document provides a scientific foundation and direction for program implementation.

Calgary's creeks and rivers provide precious opportunities to experience nature in our city.

Recognizing the value of Calgary's riparian ecosystems

The benefits provided to humans by natural areas are often referred to as ecosystem goods and services. Networks of healthy, well-connected riparian areas are vital ecological infrastructure for cities and provide distinct goods and services with high environmental, social and economic values. By integrating natural and built infrastructure, water managers reduce their reliance on the latter, while at the same time realizing a host of riparian benefits, including:

Flood risk management Natural riparian floodplains act as a watershed safety valve by storing water during floods. Wide riparian buffers respect flood hazards and natural channel migration processes. Deep-rooted native plants in riparian areas reduce erosion, instability and bank failure. By retaining natural riparian areas and restoring degraded riparian areas, we will reduce infrastructure damage and risks to safety during future extreme floods.

Clean, safe water Healthy riparian areas are part of source water protection strategies that provide Calgary and downstream communities with fresh, clean water. Well-managed riparian areas can also provide natural filtration systems to help capture, store and filter a wide range of pollutants.

Biodiversity Riparian areas are among the most biologically diverse and productive places in Alberta. Networks of riparian open spaces provide critical habitat and corridors for plant, animal and fish populations.

Economic benefits Well-vegetated riparian areas provide free natural services that reduce the need for costly restoration and additional infrastructure over time. Functioning riparian ecosystems reduce the need for intervention and investment in water quality improvement, stormwater management and erosion protection. If riparian functions degrade, regulatory water quality and quantity targets may be more costly to meet, and reactive repairs or responses–like restoring stream banks and damaged property–may be required.

Quality of life Natural areas and open spaces provide a sense of place, opportunities for activities and play, tourism and education, as well as moments of quiet solitude in areas of natural beauty. High-quality recreation opportunities and scenic amenities contribute to our quality of life, improve our health and improve property values in surrounding communities.

Ecosystem service valuation method

While practitioners have yet to develop a simple, widely accepted method to calculate ecosystem service values, valuation techniques include:

- replacement costs
- avoided damage costs
- contingent valuation + willingness to pay
- choice experiment
- benefits transfer

An example of the avoided damage cost method would be the 2013 Inglewood critical erosion site. It required almost $5 million to repair and harden the bank. An intact, healthy riparian area, with deep-rooted trees and shrubs, would have slowed erosion at this site and may have eliminated the need for a major engineering intervention.

Therefore, the avoided cost of damage for a healthy riparian area at this site in Calgary is $2.5 million per hectare or $4,800 per linear metre of bank.*

*This cost value may be an underestimate, as it does not capture all types of ecosystem services (e.g., fish habitat, aesthetics, etc.)

Riparian areas are places where land meets water

Education and stewardship Riparian areas are premium outdoor classrooms. Spending time in natural riparian landscapes provides critical opportunities for Calgarians to connect with nature and helps them to develop an understanding of how Calgary's watershed functions. Increasing public awareness and understanding of how we are all connected to the river is essential to long-term environmental stewardship.

Assessing riparian conditions in Calgary: the legacy of urban planning

The condition of riparian areas in Calgary is measured using a riparian health inventory, which estimates the ability of a riparian area to provide a range of ecosystem goods and services, including the maintenance of watershed health. In Calgary's urban environment, riparian health has been reduced by a range of factors, including upstream dams, fragmentation by development, recreational activities, bank hardening, channelization and increased stormwater runoff and erosion.

The City of Calgary began conducting baseline riparian health inventories in 2007. The baseline assessments showed that more than 49 per cent of riparian areas city wide were unhealthy, and 40 per cent were healthy with problems. More recently, 2015 assessments showed considerable improvements over baseline levels, including an overall increase of four per cent in average city-wide riparian health (see Figure 7 on page 24). This trend was most pronounced in recently restored riparian areas and those areas beneficially influenced by the 2013 flood.

Mapping riparian areas

Though floodplains and riparian areas occupy the same physical space within our watersheds (see Figure 4), traditionally they have been modelled and mapped separately using different modelling methods. While flood mapping tends to focus on identifying hazards and risks to infrastructure, property and people, riparian mapping tends to focus on defining the boundaries of riparian ecosystems. Over the past years, The City has invested considerable resources in mapping riparian areas, including the application of a variable-width riparian areas model along Calgary's major rivers and, more recently, the mapping of ephemeral and intermittent streams. At the same time, The City and the Government of Alberta have continued to work closely to update flood hazard mapping.

This mapping work has highlighted that many riparian areas are either considerably larger than the current designated floodway, or are larger than the Environmental Reserve policy setback. As such, riparian and stream valley corridors are not fully protected in current land-use planning processes. Smaller headwater-drainage features that generate the majority of a river's flow and play a critical role in maintaining water quality [2] may be vulnerable to development.

Similarly, river morphology mapping has helped to delineate channel migration zones and better account for how water channels change and migrate over time in our city. If we make room for rivers and creeks at the outset of planning, we can help prevent expensive damage to infrastructure and eliminate the need for expensive bank-hardening projects.

Overall, an important piece of work that lies ahead for The City and stakeholders is to better understand how mapping related to flood hazards and riparian areas (variable-width, morphology and ephemeral and intermittent streams) can be integrated with land-use planning systems. In doing so, we may base decision-making on best available science and adopt a more holistic approach to living with the river.

Riparian areas in our source watershed protect and support water quality and quantity.

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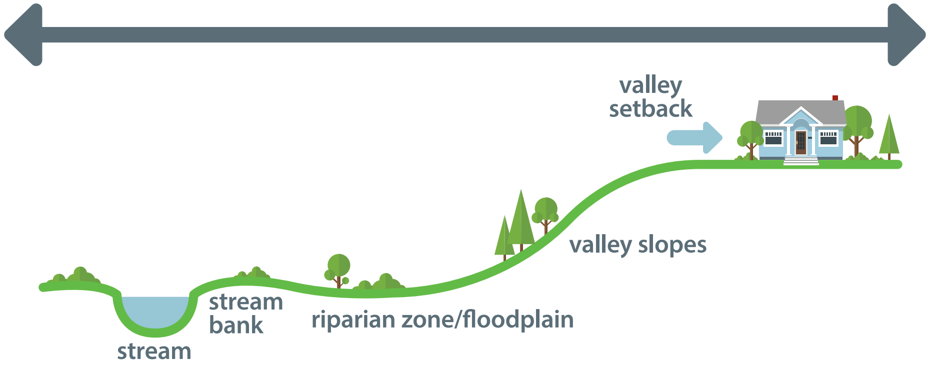
[2] See (Bentrup, 2008; TRCA, 2014; USEPA, 2015).

Figure 4. River valley corridor and setback

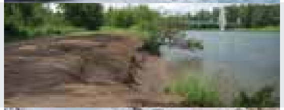
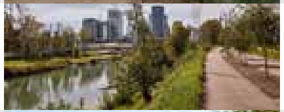
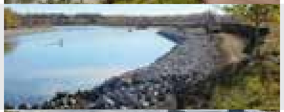


Classifying riparian management categories

Given their natural beauty and biodiversity, riparian areas are highly valued landscapes. To better manage these natural assets, The City developed a framework of riparian management categories that can guide river engineering approaches to restoration and bank stabilization, as well as potentially inform decisions about appropriate land uses within riparian areas.

Calgary's riparian management categories include: 1) **conservation**, 2) **restoration**, 3) **recreation**, 4) **flood/erosion control**, and 5) **developed**.

Table 1. Definition of riparian category and an example found within Calgary.

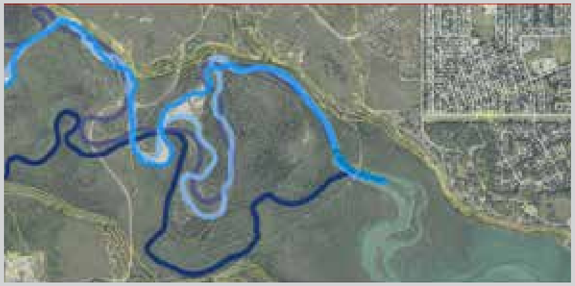
Management Category	Examples	Definition
Conservation		Riparian areas retained for natural open space.
Restoration		Riparian areas with poor health that are intended to be reclaimed or restored.
Recreation		An area of high recreational value and use.
Flood and erosion control		Riparian areas subject to flood and erosion risk. The priority is to mitigate potential flood or erosion damage using the best options available.
Developed		Riparian areas affected by development. If suitable opportunities arise (e.g., redevelopment), these areas will be assessed for restoration.

Making room for the shifting river

Provincial floodplain boundaries represent only a snapshot in time. Rivers, streams and floodplains are not fixed in place, but rather continuously shift in response to natural processes. During floods, these shifts occur particularly rapidly as swelling channels cut new banks, move out onto the floodplain and deposit gravel and debris picked up and carried from upstream areas.

Accounting for channel migration is increasingly important to sustainable land-use planning. Delineating channel migration zones and making room for the river can help prevent expensive damage to infrastructure and eliminate the need for expensive bank hardening projects to prevent flooding and erosion. Avoiding major new developments in river valley corridors makes sense.

It is predicted that the effects of climate change will alter the frequency and magnitude of floods and droughts. Scientists have recently observed changes to the jet stream that are slowing the progression of weather systems and increasing the likelihood of extreme weather. It is prudent to consider climate change risks in relation to the amount and type of new development allowed in these vulnerable areas.



The Elbow River changes over time

🟦 2014
🟦 1997
🟪 1924
🟦 Pre - 1900

Riparian zones clearly correspond with flood extents

Riparian areas are dynamic, variable systems that respond to cycles of drought and deluge on time scales that range from hours to decades. It is very clear that riparian areas and flooded areas correspond highly with one another. The photos below contrast a sample riparian-zone map along the Bow River in South East Calgary with an air photo from the 2013 flood. Note: inner riparian zones typically correspond with the 1:5 year floodplain boundary; middle riparian zones tend to occupy the 1:20 year floodplain boundary; outer riparian zones tend to occupy between the 1:50 and 1:100 year floodplain boundaries; and the potential outermost riparian zone typically extends beyond the 1:100 year floodplain.

Mapped variable width riparian area (top) versus 2013 flood extent (bottom)

- 🟦 Inner Riparian Zone
- 🟩 Middle Riparion Zone
- 🟨 Outer Riparian Zone
- ⬜ Potential Outermost Riparian Zone

Implications for management practices and land uses in riparian areas

Key policy gaps related to land-use planning include a need for consistency in riparian river engineering approaches and permitted land uses. Ultimately, riparian management categories address these gaps by providing a city-wide framework and geospatial vision for the use, protection and management of riparian lands. For example, all project engineers and consultants involved with bank stabilization and erosion control are directed to use these management categories when designing bank stabilization and river engineering projects (see Riparian Decision Matrix on page 58).

It is our recommendation that, where possible, these management categories direct City of Calgary guidelines, processes, policies and bylaws related to riparian areas. Key work moving forward will be to consult with internal and external stakeholders to reconcile other land-use planning processes and policies with the proposed management categories.

Understanding citizen and stakeholder values

At the heart of the Riparian Action Program are two discreet, yet related, areas of activity: riparian protection and riparian restoration. Essential to achieving success in both areas will be the engagement of citizens and riparian landowners to understand, value and take action. To this end, The City developed a robust research plan to gain a better understanding of the audiences and potential programs that could be designed to advance riparian protection in Calgary.

Research took place over a six-month period and used a mixed-methods approach that included semi-structured and in-depth interviews, focus groups, surveys and literature review. In addition to informing program development, this research also established a baseline and indicators and has revealed the foundational citizen values and expectations that will inform subsequent stages of community engagement related to land-use planning and policy, and restoration.

The floodplain provides vital space to hold water during spring melts.

Chapter 2. Riparian Action Program: A blueprint for resilience

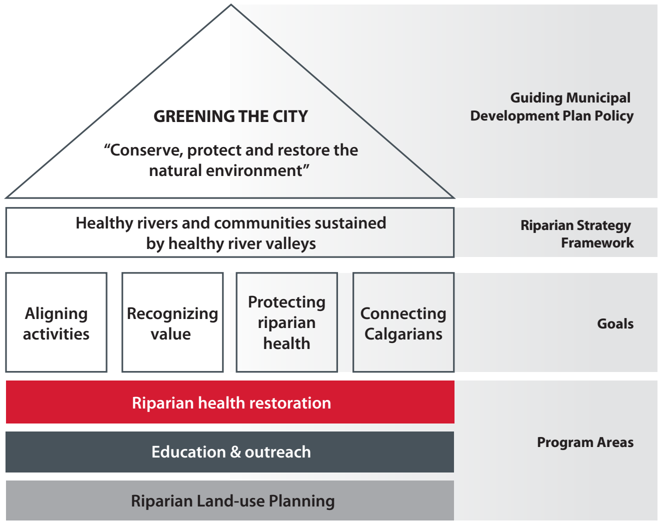
Building resilience through a systems approach to programming

The challenges facing our watershed and water management approaches cannot be understood in isolation. They are often systemic problems, interrelated and interdependent. Just as the challenges facing riparian areas are interconnected, so too are the intervention points for change. The ability of our riparian areas to provide Calgarians with ecosystem services is intimately tied to their health and to our land use planning choices. Similarly, it is also tied to the citizen and community values that influence and shape our choices. As such, the program contains three areas of focus:

1. land use planning
2. health restoration
3. education and outreach

This program has been designed purposely to deliver on the goals outlined within the **Riparian Strategy** framework (see Figure 5). It is also based on best-available science and a robust planning process. The following chapter discusses these program areas in more detail, including desired outcomes, current trends, key actions to improve our performance and how we will measure our results.

Figure 5. Alignment of Riparian Action Program with Riparian Strategy



83 per cent of Calgarians care about The City having a plan to preserve and protect river areas

Ipsos Public Affairs (2016b)

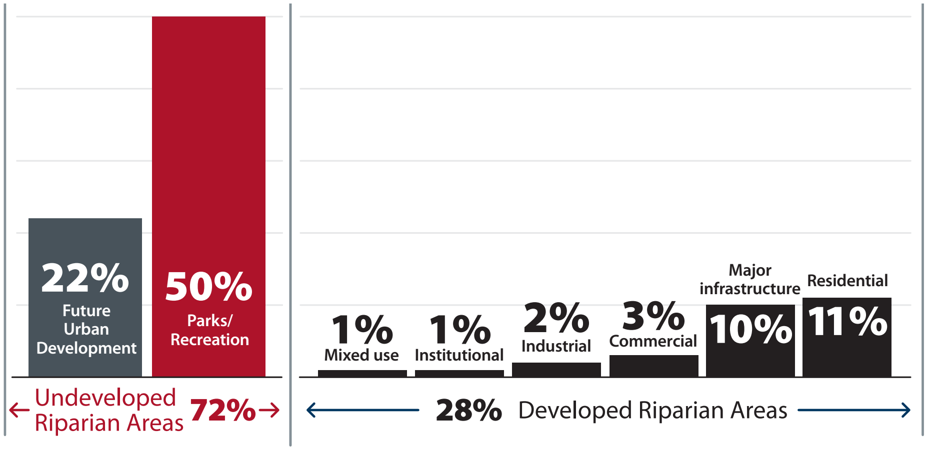
Outcome: Further loss of riparian areas is minimized.

Program area one: riparian land-use planning

Indicator #1: Retain open spaces along major perennial creeks and rivers.

Less than one third (28 per cent) of riparian areas are developed in Calgary. The vast majority (72 per cent) of these areas have been effectively conserved due to a combination of regulation, philanthropy and buyouts in the 1950s, a remarkable legacy that continues to define the lives of Calgarians today. The remaining 22 per cent awaiting planning and development is largely agricultural land in various stages of the planning process.

Figure 6. Major land uses in Calgary's riparian area (2012)



Indicator #2: Limit the conversion of riparian areas to new development along ephemeral and intermittent watercourses.

Work to inventory and map ephemeral and intermittent watercourses is ongoing. Once complete, limits of acceptable change related to the loss of ephemeral and intermittent watercourses will be defined.

Three key actions to improve performance

1. **Identify riparian areas.** While many riparian areas have been identified and protected, significant work remains. First, most river maps represent only a snapshot in time, because rivers, streams and floodplains are not fixed in place, but continuously shift in response to natural processes. As such, it is important to assess river geomorphology to better understand the changing landscape of riparian areas. Second, The City must identify ephemeral and intermittent streams. The health of our rivers and streams depends on the ephemeral and intermittent watercourses and wetlands where they begin. Yet, due to their small size, intermittent nature and lower aesthetic value, small drainage features are often lost or highly vulnerable to the impacts of urban development. Identifying these areas is an important step towards enhancing green infrastructure and working with nature.
2. **Protect riparian areas.** Riparian floodplains are just one component of river or stream corridors, which contain a mosaic of landscape types. Protection of slopes associated with valleys, ravines, gullies and coulees is also critical for watershed protection, as these slopes are often prone to erosion and sediment mobilization.

Support tools for practitioners: land-use decision trees

In response to stakeholder demand and identified gaps in process, The City has developed a series of decision-making trees to support land use planners and developers. These flow charts integrate riparian area direction policies from a wide number of documents. See Supplement Two.

Currently, Environmental Reserve (ER) is the most effective planning tool to protect riparian areas. The City's ER setback policy and guidelines[3] are based on the Municipal Government Act (MGA) and are variable widths based on a number of factors, including waterbody type, slope, vegetation cover and local groundwater influence. However, they do not go far enough to protect all riparian areas, such as ephemeral and intermittent streams, nor provide a large enough setback to ensure healthy and functioning riparian areas. Generally, best-practice provides more space to rivers and streams, so that natural processes can occur. To achieve this, the current ER setback policy and guidelines must be reviewed, and processes must be developed to ensure new guidelines are consistently interpreted and applied throughout The Corporation. It is recommended that Administration also investigate other ways to protect riparian areas. For example, once the Municipal Government Act is updated, other planning tools may become available.

3. **Manage development along riparian areas.** Allowing appropriate land uses and managing the interface between development and riparian areas in greenfield areas will help ensure that riparian areas remain healthy and continue to provide ecosystem benefits. It is recommended that Administration investigate other planning tools or approaches to manage and inform appropriate land uses along riparian areas.

Who will benefit

Current and future Calgarians will benefit from improved community safety, as these drainage features can be designed as emergency valves for extreme rainfall events. Other benefits include access to nature and increased ability to recover from climatic events, including flood and drought. As more riparian areas are protected from development, The City could lower its maintenance costs by having less engineered drainage infrastructure.

Partners who can help us

City of Calgary. Parks, Planning and Development, Water Resources.

Other. Cows and Fish, Calgary River Valleys, Federation of Calgary Communities, community associations, citizens, Urban Development Institute, Canadian Home Builders Association, consultants, planners and developers.

Performance measurement Measuring and reporting on program progress will rely on a results-based framework including indicators and targets. These provide guidance over the long term and assist with assessing our performance during the implementation period. See Table 1 below for an overview of indicators and targets.

Table 2. Riparian land-use indicators and targets

Outcome	Indicator	Area	Baseline	2026 Target
Further loss of riparian areas is minimized.	riparian open spaces along major perennial creeks and rivers*	City wide	73%	No net loss
		Bow River	75%	
		Elbow River	62%	
		Nose Creek + West Nose Creek	67%	
	riparian open spaces along ephemeral and intermittent watercourses	City wide	**Limits of acceptable change/thresholds for ephemeral and intermittent streams are to be determined.**	

See Supplement Three for detailed methodology and land-use monitoring protocols.

The health of our rivers and streams depends on the ephemeral and intermittent watercourses and wetlands where they begin.

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[3] See http://www.calgary.ca/CSPS/Parks/Documents/Planning-and-Operations/Natural-Areas-and-Wetlands/environmental_reserve_setback_policy.pdf

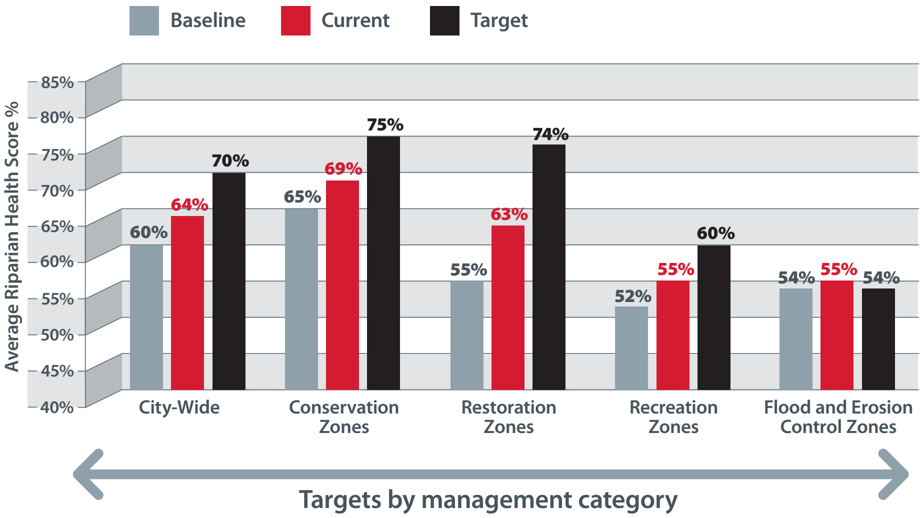
Outcome:
City-wide riparian health is improved.

Program area two: riparian health restoration and monitoring

Indicator #3: City-wide riparian health index scores improve over time.

Baseline surveys of riparian health were conducted from 2007 to 2010 across 57 sites in Calgary, representing over 368 hectares of riparian habitat. All of these sites were revisited in 2014-2015. Assessments show that, overall, riparian health scores in Calgary have improved over this time period, with 25 per cent of sites showing an improving health trend and very few sites showing a declining health trend. Overall, the City-wide average riparian health score increased by approximately four per cent (from 60 per cent to 64 per cent). Key factors contributing to this trend include restoration and management improvements, natural vegetation recovery and the beneficial impacts of the 2013 flood on riparian ecology.

Figure 7. Trends and targets of riparian health



Unhealthy riparian area.

Healthy with problems riparian area.

Healthy riparian area.

Three key actions to improve performance

1) **Integrate bioengineering techniques into bank restoration.** Bioengineering[4] is more ecologically beneficial than hard riprap designs—the practice of armouring and stabilizing banks with rock. While riprap is an effective immediate answer to erosion, it impacts riparian health, and its long-term effects can be less than ideal. The hard rock surfaces tend to increase water flow, which reinforces the damaging effects of high flows downstream. The rocks also impact sensitive spawning areas, by heating the water and depriving fish and wildlife of oxygen, food and habitat. Vegetating degraded areas is a lower-maintenance and self-sustaining solution with multiple benefits, such as providing critical habitat for fish and wildlife and creating areas of natural beauty in our urban landscape. Bioengineering can also enhance hydraulic benefits, as the surface roughness associated with plants absorbs energy and reduces water velocities. Evidence shows that bioengineering can outperform riprap alone, with its higher resistance to shear stresses.[5] The City of Calgary promotes multi-functional bioengineering designs, and significant progress has been made to encourage adoption of these approaches within the community at large. See Supplement One for a discussion of the differences between structural and plant bioengineering, as well as examples of successful bioengineering projects in Calgary.

2) **Monitor riparian health and evaluate performance.** As restoration projects are conducted, systematic collection of successes and failures helps to identify trends, monitor performance and inform future improvements to procedures and specifications. The City already monitors riparian health conditions and collects data on planting survival rates in restoration sites. This data has been used to develop design recommendations to maximize survival rates and to inform choices related to installation timing, irrigation and environmental factors (TCS 2016).

3) **Build capacity for riparian restoration.** Riparian restoration requires specialized knowledge of hydrology, riparian processes, engineering, plant biology, soils and ecology. It also requires the capacity to undertake the work and the ability to monitor and evaluate site performance. Significant portions of Calgary's river and creek banks require restoration in the upcoming years. While The City has some capacity, it will need new and additional resources internally and externally. Superior results may be achieved by investing strategically in partnerships with academia, NGOs and private industry to accomplish this work and build riparian restoration capacity within the community.

Bioengineering incorporates living and non-living plant materials in combination with natural and synthetic support materials.

Many fisheries experts believe that the most critical impacts to fish and fish habitat occur, not as a result of a flood event itself, but rather from our response to the flood. Bioengineering is more ecologically beneficial than hard riprap designs—the practice of armouring and stabilizing banks with rock.

Almost all fish and wildlife depend on the areas bordering our rivers and creeks for some part of their life cycle.

Support tools for practitioners: bank restoration decision matrix

In response to stakeholder demand and identified gaps in process, The City developed a decision-making tool to support river bank engineers and developers choosing the type of bank stabilization design to apply to different areas. See Supplement One.

Bioengineering can outperform riprap—the practice of armouring banks with rock.

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[4] Bioengineering is an approach that incorporates living and nonliving plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction and vegetation establishment.

[5] See Pack and Gaffney (2014).

See the watershed maps in Chapter Three for an overview of planned future riparian restoration projects.

Who will benefit

As more riparian areas are restored to health, current and future Calgarians will benefit from improved water quality in our waterways, improved drainage and improved public safety due to increased ability to recover from climatic events, including flood and drought. Healthy banks are also more aesthetically pleasing, require less engineered bank infrastructure and provide critical habitat and corridors for plant, animal and fish populations.

Partners who can help us

City of Calgary. Parks, Water Resources

Other. Cows and Fish, watershed stewardship groups, external consultant planners and riverbank engineers

Performance measurement

The condition of riparian areas is a critical indicator of watershed health. Riparian areas are strongly influenced by surrounding watercourses and landscapes, including historic and current land uses and activities. Consequently, targets or indicators depend on both location and context. Riparian zones in heavily urbanized areas require targets different from those in riparian areas within intact natural open spaces. The size of a river or creek also influences target-setting.

Table 3. Riparian health indicators and targets

Outcome	Indicator	Area	Baseline	2026 Target
City-wide riparian health is improved.	riparian health index score	City wide	61%	72%
		Conservation zones	65%	77%
		Restoration zones	56%	71%
		Recreation zones	52%	60%
		Flood and erosion control zones	55%	54%

See Supplement Three for a detailed explanation of riparian health index (RHI) score methodology and monitoring protocols.

Flooding, upstream dam operations and influences on riparian health

Seasonal peak flows and occasional large floods are natural processes that renew riparian vegetation. Between the 1950s and 2000s, dam operations, combined with a lack of major natural floods, created a deficiency of new natural vegetation along the Bow River within Calgary. After the 2013 flood, many new gravel bars were deposited or expanded in Calgary, providing suitable conditions for native vegetation to colonize and grow. Observations during summer 2014 revealed extensive balsam poplar seedlings along new gravel bars and scoured floodplain surfaces.

Dr. Stuart Rood of the University of Lethbridge has been working with TransAlta to develop flow “stage ramping” criteria for the Bow River to imitate natural hydrographs and promote the establishment and growth of native balsam poplar and willow. This can be optimized with June peak spring flows of 350-375 m3/s on the Bow in downtown Calgary, followed by a gradual decrease in stage elevations of 2.5 cm per day in June/July, and 1 cm per day in August. Restoring these more natural flows can provide highly efficient restoration compared to riparian plantings, which are only locally effective and may require periodic replenishment and maintenance.

Seasonal peak flows and occasional large floods are natural processes that renew riparian vegetation.

Program area three: education and outreach

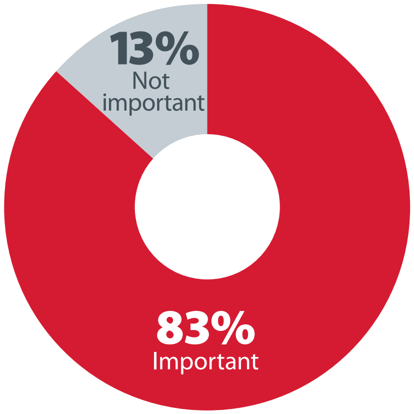
Indicator #4: Community engagement with riparian areas (awareness, attitudes and actions) increases over time.

A general population survey conducted in 2016 provided a baseline of Calgarians' awareness, attitudes and values related to riparian areas. Results show that while the majority (83 per cent) of citizens report that rivers areas are personally important to them, few Calgarians are aware of the true health of riparians areas. Also, a lack of awareness of what to do was reported as the biggest barrier to not doing more to take care of river areas. These findings will help direct long-term riparian education and outreach efforts.

Indicator #5: Community stewardship actions increase over time.

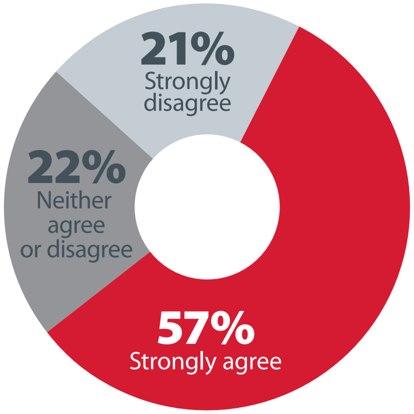
While indicator data, such as polling, give us a sense of how Calgarians are progressing in terms of their awareness, attitudes and actions, community actions bring numbers to life and provide real examples of engagement. Insights from indicator data can be bolstered by stories of community actions and by tracking stewardship activities within City programs and community partners.

Figure 8. Calgarians who say river areas are personally important to them



Source: Ipsos Public Affairs (2016b)

Figure 9. Calgarians who agree not knowing is reason for not acting



Source: Ipsos Public Affairs (2016b)

Three key actions to improve performance

1. **Tell a holistic story of living with the river.** The unique nature of riparian ecosystems provides a rich and tangible narrative to knit together water conversations that we've often had in isolation or not at all. Riparian areas also offer an important invitation into conversations about past water management decisions and the need for newer, greener solutions to infrastructure challenges and land-use planning.
2. **Create opportunities for Calgarians to connect.** The tangibility of the river's edge will help make otherwise complicated concepts of ecosystem services and natural assets more real and accessible. Connecting to the river is also a powerful way to foster environmental stewardship and civic engagement. Stakeholders must be given opportunities to be a part of the work happening within their communities from the beginning and to shape and own the success of these riparian projects. In bringing citizens along on the journey of restoration, projects become community celebrations and our civic environmental stewardship is strengthened.

Outcome: Citizens and riparian landowners value riparian areas.

71 per cent of Calgarians agree that it is only through educating the public that we will be able to improve the health of our river areas

Ipsos Public Affairs (2016b)

Utilities and Environmental Protection's Public Art Plan: bringing water into public focus

Utilities and Environmental Protection's Public Art Plan merges ecology, art and community to bring our creeks, rivers and watershed landscapes into public focus. Integrated public art, which is open to interpretation, is designed to encourage dialogue about watershed protection and strengthen the emotional connection citizens have with their natural environment. Throughout each project, artists incorporate resident neighbourhood perspectives and insights into their work.

In 2010, approximately 20,000 Calgarians took part in The Celebration of the Bow, the plan's first major temporary project, during which illuminated spheres were floated down the Bow River. Currently, there are more than twenty public art initiatives underway. One project completed in 2014 is Bow Passage Overlook, located next to Harvie Passage at Pearce Estate Park. From a series of terraces and a grotto-like seating area, visitors can capture views of the Bow River and surrounding landscapes, while pathways and river-access points bring them to the river's edge. Visitor experiences like these enrich our urban life and help renew the public's relationship with our watershed.

Celebration of the Bow

3. **Prioritize and focus engagement and education efforts.** While we are all connected to the river, some stakeholders are more connected than others by virtue of being a landowner or living in a community close to the river's edge. Similarly, some riparian initiatives will be of greater priority than others due to restoration or protection needs. Rather than applying a one-size-fits-all approach, it will be important to prioritize landscapes and focus on those stakeholders best positioned to make change in that area. Riparian landowners, developers, civil and community planners, as well as residents and communities near riparian areas, will need to be equipped, properly supported and empowered in the protection and maintenance of their landscape. A second aspect of this key action is to identify existing riparian stewardship groups/programming and focus municipal efforts on building capacity only where needed.

Who will benefit

Current and future Calgarians will benefit from a greater connection to Calgary's rivers and creeks. Other watershed groups working within the area of riparian protection and restoration will also benefit through increased watershed literacy among citizens, increased support for their work and specific opportunities to partner with The City.

Partners who can help us

City of Calgary. Water Resources, Parks, municipal land owners, City of Calgary employees

Other. Residents, community leaders, private land owners, community associations, non-governmental organizations involved with water management, the development industry, technical consultants, golf courses and regional partners

Performance measurement

The City is currently developing baseline measures and indicators of the value of riparian areas for communities.

Table 4. Riparian education and outreach indicators, baselines and targets

Outcome	Indicator	Aspect	Baseline	2026 Target
Citizens and riparian landowners value riparian areas.	Stakeholder engagement with riparian areas	Awareness of riparian health	26%	↗ trend
		Lack of awareness of what to do	57%	↘ trend
		Personal importance of river areas	83%	→ maintain
		Behaviours taken by citizens	To come	↗ trend
	Customer satisfaction	Satisfaction with City's performance to protect and restore river areas	58%	↗ trend
	Community stewardship actions	Citizens engaged in restoration and stewardship activities	To come	↗ trend
		Riparian spaces restored or stewarded by community groups/members	To come	↗ trend

See Supplement Three for detailed explanation of education and outreach methodology and monitoring protocols.

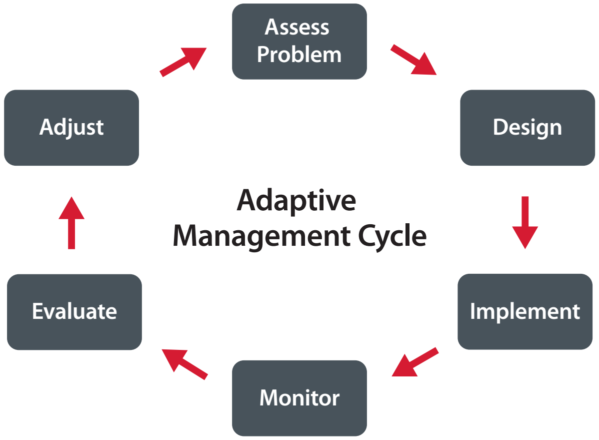
Monitoring and adaptive management

The Riparian Action Program (RAP) includes annual check-ins and adjustments. This includes two minor program reviews as part of The City's business planning and budgeting processes and a comprehensive 10-year program review in 2026. Over time, successes and failures will be documented, and the program will be updated accordingly. This adaptive management approach can deal with the uncertainty and complexity involved in resource management. It is a structured, science-based process that integrates experience and scientific information. Adaptive management also enables continual improvement, accountability and transparency, and addresses the dynamic nature of riparian systems.

The RAP adaptive-management process follows a six-step cycle:

- **Assess problem**
  At this step, knowledge is assessed and synthesized to evaluate resource conditions and establish high-level direction. All background riparian studies conducted from 2008-2013 were part of this step, including (i) baseline riparian health inventories; (ii) riparian mapping studies; and (iii) the Riparian Strategy.
- **Design.** The second step consists of program design, including the establishment of explicit outcomes, delineation of key actions and timelines, establishing methods to monitor results over time and setting appropriate indicators and targets. The Riparian Action Program represents the output of the program design process.
- **Implement** During this step, projects and actions outlined in the program plan are carried out. Riparian implementation activities began in 2014 with the release of the Riparian Decision Matrix for River Engineering Projects (see Supplement One on page 54) and through the planning and initiation of several restoration and research projects. Implementation is expected to continue throughout future business cycles.
- **Monitor.** The monitoring of indicators is undertaken to determine whether the observed effects match predictions. Post-flood monitoring of riparian health conditions and future monitoring of indicators over time fall under this step.
- **Evaluate.** Over time, successes and failures need to be documented and the program reviewed, adapted and updated as necessary. This will include a minor five-year program review in 2021.
- **Adjust.** Adjustments will be made during a 10-year program review, currently planned for 2026.

Figure 10. The Riparian Action Program follows an adaptive management approach



Restoring riparian landscape more empowering than you might think

Volunteer restoration activities involve participants in active relationships with the natural environment around them. Connecting to the land not only provides vivid examples of how our watershed works, it also kindles and fosters a desire to preserve and maintain our collective natural environment.

Studies demonstrate that:

1. Stewardship volunteering enhances civic engagement among participants.
2. Restoration activities deepen existing environmental ethics.
3. Self-identifying as a steward exerts the strongest influence on our intention to behave in pro-environmental ways.
4. Spending time with like-minded stewards is the most effective way to translate attitudes into eco-behaviour.
5. The stronger a person's emotional attachment to a place, the more they engage in pro-environmental behaviours.

As well, restoration and stewardship activities provide important outlets for action.

Connecting to the river is also a powerful way to foster environmental stewardship and civic engagement.

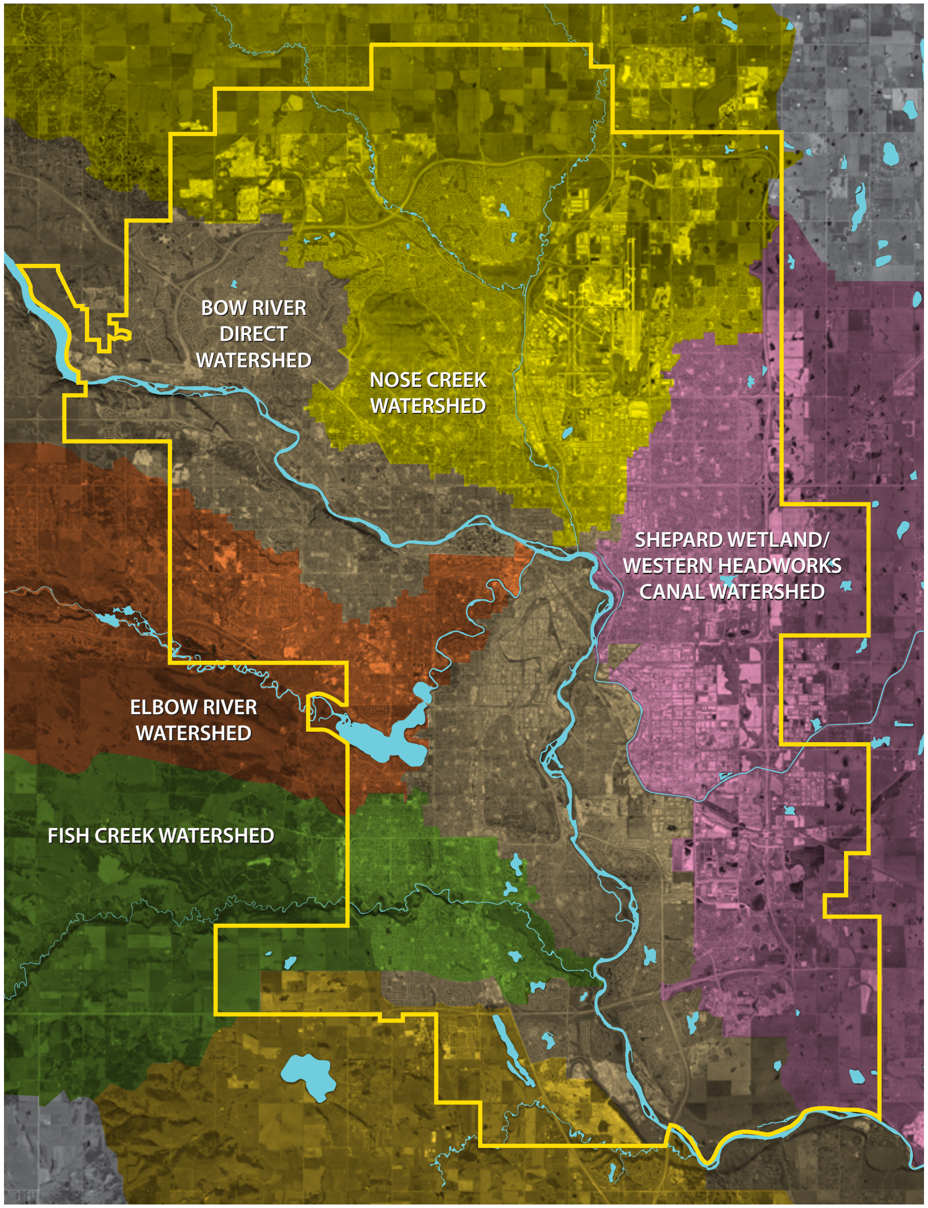
Almost all fish and wildlife depend on the areas bordering our rivers and creeks for some part of their life cycle.

Chapter 3. Calgary's commitment to our river areas

Beneath Calgary’s built environment—such as roads and buildings—lies an ecological landscape defined by the flow and storage of water. The following maps tell a holistic story of how riparian areas in Calgary are used and how this program integrates with the **Flood Resiliency and Mitigation Program** and stormwater management. They knit together several collections of information, including riparian restoration priorities and restoration techniques. They are the culmination of years of research and mapping and are a defining tool in The City’s commitment to the protection of riparian areas.

Within city limits, Calgary is situated within the Bow River Watershed and includes six major sub watersheds.

The information in this chapter corresponds to The City of Calgary's data as of March 2016. The information and maps are made available in good faith, but accuracy and completeness cannot be guaranteed. The City's riparian data and maps may be updated from time to time as resources allow.



- **City limits**
- **Rivers, creeks, streams, and wetlands**
- **Bow River Direct**
- **Elbow River**
- **Fish Creek**
- **Nose Creek**
- **Shepard Wetland/Western Headworks Canal**
- **Pine Creek**

Upper Bow River Direct Watershed

Watershed summary

The Bow River Basin includes over 25,000 km^2 of land, from the headwaters in Banff National Park to the confluence with the Oldman River in semi-arid southeastern Alberta. Virtually all of Calgary is within the Bow River Basin, as most land drains into one of six watersheds that are tributaries to the Bow River. Within city limits, the Bow River Direct watershed includes all areas that drain to the Bow River without passing through a major tributary first (e.g., Nose Creek).

Importantly, the Bow is the source water for the Bearspaw Water Treatment Plant, which provides approximately 60 per cent of The City's water supplies to Calgarians. Due to the extensive nature of the Bow River Direct watershed, which spans all of Calgary, it has been subdivided into upper and lower sections.

Upper Bow River direct watershed

The Upper Bow River direct watershed includes lands in Calgary draining directly to the Bow River upstream of the Elbow River confluence, as well as smaller catchments associated with Coach Creek and 12 Mile Coulee Creek.

Riparian land uses

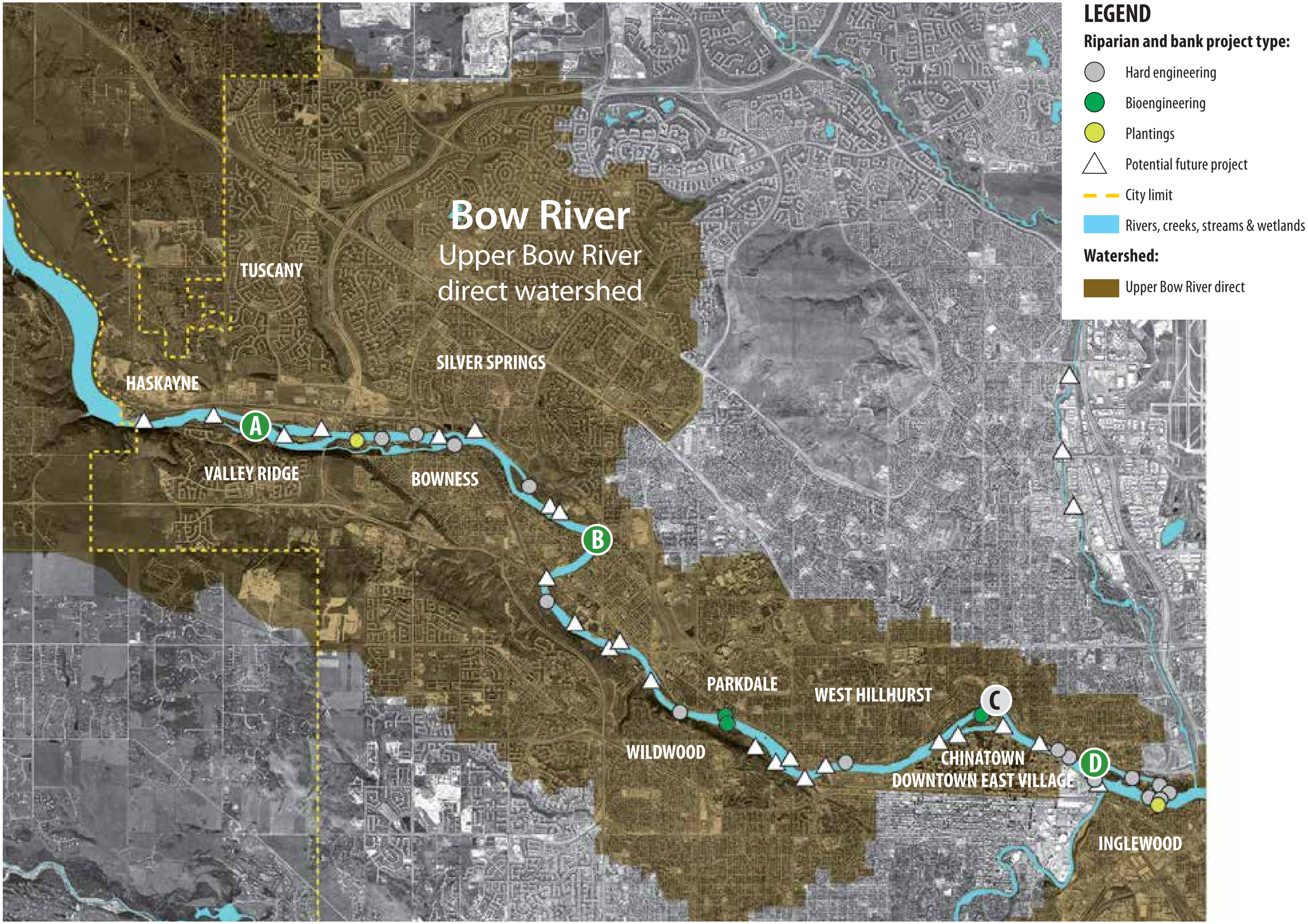
- Extensive (>2,800 ha) riparian areas fringe the Bow River in Calgary.
- Parks and recreation areas cover 52 per cent of Calgary's riparian areas along the Bow. This includes many of Calgary's defining parks, including Bowness Park (donated to the City in 1912 by a developer), Bowmont Park, Edworthy Park, Shouldice Park, Prince's Island Park, and Saint Patrick's Island.
- Residential land uses intersect 11 per cent of the Bow's riparian zones in Calgary, including the neighbourhoods of Bowness, Hillhurst, Sunnyside, and Eau Claire. The East Village mixed use development intersects about one per cent of the Bow River's riparian area.
- Railways and major highways (Stoney Trail, Crowchild Trail) occupy almost eight per cent of the riparian areas in this watershed.
- Commercial areas occupy about four per cent of the riparian zone along the Bow, concentrated in the downtown core.
- The legacy of urban development along the Upper Bow River in Calgary has created considerable flood risks to people, businesses and infrastructure, and requires careful ongoing management.
- Riparian habitats are also located along Coach Creek (18 ha) and Twelve Mile Coulee (39 ha). The majority of these have been retained as open spaces within Crestmont and Tuscany.

Vegetated rip rap – outfall B134

Home Road bank stabilization

Rip rap and groynes – Sunnyside, Memorial Drive

St. Patrick's Island – Calgary Municipal Land Corporation


Bow River
Upper Bow River direct watershed
LEGEND
Riparian and bank project type:
● Hard engineering
● Bioengineering
● Plantings
△ Potential future project
– – City limit
Rivers, creeks, streams & wetlands
Watershed:
Upper Bow River direct
TUSCANY
SILVER SPRINGS
HASKAYNE
VALLEY RIDGE
BOWNESS
PARKDALE
WEST HILLHURST
WILDWOOD
CHINATOWN
DOWNTOWN EAST VILLAGE
INGLEWOOD
A
B
C
D

Lower Bow River Direct Watershed

Watershed summary

The Bow River Basin includes over 25,000 km^2 of land, from the headwaters in Banff National Park to the confluence with the Oldman River in semi-arid southeastern Alberta. Virtually all of Calgary is within the Bow River Basin, as its lands drains to one of six watersheds that are tributaries to the Bow River. Within city limits, the Bow River Direct watershed includes all areas that drain to the Bow River without passing through a major tributary first (e.g., Nose Creek).

Lower Bow River direct watershed

This highly urbanized watershed includes all lands within Calgary that drain to the Bow River downstream of the Elbow River confluence. This section of the Bow River experienced severe erosion during the 2013 flood, particularly along stretches with unhealthy riparian areas.

Riparian land uses

- Extensive (>2,800 ha) riparian areas fringe the Bow River in Calgary.
- Parks and recreation areas cover 52 per cent of Calgary's riparian areas along the Bow. This includes many of Calgary's defining parks in South East Calgary, including Pearce Estate Park, the Inglewood Bird Sanctuary, Beaverdam Flats, Sue Higgins Park, Carburn Park, and Fish Creek Provincial Park. This category also includes two major golf courses: Inglewood Golf Course and McKenzie Meadows Golf Course.
- Residential land uses intersect 11 per cent of the Bow's riparian zones in Calgary, including the neighbourhoods of Inglewood, Bridgeland, Riverbend, Quarry Park, and Cranston.
- Major Infrastructure is the third most common land use category, occupying eight per cent of the Bow's riparian areas. This includes The City's three Wastewater Treatment Plants, as well as railways, railyards, and major highways (Deerfoot Trail, Stoney Trail).
- Commercial areas occupy four per cent of the riparian zone along the Bow, including the Deerfoot Meadows shopping centre.
- Significant riparian lands, particularly those downstream from Cranston within City limits, are currently unplanned, but will be under pressure for future development as the City continues to expand outwards.
- Flood risks to people and infrastructure along the Lower Bow have been reduced by: the Inglewood flood berm, which protects the community of Inglewood up to a 1:100 year flood event. Land Use Bylaw overlay regulations developed in the 1980s have also reduced flood risk to newer communities such as Douglasdale, Deer Run, Quarry Park, Chaparral and Cranston, although these areas could still be affected by extreme floods beyond the design standard.
- Some SE Calgary residential areas were developed with insufficient setbacks from the Bow River valley, creating slope stability issues and a need for expensive erosion control projects (e.g., Diamond Cove, McKenzie Lake).

Inglewood community planting "Street to Stream" project

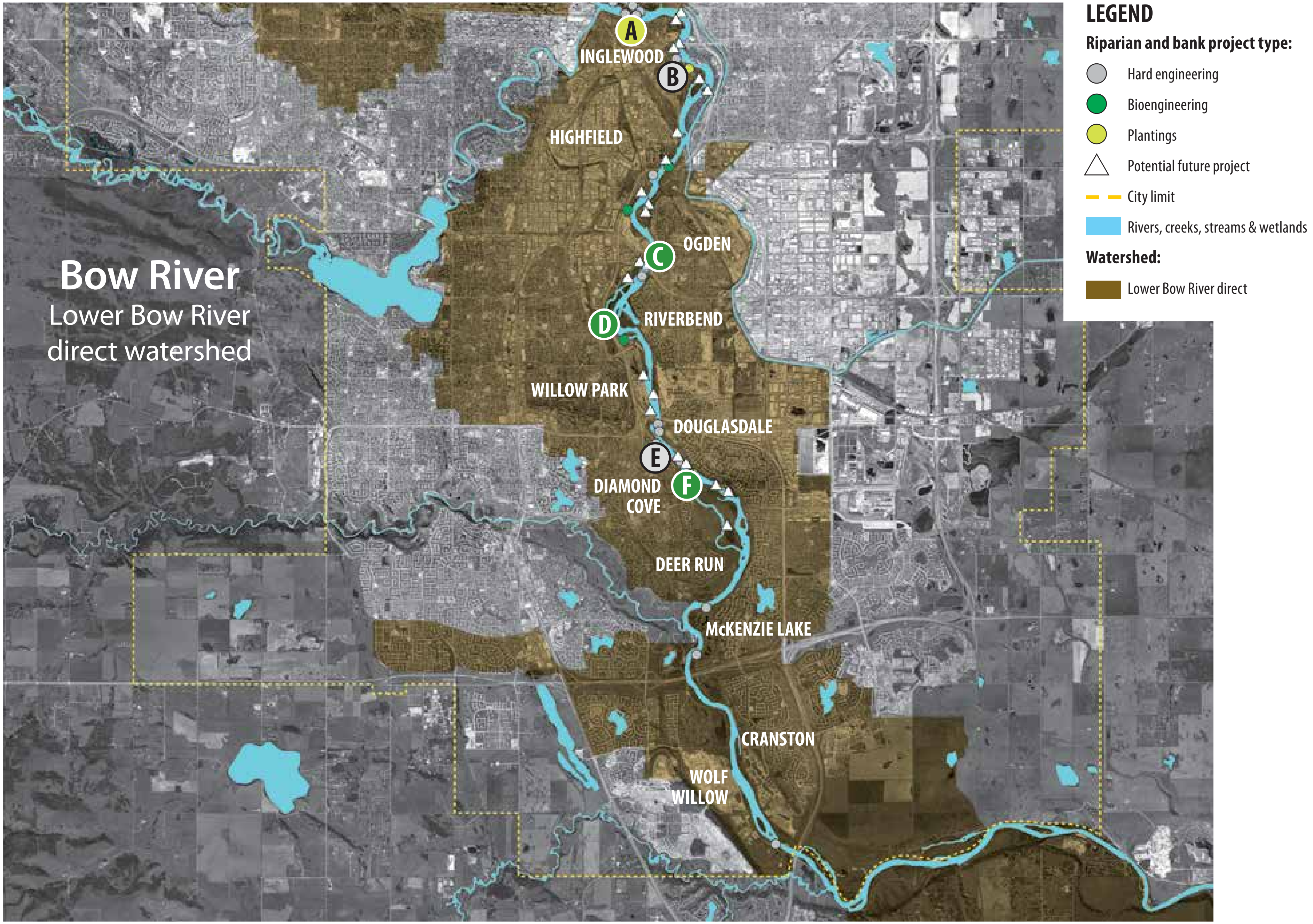
Inglewood critical erosion site – construction 2014

Timber crib wall – upstream of Glenmore Trail

Timber crib wall – Sue Higgins Park

Diamond Cove rip rap and slope toe protection

Mallard Point bioengineering project – Trout Unlimited


Bow River
Lower Bow River direct watershed
A
B
C
D
E
F
INGLEWOOD
HIGHFIELD
OGDEN
RIVERBEND
WILLOW PARK
DOUGLASDALE
DIAMOND COVE
DEER RUN
McKENZIE LAKE
CRANSTON
WOLF WILLOW
LEGEND
Riparian and bank project type:
Hard engineering
Bioengineering
Plantings
Potential future project
City limit
Rivers, creeks, streams & wetlands
Watershed:
Lower Bow River direct

Elbow River Watershed

Watershed summary

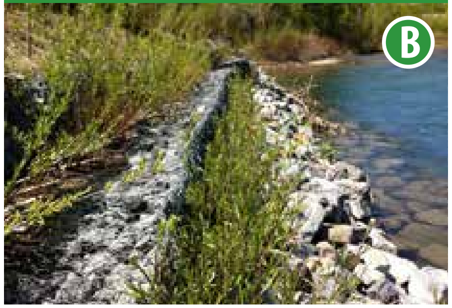
The headwaters of the Elbow River watershed begin in the mountains of Kananaskis Country. Moving downstream, landscapes in the watershed gradually change from mountains to foothills, to rural agriculture and country residential in Rocky View County, then to suburban neighbourhoods and finally high-density urban areas in Calgary. Importantly, The Elbow feeds the Glenmore Reservoir and provides source water to the Glenmore Water Treatment Plant, which supplies 40 per cent of The City`s water supplies to Calgarians. Many South West Calgary communities are located in the Elbow River watershed. Communities upstream from the Glenmore raw water intake include Springbank, Rutland Park, Glamorgan, Discovery Ridge, Lakeview, and Oakridge. Further downstream, Altadore, Elbow Park, Britannia, Roxboro, and Mission, and a large portion of the downtown Beltline also drain into the Elbow River.

Riparian land uses

- Extensive riparian areas fringe the Elbow, including over 728 ha within City limits.
- About 56 per cent of these are designated parks and open spaces, such as Griffith Woods, The Weaselhead, Sandy Beach Park, The Calgary Golf and Country Club, Stanley Park, and Lindsay Park.
- In contrast, 38 per cent of this area has been developed, including residential communities (Elbow Park, Roxboro, Erlton), commercial and mixed uses (Mission), and the Calgary Stampede grounds.
- These land-use legacies have created significant flood risk to people and businesses along the Lower Elbow, which requires careful ongoing management. Finally, undeveloped private lands represent a small fraction of the Elbow`s riparian area along The City`s western edge.

Rip rap with root ads, Stampede Grounds

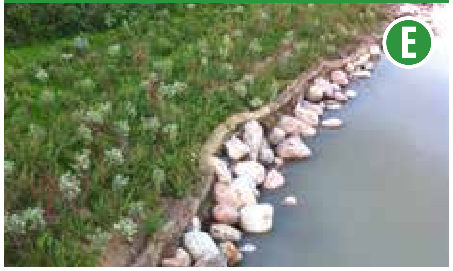
Vegetated gabion across from Stampede Grounds



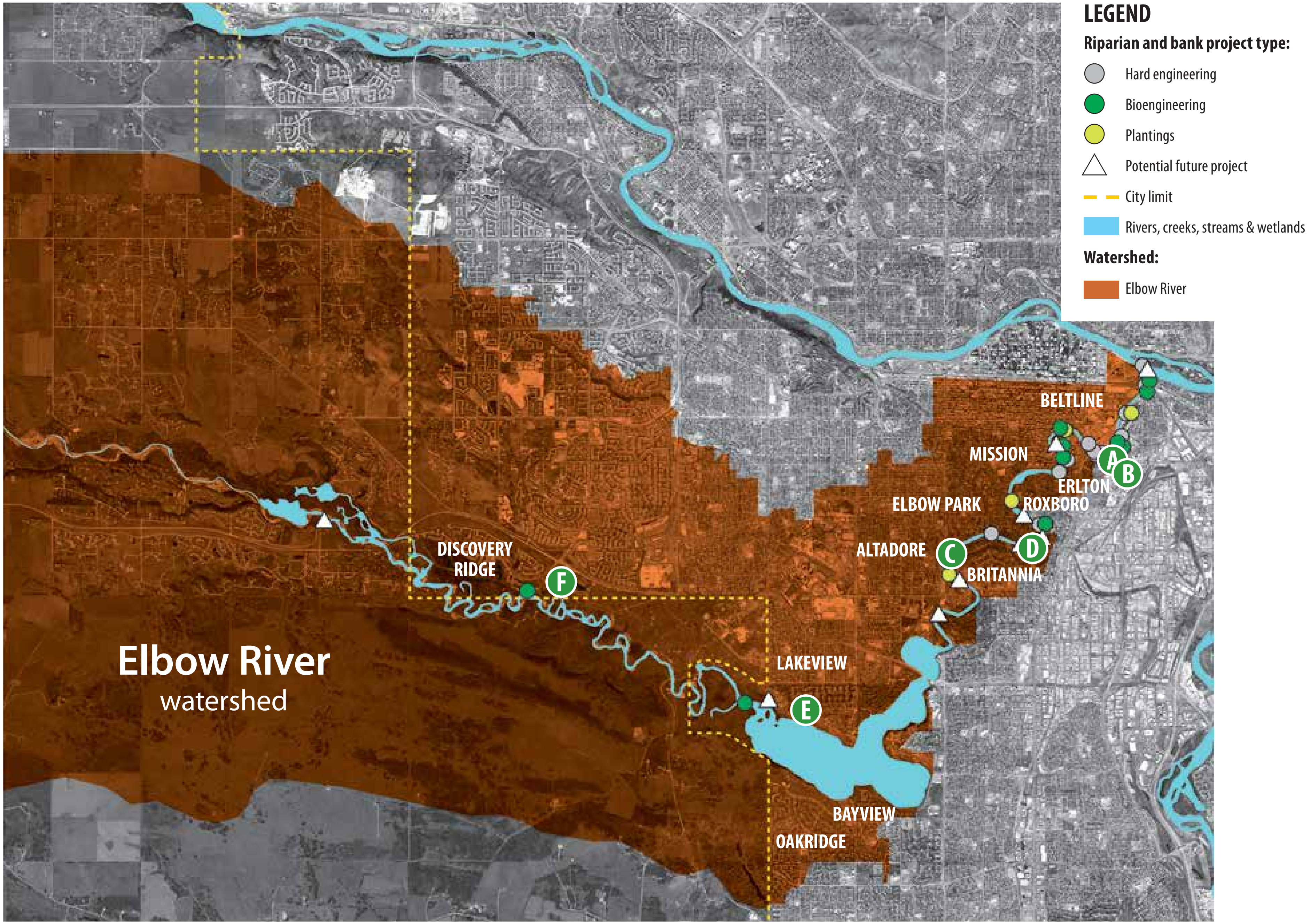
Peak stone with willow brush layering, Sandy Beach Park

Riverdale Ave. willow wattle fence

Weaselhead natural area bank stabilization project by ATCO Gas



Discovery Ridge timber crib Wall with woody debris


LEGEND
Riparian and bank project type:
Hard engineering
Bioengineering
Plantings
Potential future project
City limit
Rivers, creeks, streams & wetlands
Watershed:
Elbow River
BELTLINE
MISSION
A
B
ERLTON
ELBOW PARK
ROXBORO
ALTADORE
C
D
BRITANNIA
DISCOVERY RIDGE
F
LAKEVIEW
E
BAYVIEW
OAKRIDGE
Elbow River
watershed

Fish Creek & Pine Creek Watersheds

Pine Creek

The headwaters of Pine Creek begin in forested areas just west of Calgary. Pine Creek flows east through largely rural areas in the M.D. of Foothills before entering The City of Calgary. Pine Creek eventually drains into the Bow River just east of Heritage Pointe. The Pine Creek corridor is largely undeveloped at this point. Radio Tower Creek, located in the southwest of the city, is a meandering water body that contains two separate small tributaries that feed into Pine Creek.

Fish Creek

The headwaters of Fish Creek originate in the rolling Rocky Mountain foothills southwest of Bragg Creek. West of the City it crosses the M.D. of Foothills, the Priddis area, and the Tsuu Tina Nation. Resident beaver populations continually shift the watercourses within the watershed, creating dynamic floodplains with many oxbow wetlands.

Riparian land uses

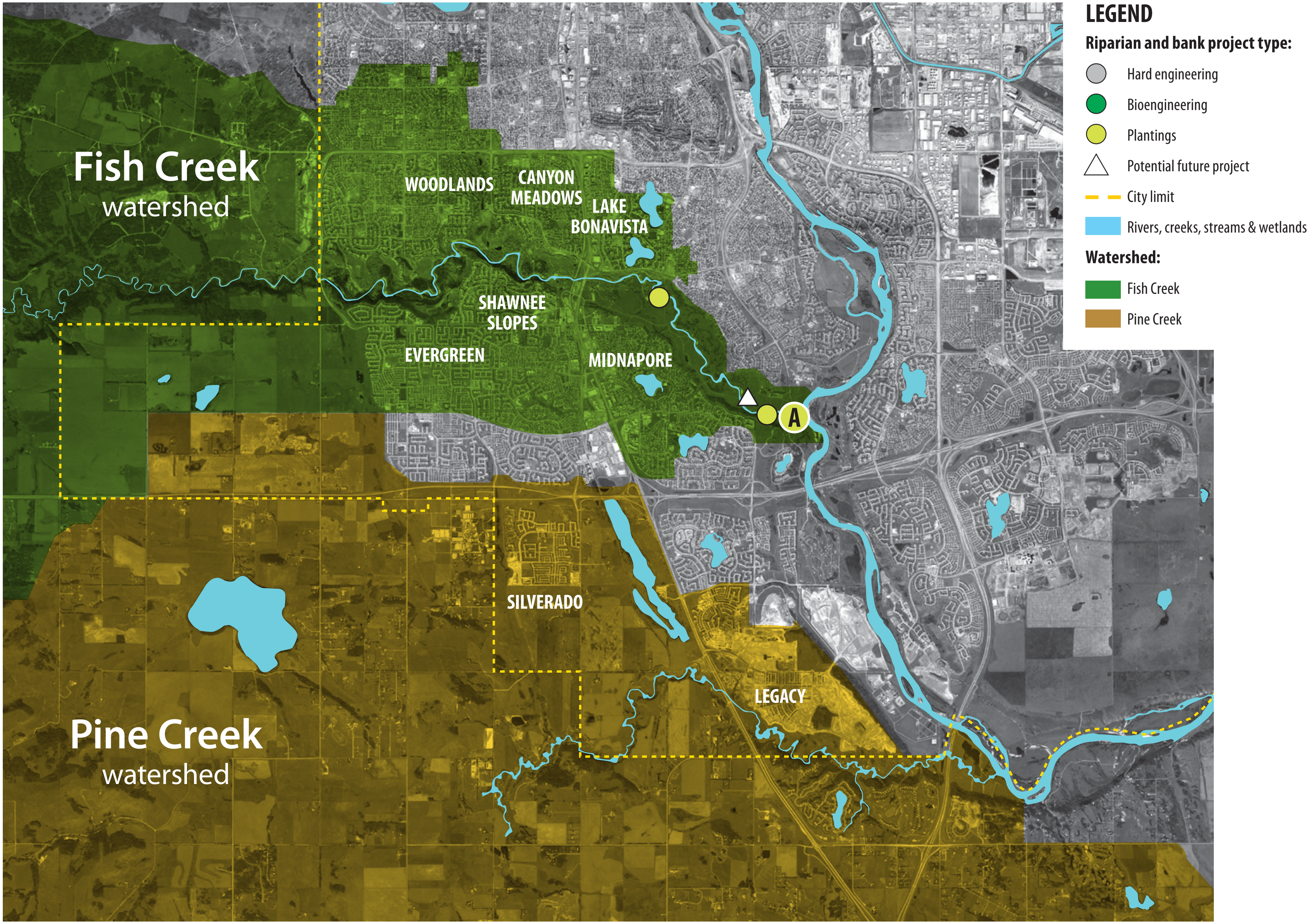
Within Calgary, Fish Creek`s riparian floodplains are entirely protected by one of the largest urban parks in North America. Fish Creek Provincial Park stretches 19 km from east to west and occupies over 13 km$^2$. As a provincial park, it was largely protected from development by Peter Lougheed`s government in 1973, and has since then become a rare wild natural riparian area within our built environment.

Pine Creek`s riparian areas are largely undeveloped within a steep ravine system, and a large portion of these areas were recently retained as open space in the recent Legacy residential subdivision.

Radio Tower Creek`s current riparian land uses in Calgary include:

- 23 per cent designated parks and recreation areas (including the Bridlewood wetland).
- 23 per cent within the Transportation and Utility Corridor.
- 17 per cent residential (largely within the communities of Bridlewood and Evergreen).
- 37 per cent currently remains unplanned (largely in agriculture), whereas the recently approved Providence Area Structure Plan (2015) flags most of this area as Environmental Open Space that may be retained as open space during future subdivision.

Friends of Fish Creek Hull's Wood restoration site


LEGEND
Riparian and bank project type:
Hard engineering
Bioengineering
Plantings
Potential future project
City limit
Rivers, creeks, streams & wetlands
Watershed:
Fish Creek
Pine Creek
Fish Creek watershed
WOODLANDS
CANYON MEADOWS
LAKE BONAVISTA
SHAWNEE SLOPES
EVERGREEN
MIDNAPORE
A
SILVERADO
LEGACY
Pine Creek watershed

Nose Creek Watershed

Watershed summary

The Nose Creek watershed originates in Rocky View County north of Calgary. Nose Creek flows south for 75 km through Airdrie, Balzac, and Calgary, before joining the Bow River near the Calgary Zoo. The West Nose Creek and Confederation Creek drainage basins are also included in the Nose Creek watershed.

The Nose Creek watershed and its` riparian areas are heavily impacted by urban and agricultural uses, channelization, stormwater inputs, and chronic erosion and water quality concerns. Urban communities in the Nose Creek watershed include Coventry Hills, Harvest Hills, Country Hills, Huntington Hills, Winston Heights, and Renfrew. Newer communities such as Sage Hill, Evanston, Hidden Valley and Panorama Hills are located in the West Nose Creek subwatershed. Confederation Creek is bordered by the communities of Capitol Hill, Rosemont, Collingwood, and North Mount Pleasant.

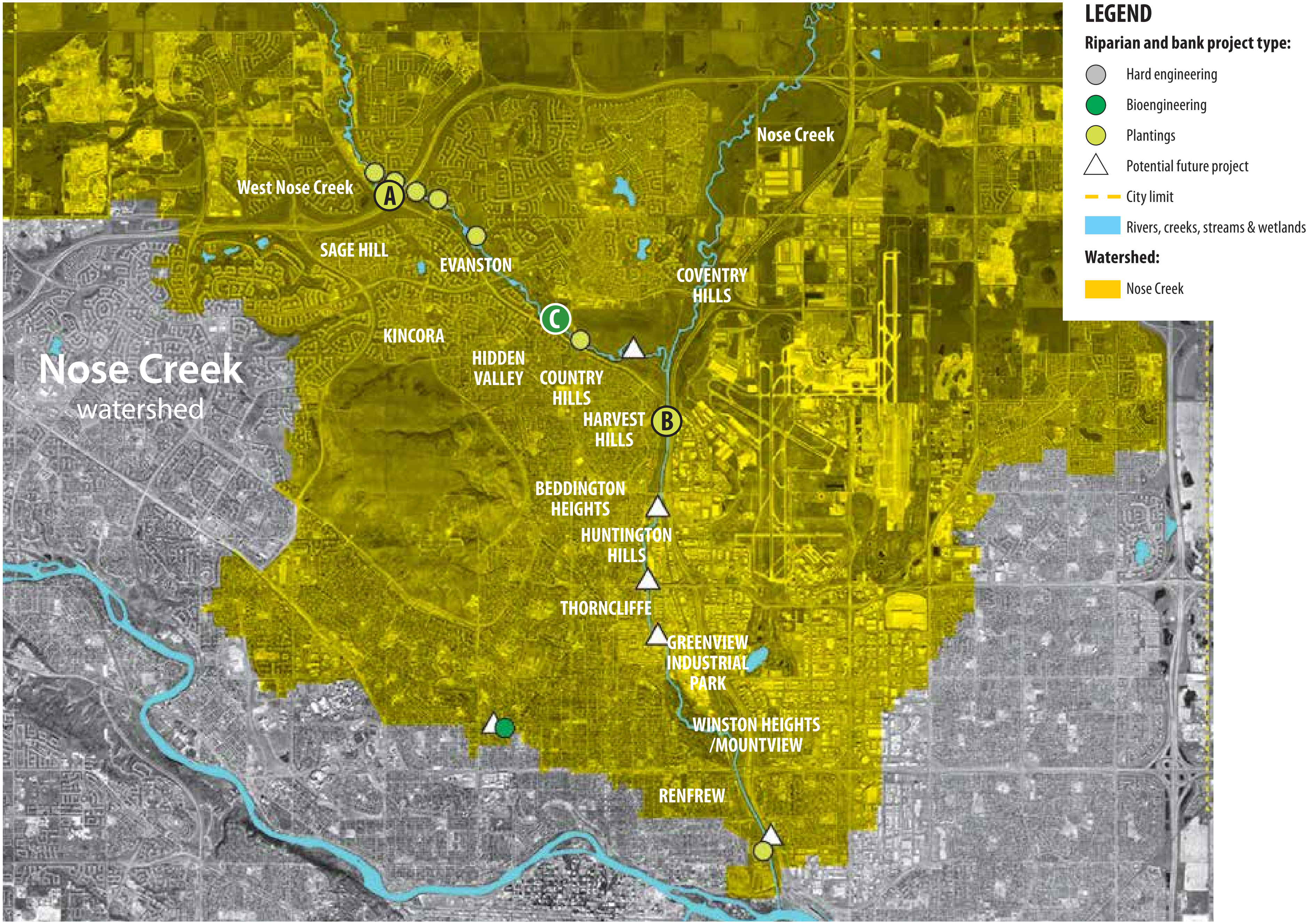
Riparian land uses

- Approximately 468 ha of riparian areas are located in this watershed within Calgary along the Nose Creek, West Nose Creek, and Confederation Creek systems.
- Most of these riparian areas (59 per cent) are designated as parks and open spaces such as:
  - Laycock Park, the Elks Golf Club, and Bottomland Park along Nose Creek.
  - A largely unbroken riparian greenway extending from Sage Hill to Confluence Park along West Nose Creek.
  - Confederation Park along Confederation Creek, before the creek disappears into a large concrete stormwater vault upstream of Highland Park.
- Major infrastructure such as highways (Stoney Trail, Deerfoot Trail, Beddington Trail) and railways intersect 14 per cent of the riparian areas in the watershed, and often restrict the meandering of Nose Creek across its' floodplain.
- Undeveloped areas also intersect 14 per cent of riparian areas in the watershed; however the approved Glacier Ridge Area Structure Plan (2015) and Nose Creek Area Structure Plan (2015) provide direction that these riparian areas are to be retained as open spaces within future communities.
- Industrial lands occupy 12 per cent of Nose Creek`s riparian area, primarily within the Greenview industrial area.
- Residential riparian land use is very sparse in the watershed, occupying less than four per cent of all mapped riparian areas.

Evanston planting site – Bow Valley habitat development

Confluence Park riparian planting site – Bow Valley habitat development

West Nose Creek meander and riffle restoration


LEGEND
Riparian and bank project type:
● Hard engineering
● Bioengineering
● Plantings
△ Potential future project
– – City limit
▬ Rivers, creeks, streams & wetlands
Watershed:
▬ Nose Creek
Nose Creek
watershed
West Nose Creek
Nose Creek
A
B
C
SAGE HILL
EVANSTON
COVENTRY HILLS
KINCORA
HIDDEN VALLEY
COUNTRY HILLS
HARVEST HILLS
BEDDINGTON HEIGHTS
HUNTINGTON HILLS
THORNCLIFFE
GREENVIEW INDUSTRIAL PARK
WINSTON HEIGHTS /MOUNTVIEW
RENFREW

Shepard Wetland and Western Headworks Canal Watershed

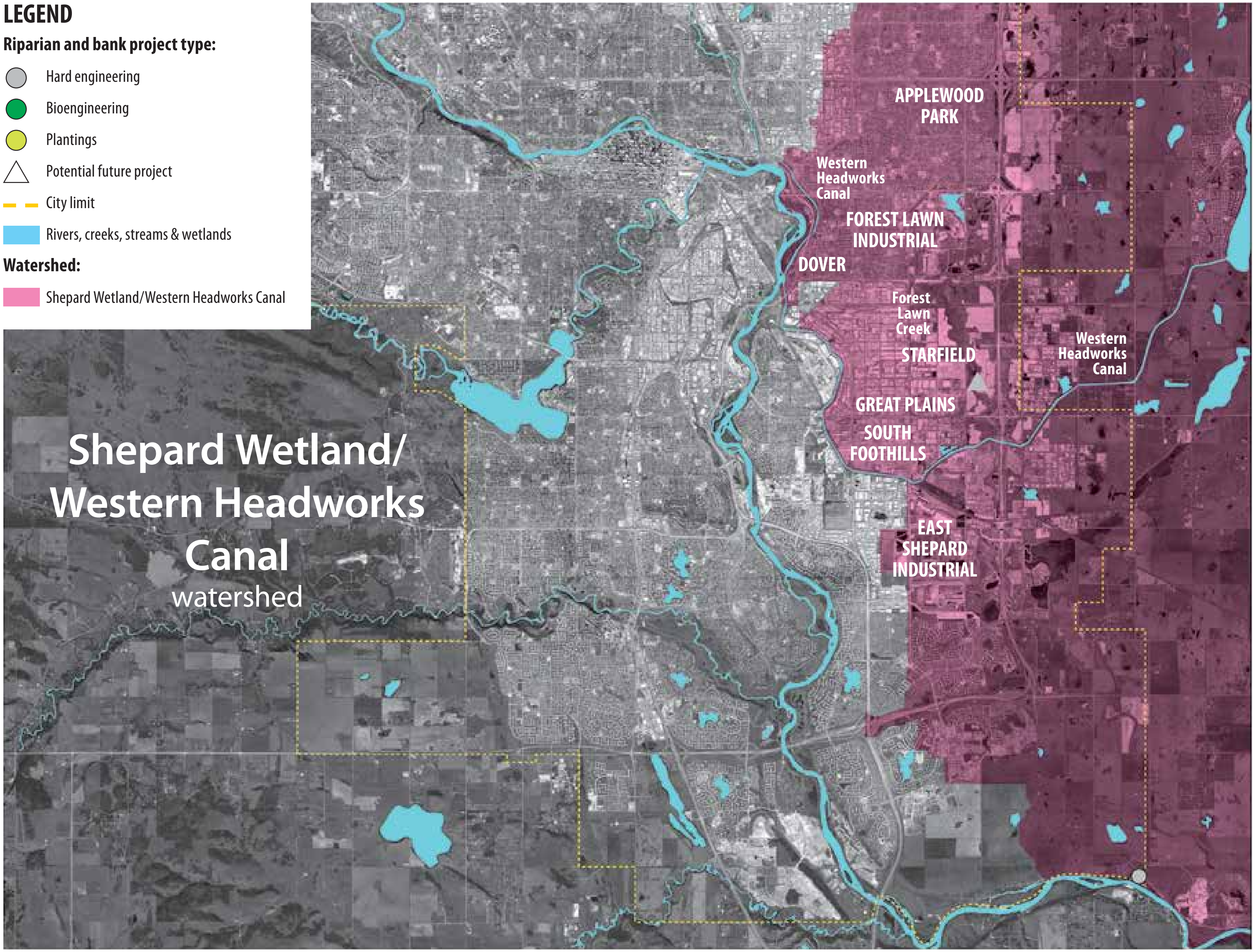
Watershed summary

This watershed, covering the eastern areas of Calgary, is notable for its high cover of wetlands in a `prairie pothole` landscape. The Western Headworks Canal, which supplies water to the Western Irrigation District, bisects the watershed. Forest Lawn Creek, as well as the large constructed Shepard Wetland and Shepard Ditch systems, are other major drainage features in the watershed.

Forest Lawn Creek, which runs through a heavily industrialized area of Southeast Calgary, is surrounded by undeveloped lands owned by The City of Calgary, although the surrounding areas will be developed to industrial lots by The City in the near future. Parts of Forest Lawn Creek were recently rerouted and restored into a series of in-stream constructed wetlands as part of the Peigan Trail expansion, completed in 2013.

Riparian land uses

Around the Forest Lawn Creek corridor, 84 per cent of the riparian areas are currently unplanned, but are intended to be incorporated as open space in the future Forest Lawn Creek industrial land development led by The City. The remaining 16 per cent of Forest Lawn Creek`s riparian areas are impacted by major infrastructure, such as Stoney Trail, a railway line, the Transportation and Utility Corridor, and Stoney Trail.



LEGEND

Riparian and bank project type:

- ● Hard engineering
- ● Bioengineering
- ● Plantings
- △ Potential future project
- – – City limit
- ▬ Rivers, creeks, streams & wetlands

Watershed:

- ▬ Shepard Wetland/Western Headworks Canal

Appendix: Ten year program area workplans

The Riparian Action Program provides guidance by linking Calgary's previous riparian technical research and data collection to specific program area outcomes and actions over the next ten years. The following timeline provides a brief history of The City of Calgary's work to date followed by work plan tables, which outline specific actions in the areas of land use planning, health restoration and education and outreach.

Figure 11. Timeline of riparian research, data collection, planning and reporting

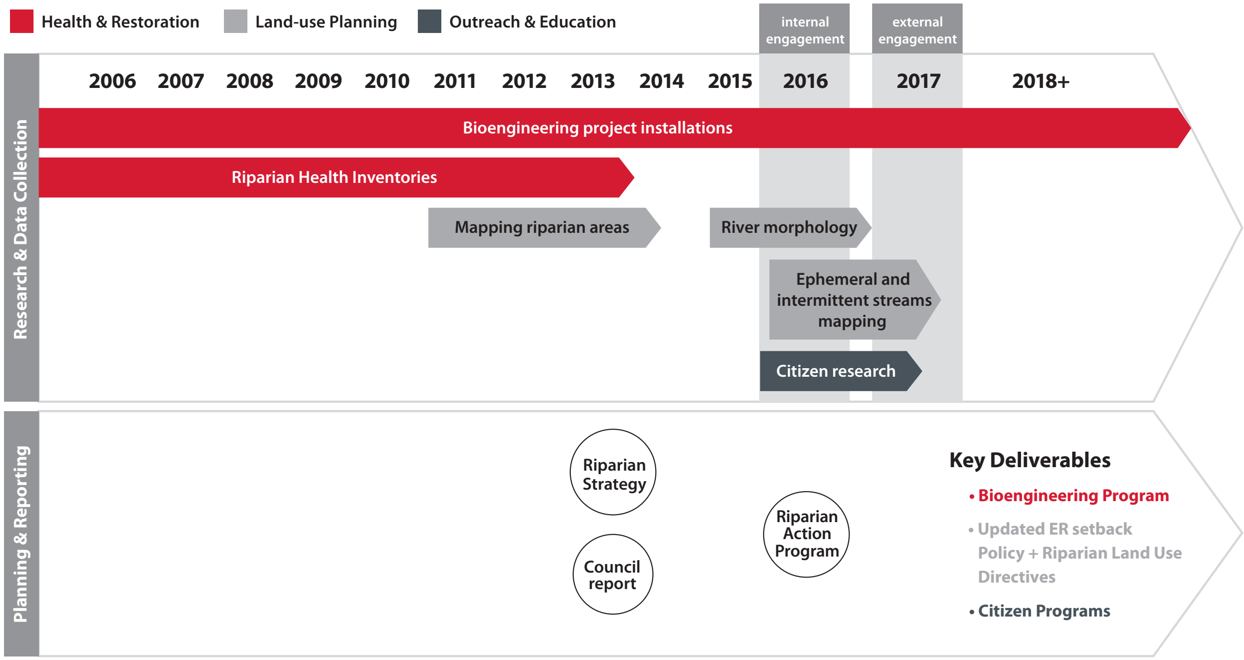


Table 5. Work plan for riparian land-use planning

Timeframe*	Project or action	Lead business unit	Stakeholders and level of engagement**		
			Collaborate	**Consult**	**Listen & learn**
Short-term	Mapping: Ephemeral and intermittent watercourses in Calgary.	Water Resources	Parks	Planning	developers, consultants, NGOs
Short-term	Research: Assess river geomorphology to better understand how the river and riparian areas will change.	Water Resources	Parks, University of Lethbridge	Planning	developers, consultants, NGOs, riparian landowners
Short-term	Policy/process: Update riparian information in the new Stormwater Management and Design Manual.	Water Resources	Other	Parks	other developers, consultants
Short-term	Process: Support internal Water Resources staff and other City business unit staff (Parks, Planning, etc.) with maps and decision support, processes, tools and policies related to land-use approvals and riparian areas.	Water Resources and Parks	Parks, Planning	developers, consultants	
Mid-term	Policy/process: Define the scope of integration of riparian and floodplain data in urban planning policies, processes, tools and bylaws.	Water Resources	Planning, Parks	developers, riparian landowners, consultants, NGOs	community associations, citizens
Mid-term	Policy/process: Update the Environmental Reserve (ER) Setback Guidelines.	Water Resources	Parks, Planning, Law	developers, riparian landowners, consultants, NGOs, Council	community associations, citizens
Mid-term	Policy/process: Investigate additional new bylaws and land use policies supporting riparian area protection.	Water Resources	Parks, Law Planning	developers, riparian landowners, consultants, NGOs Council	citizens
Mid-term	Research: Complete a detailed riparian land-acquisition study.	Water Resources	Parks, Planning, Corporate Properties, Law	developers, riparian landowners	
Mid-term	Research: Ecosystem-services valuation scoping/research studies for riparian areas.	Water Resources	post-secondary institutions	developers, Office of Sustainability, Corporate Economics	
Ongoing	Process: Continue with decision support to City staff.	Water Resources	Parks, Planning	n/a	

Notes:

*Short-term=2016-2019; mid-term=2020-2023; long-term=2023-2026.

** Levels of engagement are defined in The City's engage! policy at: http://www.calgary.ca/CA/city-clerks/Documents/Council-policy-library/CS009-engage.pdf

Outcome:
Further loss of riparian areas is minimized.

Outcome: City-wide riparian health is improved.

Table 6. Work plan for riparian health restoration

Timeframe*	Project or action	Lead business unit	Stakeholders and level of engagement**		
			Collaborate	Consult	Listen & learn
Project-specific	Restoration: Design and construct new projects to restore riparian health.	Water Resources or Parks	Parks, Water Resources	consultants	local communities, citizens, NGOs
Project-specific	Restoration: Integrate bioengineering designs in riverbank stabilization projects.				
Ongoing	Engagement: Support city staff, consultants and contractors with maps, information and decision support tools (e.g., riparian decision matrix for river engineering projects) to promote bioengineering designs.	Water Resources		Parks, consultants, riparian landowners	Local communities, citizens, NGOs
Ongoing	Assessment/monitoring: Monitor vegetation establishment at restoration sites.	Water Resources	Parks, consultants		
Ongoing	Research: Facilitate research projects on riparian health (e.g., post-flood riparian recruitment studies, ephemeral and intermittent water courses analysis, etc.).	Water Resources	post-secondary institutions		
Long-term	Restoration/engagement: Design and implement new tools, procedures and checklists to restore and manage riparian lands.	Water Resources	Parks		
Long-term	Policy/process: Standardize processes, tools, roles and responsibilities.		Parks		
Long-term	Assessment/monitoring: Monitor/report on riparian health improvements by 2026.	Water Resources		Parks, Council	local communities, citizens, NGOs

Notes:

*Short-term=2016-2019; mid-term=2020-2023; long-term=2023-2026.

** Levels of engagement are defined in The City's engage! policy at: http://www.calgary.ca/CA/city-clerks/Documents/Council-policy-library/CS009-engage.pdf

Table 7. Work plan for riparian engagement and education

Timeframe*	Project or action	Lead business unit Collaborate	Stakeholders and level of engagement**		
			Collaborate	**Consult**	**Listen & learn**
Short-term	Research: Develop and execute mixed-methods research plan that scopes, explores and validates how citizens and riparian landowners understand and live with riparian areas.	Water Resources	research consultant	riparian landowners, Parks, gov't agencies, relevant WPACs	citizens
Short-term	Planning: Develop education-program framework, work plan and evaluation plan.	Water Resources	Consultant		
Short-term	Communications: Develop strategic-communications strategy to identify audiences, partners/messengers, key messages, programming, media and evaluation measures (including social media campaign).	Water Resources	WR communications		
Mid-term	Partnerships: Establish partnership agreements with organizations.	Water Resources			
Mid-term	Education: Develop education/restoration site-selection criteria and identify specific riparian health restoration initiatives/sites to engage citizen-based restoration activities.	Water Resources	Parks		
Mid-term	Education: Develop program(s) to support riparian area enhancement on private landowner sites.	Water Resources		private landowners	
Mid-term	Partnerships: Identify public arts-based programming opportunities (i.e., Watershed+) that help promote the value of riparian areas.	Water Resources	UEP Public Art		
Mid-term	Education/communication: Develop and produce educational materials.	Water Resources			

Notes:

*Short-term=2016-2019; mid-term=2020-2023; long-term=2023-2026.

** Levels of engagement are defined in The City's engage! policy at: http://www.calgary.ca/CA/city-clerks/Documents/Council-policy-library/CS009-engage.pdf

Outcome:
Citizens and riparian landowners value riparian areas.

Glossary

adaptive management (i) a dynamic process of task organization and execution that recognizes that the future cannot be predicted perfectly. Adaptive management applies scientific principles and methods to improve management activities incrementally as decision-makers learn from experience, collect new scientific findings and adapt to changing social expectations and demands (AESRD, 2008). (ii) a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form – "active" adaptive management – employs management programs designed to experimentally compare selected policies or practices by evaluating alternative hypotheses about the system being managed (BCMFR, 2014).

alluvial aquifer a non-confined aquifer comprised of groundwater under the influence of surface-water bodies, such as rivers and lakes. It typically occurs within alluvial sediments deposited by a river or other body of flowing water (BRBC, 2012).

aquifer (i) an underground water-bearing formation that is capable of yielding water (SSRP 2014); (ii) a sub-surface layer or layers of porous rock that hold water within the spaces between the rocks (interstitial spaces) (BRBC 2012).

bank the margins of a channel. Banks are called right or left as viewed when facing in the direction of the flow (USGS, 1995).

base flow the component of stream flow that can be attributed to groundwater discharge into streams.

bed and shore land covered so long by water that vegetation is either wrested from it or marked by a distinctive character where it extends into the water. In Alberta, the province owns most of the beds and shores of all naturally occurring bodies of water pursuant to s.3(1) of the Public Lands Act.

bioengineering an approach to riverbank/streambank engineering that incorporates living and nonliving plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction and vegetation establishment (USDA, 2007).

buffer a strip of land managed to maintain desired ecological processes and provide economic and societal benefits.

channel (watercourse) an open conduit, either naturally or artificially created, that periodically or continuously contains moving water or forms a connecting link between two bodies of water (USGS, 1995).

channelization the modification of a natural river channel, which may include deepening, widening or straightening.

cost distance model a spatial modelling approach to delineate riparian areas. Inputs include stream channel locations, the rate of elevation change ("cost") as one moves away from the river, and field sampling that includes GPS delineation of riparian vegetation edges in undisturbed open spaces. Riparian extents selected are calibrated to observations along different stream and river systems (Hemstrom, 2002; O2, 2013).

coulee (i) a deep, steep-sided gulch or valley that is often dry during the summer months **(Canadian Dictionary of the English Language)**; (ii) a dry stream valley, especially a long steep-sided ravine that once carried melt water **(Alberta EAP Integrated Standards and Guidelines)**.

cumulative effects the combined effects of past, present and reasonably foreseeable future land-use activities on the environment (SSRP 2014).

drainage course See watercourse.

ecosystem function processes that are necessary for the self-maintenance of an ecosystem, such as primary production, nutrient cycling, decomposition, etc. Ecosystem "function" is primarily distinguished from "ecosystem" values (SSRP 2014).

ecosystem services ecosystem services are the benefits people obtain from nature (WRI, 2003). These include provisioning services (i.e., clean water supplies); regulating services related to disturbances (floods, droughts, pest outbreaks); supporting services (i.e., soil formation, nutrient cycling); and cultural services (i.e., recreational, spiritual, religious, etc.) (WRI, 2003).

environmental reserve (ER) land designated as Environmental Reserve by a subdivision authority under section 664 of the **Municipal Government Act**.

ephemeral watercourse (i) watercourse that flows briefly in direct response to precipitation; these channels are always above the water table (USEPA 2015). (ii) A watercourse that flows only during and immediately after snowmelt or heavy rainfall (<10% of the time) (Hedman & Osterkamp, 1982).

erosion the natural breakdown and movement of soil and rock by water, wind or ice. The process may be accelerated by human activities (AESRD, 2008).

flood, maximum probable the largest flood for which there is any reasonable expectancy in this climatic era (Leopold & Maddock, 1954; USGS, 1995).

flood fringe (i) The portion of the flood hazard area outside of the floodway; water in the flood fringe is generally shallower and flows more slowly than in the floodway (COC, 2014). (ii) Those lands abutting the floodway, the boundaries of which are indicated on the floodway/flood fringe maps, that would be inundated by floodwaters of a magnitude likely to occur once in one hundred years (City of Calgary Land Use Bylaw 1P2007).

floodplain (i) the area of land adjacent to a river that stretches to the base of the enclosing valley walls and experiences flooding during periods of high river flow (COC, 2014); (ii) an area adjoining a body of water that has been or may be covered by flood water (AESRD, 2008).

floodway (i) the portion of the flood hazard area where flows are deepest, fastest and most destructive. The floodway typically includes the main channel of a stream and a portion of the adjacent area (COC, 2014). (ii) the river channel and adjoining lands indicated on the floodway/flood fringe maps that would provide the pathway for flood waters in the event of a flood of a magnitude likely to occur once in one hundred years (City of Calgary Land Use Bylaw 1P2007).

1:100 (or 100 Year) Flood a flood level with an estimated 1per cent chance of being equalled or exceeded in any year based on historical records (COC, 2014).

green infrastructure green infrastructure uses vegetation, soils and natural processes to create healthier urban environments. On the scale of a city, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air and cleaner water. On the scale of a neighbourhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water (USEPA, 2014).

gully a trench that was originally worn in the earth by running water and through which water often runs after heavy rain or snowmelt (Merriam-Webster dictionary).

hydrology the study of water on the earth and in the atmosphere, its distribution, uses and conservation.

indicator (i) a measurable surrogate for outcomes that are of value to the public (Noss, 1990); (ii) a direct or indirect measurement of some valued component or quality in a system, such as an ecosystem or organization. For example, an indicator can be used to measure the current health of the watershed or to measure progress towards meeting an organizational goal (AESRD, 2008).

integrated water resources management (IWRM) co-ordinated water and land management that achieves economic and social benefits without compromising ecosystem sustainability (Global Water Partnership 2012).

integrated watershed management focuses on retaining or enhancing natural features and hydrologic functions within the landscape.

intermittent watercourse (i) a watercourse or portion of a watercourse that flows continuously only at certain times of year. At low flow, dry segments alternating with flowing segments can be present (USEPA 2015). (ii) a watercourse that flows for part of each year (e.g., flow occurs 10 to 80 per cent of the time) (Hedman & Osterkamp, 1982).

live stakes live, woody cuttings tamped into the soil to root, grow and create a living root mat that stabilizes the soil by reinforcing and binding soil particles together and extracting excess soil moisture (UNEP 2004).

low impact development a land planning and engineering design approach to managing stormwater runoff. The approach includes land use planning and conservation, as well as engineered hydrologic controls to replicate the pre-development hydrologic regime of watersheds by infiltrating, filtering, storing, evaporating and detaining runoff close to its source.

meander belt the land area on either side of a watercourse representing the farthest potential limit of channel migration. Areas within the meander belt may someday be occupied by the watercourse; areas outside the meander belt typically will not.

outcome a desired future condition guiding the development and implementation of an organization’s related programs.

perennial watercourse: (i) a watercourse or portion of a watercourse that flows year-round (USEPA 2015); (ii) a watercourse that generally flows continuously year-round (e.g., flow greater than 80 per cent of the time) (Hedman & Osterkamp, 1982); (iii) watercourses where base flow is dependably generated from the movement of groundwater into the channel (USEPA, 1998); (iv) perennial channels that convey water throughout the year (AESRD, 1998).

project a temporary activity designed to produce a unique product, service or result. A project is temporary in that it has a defined beginning and end in time and, therefore, defined scope and resources (PMI, 2014).

ravine (i) a small, narrow, steep-sided valley that is larger than a gully and smaller than a canyon, usually worn by running water (Merriam-Webster Dictionary); (ii) a deep, narrow valley or gorge in the earth’s surface worn by running water (Canadian Dictionary of the English Language).

resilience (i) the ability of a social or ecological system to absorb disturbances while retaining its functions and capacity to adapt to stress and change; (ii) the capacity of a system to deal with change while continuing to develop.

riparian “riparian” is derived from the Latin word “ripa,” meaning bank or shore, and refers to land adjacent to a water body.

riparian area The following definition has been developed by the Alberta Water Council Riparian Land Conservation and Management Project Team. It provides a common, science-based, ecological characterization of riparian areas for the province of Alberta and our work.

> Riparian lands are transitional areas between upland[6] and aquatic ecosystems. They have variable width, extend above and below ground, and perform various functions. These lands are influenced by, and exert an influence on, associated water bodies[7], including alluvial aquifers[8] and floodplains. Riparian lands usually have soil, biological and other physical characteristics that reflect the influence of water and hydrological processes (Alberta Water Council, 2013).

riprap a layer of stone, pre-cast blocks, bags of concrete or other suitable materials, generally placed on the upstream slopes of an embankment or along a watercourse as protection against wave action, erosion or scour (AESRD, 2008).

river a natural watercourse of fairly large size flowing in a well-defined channel or series of diverging and converging channels (Random House Kernerman Webster’s College Dictionary, 2010).

setback minimum distance that must be maintained between a land use or development and a water body. The distance is measured from the legal bank of the water body to the boundary line of the adjacent development.

stream a flowing body of water, especially a small river (Canadian Oxford Dictionary, 2nd edition).

target a specific, quantitative value assigned to an indicator that reflects a desired outcome.

terrace abandoned floodplain remnants.

timber crib wall hollow, box-like interlocking arrangements of untreated logs or timber filled above base flow with alternating layers of soil material and live branch cuttings that

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[6] Upland is land located above the alluvial plain, stream terrace(s), or any similar area associated with a water body.

[7] A water body is any location where water flows or is present, whether or not the flow or presence of water is continuous, intermittent or occurs only during a flood. It includes, but is not limited to, wetlands and aquifers.

[8] Alluvial aquifers are defined as areas where groundwater is under the direct influence of surface water.

root and gradually take over the structural functions of the wood members (UNEP, 2004).

triple bottom line (i) refers to the goal of sustaining our growing economy, while considering economics with Albertans' social and environmental goals (SSRAC, 2011); (ii) fiscal responsibility, environmental responsibility and social responsibility.

vision statement an aspirational description of what an organization would like to achieve in the mid- to long-term future.

watercourse/drainage course the bed and shore of a river, stream, lake, creek, lagoon, swamp, marsh or other natural body of water, or a canal, ditch, reservoir or other artificial surface feature made by humans, whether it contains or conveys water continuously or intermittently (AESRD, 2008).

watershed all lands enclosed by a continuous hydrologic-surface drainage divide and lying upslope from a specified point on a stream (SSRP 2014).

wetland wetlands are land that is saturated with water long enough to promote wetland or aquatic processes. Wetlands are indicated by poorly drained soils, water-loving vegetation and various kinds of biological activity adapted to a wet environment (AESRD, 2008).

Almost all fish and wildlife depend on the areas bordering our rivers and creeks for some part of their life cycle.

From the river to the tap and back, we all have a connection to the watershed.

When natural systems are no longer intact, infrastructure is typically needed to provide these lost services.

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The Bow supports life in many forms.

Plants help reduce the amount of sediment, pollution and nutrients reaching our rivers.

Supplement One: Bioengineering

Audience: river and civil engineers

During stakeholder engagement, participants clearly told The City of Calgary that civil and river engineers require additional guidance on where to use bioengineering structures in place of hard engineering riprap for the purpose of stream and riverbank erosion control. To better support river and civil engineers, a number of tools have been developed, including:

1. An overview of the differences between structural versus plant-based bioengineering.
2. Examples of past bioengineering projects with The City.
3. A Riparian Decision Matrix for river engineering projects.

Inventory of riparian restoration projects and priorities

Since 2008, The City of Calgary has promoted bioengineering practices for bank stabilization and riparian restoration. The erosion stabilization projects constructed immediately after the June 2013 flood were driven by the need to protect critical infrastructure and typically applied hard riprap designs. Current and future restoration sites and priorities set out by The City are based on studies conducted by AMEC Foster Wheeler, engineering consultants, ongoing flood recovery efforts and expert opinions of Water Resources and Parks staff. Priority sites are reviewed and re-established each year.

Riparian infrastructure tools

Table 8. Structural versus plant-based bioengineering techniques

Treatment features	Structural-based bioengineering	Plant-based bioengineering
Typical applications	Urban or suburban situations where high value infrastructure is adjacent to the waterway	Suburban, rural, or park situations where some movement of the bank line will not endanger life or property
Bank line	Determined by designer and defined by hard material placement	Approximated by designer and defined over time by natural processes
Dynamism	Low to none—successful project is static, with a low tolerance for movement	Moderate—successful project is as dynamic as a natural reach
Materials	Structural materials enhanced with plantings	Living riparian plants and inert materials used for temporary stabilization
Ecological benefits	Terrestrial and aquatic benefits provided by plants and placement of inert material	Terrestrial and aquatic benefits provided by plants and dynamic nature of the resulting project
Self-healing	Limited—if structural component fails, treatment is compromised	Significant—plant material can be severely impacted, yet recover
Examples	Riprap with live cuttings Vertical bundles with a rock toe Log cribs Vegetated gabions Vegetated geogrid Permanent erosion control fabric	Live cuttings Vertical bundles Wattle fence Fascines Brush revetment Temporary erosion control fabric

Examples of riverbank bioengineering projects in Calgary

Since 2008, The City of Calgary has promoted bioengineering practices for bank stabilization and riparian restoration. Key examples of riverbank bioengineering projects are highlighted in Table 9.

Table 9. Examples of riverbank bioengineering projects in Calgary

Project name	Description	Illustration/photo
Riverbank rescue site, Sandy Beach	Between 2008-2010, City of Calgary "Adopt-A-Park" staff, in partnership with the Calgary Herald and Cows and Fish, restored riverbanks along the Elbow River at Sandy Beach Park. Crews and volunteers planted shrubs and installed live sandbar willow stakes. The willow and shrubs act as structural elements to stabilize soils and slow floodwaters—a two-fold approach to preventing bank erosion. Native thorny shrubs deter access to the site to allow vegetation establishment. This site survived the 2013 flood very well.	Sandy Beach Riverbank Rescue, photo taken July 2013 
Deerfoot Meadows/ Southland Park vegetated timber crib wall	In 2009, The City of Calgary installed two timber crib walls interspersed with live willow cuttings along the Bow River near Deerfoot Meadows. Rock was installed underneath the timber crib wall to ensure structural integrity. These structures survived the June 2013 flood exceptionally well, while adjacent areas experienced erosion (photo opposite). The timber crib wall provides higher ecological and aesthetic values at this site compared to more conventional engineering approaches. Furthermore, the cost to design and install this project was lower than for conventional riprap bank hardening.	The bioengineered structures survived the June 2013 flood exceptionally well, while adjacent areas experienced erosion. photo credit: Cows and Fish, July 2013  Deerfoot Meadows/Southland Park vegetated timber crib wall 

Vegetated gabion across from Stampede grounds

The vegetated Gabion Project, located on the Elbow River, sustained damage during the June 2013 flood.

Vegetated gabion project

Elbow River (right bank) across from Stampede grounds

A vegetated timber crib wall, with willow cuttings that root inside the log structure, was installed in 2014 to repair this area and protect the adjacent Elbow River pathway, which was damaged by the 2013 flood.

Live timber crib wall across from Stampede grounds during installation, summer 2014

Weaselhead ATCO gas pipeline site

Major bank engineering projects within a natural environment park are generally highly undesirable. However, in the Weaselhead Natural Environment Park, the 2013 flood exposed a section of an ATCO gas pipeline. The solution was to provide an integrated erosion control system consisting of a rock layer, geosynthetics, engineered soil media and dense, native shrub plantings and native willow cuttings from the Weaselhead Park. Impacts to bank-swallow nesting habitat were also mitigated by placing a blanket down in the spring prior to the nesting period. The result is a bank engineering project that effectively balances infrastructure protection, aesthetics and the environmental requirements of the site.

Weaselhead ATCO Gas riparian restoration site

Riparian Decision Matrix for river engineering projects. The following matrix (Figure 10. Riparian Decision Matrix for river engineering projects below) was developed by Water Resources and is intended as a decision support tool for City of Calgary projects involving bank stabilization, restoration and/or river engineering. Project engineers and consultants involved with these projects are currently being directed to use this matrix in project management, design, administration and construction. The purpose of the matrix is to ensure bioengineering practices are applied to the maximum extent possible within Calgary.

Table 10. Riparian Decision Matrix for river engineering projects

Riparian Management Zone	Hard Engineering	Bioengineering / Soft Engineering	Example Sites*
Flood and erosion control zones	**Permitted** As necessary	**Preferred** Must be evaluated during design	**Memorial + 19th St.** **Alyth Yard Bridge** **MacDonald Bridge** **Elbow Rail Bridge**
Conservation Zones	**Prohibited**	**Required** Designs should minimize environmental impacts	**Discovery Ridge** **Parkdale**
Restoration zones	**Discretionary** Highly discouraged	**Preferred** Must be evaluated during design	**Douglasdale** **South Highfield**
Recreation zones	**Discretionary** Highly discouraged	**Preferred** Designs should minimize environmental impacts	**Lindsay Park** **Inglewood Golf Course**

*Contact City of Calgary Water Resources for more information about example sites and locations.

Understanding the width of natural riparian zones is a critical step towards informed land-use planning, understanding risk and, ultimately, protecting public safety.

Supplement Two: Riparian land-use planning

Audience: land-use planners, developers, civil engineers and stormwater professionals

To better understand and protect Calgary's riparian ecosystems during planning and development, The City has undertaken considerable work to map and delineate these areas and to develop tools that better support practitioners. The following supplement provides:

1. An overview of mapping activities/methodologies and riparian management categories.
2. Land-use planning procedures for riparian areas.
3. Land-use planning decision trees for permanent, intermittent and ephemeral streams.
4. Guidance on biophysical/ecological assessments and riparian areas.
5. Guidance on master drainage plans and riparian areas.

Riparian area mapping

Variable-width modelling of riparian areas

Generally, the farther lands are from water, and the higher they are, the less likely they are to support riparian conditions. To define Calgary's riparian areas, a variable-width riparian areas model was applied along Calgary's major rivers and streams. This model was developed based on three simple variables: 1) river and streambank locations, 2) digital elevation models and 3) field data on natural riparian vegetation occurrences. Maps and digital files were then created depicting the extent of current and historical riparian areas along permanent rivers and streams. The variable-width riparian areas model defined four zones:

- Inner Riparian Zone
- Middle Riparian Zone
- Outer Riparian Zone
- Potential Outermost Riparian Zone

Inner Riparian Zones typically correspond with the 1:5 year floodplain boundary; **Middle Riparian Zones** tend to occupy the 1:20 year floodplain boundary; Outer Riparian Zones tend to occupy between the 1:50 and 1:100 year floodplain boundaries; and the **Potential Outermost Riparian Zone** typically extends beyond the 1:100 year floodplain. Given the size of the Bow and Elbow rivers, adjacent riparian areas tend to be much larger than those adjacent to the smaller creeks in the city. Table 9 on page 59 shows the typical range of riparian widths observed in Calgary.

Table 11. Range of riparian widths along major Calgary rivers and streams

River or creek	Typical range of riparian widths* (m)
Bow River	145 m – 350 m
Elbow River	105 m – 290 m
Nose Creek	35 m – 60 m
West Nose Creek	25 m – 40 m
Forest Lawn Creek	70 m –120 m
Radio Tower Creek	30 m – 50 m
Pine Creek	35 m – 50 m
12 Mile Coulee Creek	20 m – 35 m
Coach Creek	15 m – 25 m

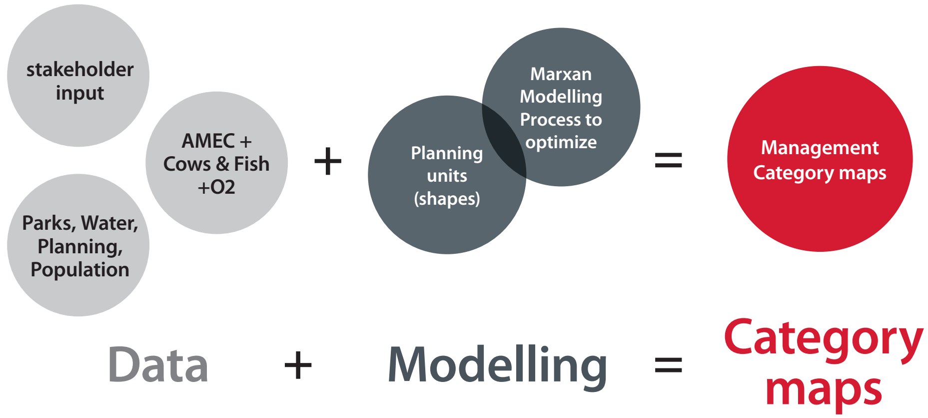
Note: *Based on 2nd quartile to 4th quartile range of the mapped riparian edge, rounded to the nearest 5 m

Riparian Management Category mapping

Mapping riparian management zones is a critical step towards developing land-management categories that guide how we restore and protect riparian areas. The following section discusses the category modelling process in more detail.

Step one of the category mapping process (see Figure 11) involved a stakeholder-led process to define possible management categories for Calgary's riparian zones. The resulting recommendations placed riparian landscape categories on a continuum based on patterns of land use ranging from completely built environments (e.g., downtown commercial high rises) to completely natural open space).

Figure 12. Overview of Riparian Management Category modelling process



Riparian mapping data sets are available online at The City of Calgary's Open Data Catalogue.

Step two involved a technical process of multi-criteria spatial modelling. More than 47 layers of data, representing various resource values and conditions, such as the presence of infrastructure or recreation features, were used to model and map each of the five riparian management categories along Calgary's major rivers and streams. The variable-width riparian zone data were also a key input in the modelling process, as they identified the physical area occupied by riparian areas; inner and middle riparian zones were weighted to have high conservation value.

Mapping river morphology An on-going project includes mapping river morphology to better account for how water channels change and migrate overtime. River morphology delineates channel migration zones at the outset of planning, makes room for the river and can help prevent expensive damage to infrastructure and eliminate the need for expensive bank-hardening projects used to prevent flooding and erosion. Areas of significant river morphology will be identified and future development in those areas will be considered.

Ephemeral and intermittent streams Ephemeral and intermittent streams are small headwater-drainage features that generate the majority of a river's flow and play a critical role in maintaining water quality on a cumulative, regional basis. Intact, well-vegetated riparian areas in and along ephemeral and intermittent watercourses reduce the mobilization of sediment, excessive nutrients and other pollutants downstream. Mapping of these areas is in progress and potential limits of acceptable change related to the loss of ephemeral and intermittent watercourses can and will be defined.

Land-use planning procedures for riparian areas

Growth in Calgary is co-ordinated by a series of plans within a planning hierarchy. Riparian area boundaries and setbacks should be flagged as early as possible in the planning process, so that constraints and opportunities can be made clear far in advance of development. Planning procedures to incorporate riparian values and boundaries in new developments are important at all levels in the planning hierarchy.

Part 17 of the Municipal Government Act (MGA) addresses planning and development in a municipality and gives the municipality the authority to require dedication of lands, including Environmental Reserve (ER) and Municipal Reserve (MR), at subdivision. Of particular relevance to riparian areas is Section 664(1) of the MGA [9], which states:

> "An area of land may be designated as Environmental Reserve if it consists of:
>
> a) a swamp, gully, ravine, coulee or natural drainage course,
>
> b) land that is subject to flooding or is, in the opinion of the subdivision authority, unstable, or
>
> c) a strip of land, not less than 6 metres in width, abutting the bed and shore of any lake, river, stream or other body of water for the purpose of (i) preventing pollution, or (ii) providing public access to and beside the bed and shore."

Any of the landscape features noted above can fall within the definition of potential ER and be identified as such in a planning document. However, whether dedication of potential ER lands is actually required at subdivision is left to the discretion of the Subdivision Authority.

By identifying potential ER related to riparian areas and other landscape elements (e.g., wetlands, steep slopes, etc.) in ASPs, expectations regarding environmental constraints and opportunities can be established. Subsequently, the Outline Plan will fill any remaining information gaps and provide more detail and refinement for decision-making purposes, including the actual designation of riparian-related ER.

In accordance with the MGA, there are six landscape elements that can qualify as potential ER. Table 10 below lists each of these, along with existing data sources and criteria, responsibilities for mapping and recommended timing of supporting studies. An Ecological Inventory Framework [10] is required to support ASPs, and Biophysical Impact Assessments (BIAs) are required to support Outline Plans.

Draft riparian decision-analysis trees have been created to support land-use planning applications (see Figure 13 and Figure 14). These are primarily intended for use within the ASP and Area Redevelopment Plan (ARP) processes. However, in the future, more refined criteria will be developed for the Outline Plan, Tentative Plan and Development Permit stages.

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[9] Anticipated changes to the Municipal Government Act may offer municipalities new tools for riparian protection.

[10] http://www.calgary.ca/CSPS/Parks/Documents/Construction/Ecological-Inventory-Framework.pdf

Table 12. Potential environmental reserve, as specified in the Municipal Government Act [11]

Potential environmental reserve element	Legal basis in Municipal Government Act	Data source/criteria	Timing of mapping studies
Gully, ravine or coulee (with escarpments >15%) [12]	664(1) (a)	Landform mapping from digital elevation models	Prior to/during ASP
Wetlands	664 (1) (a) 664(1) (b)	City wetlands data, provincial merged wetlands inventory, current and historical air-photo interpretation	During ASP field confirmation during growing season prior to Outline Plan
Natural drainage course	664 (1) (a)	Mapped stream vectors Ephemeral/intermittent watercourse mapping study Field studies of areas	As available Flag at ASP Refine at Outline Plan
Land subject to flooding	664 (1) (b)	Current floodplain maps Riparian maps for streams/rivers*	Include current floodplain boundaries (not just floodway) in ASPs, incorporate updates as available
Land that is, in the opinion of the subdivision authority, unstable	664 (1) (b)	River geomorphology study Geotechnical studies	Flag at ASP Refine at Outline Plan
A strip of land, not less than 6 metres in width, abutting the bed and shore of any lake, river, stream or other body of water for the purpose of: **(i). Preventing pollution** **(ii). Providing public access to and beside the bed and shore**	664 (1) (c)	2007 Environmental Reserve (ER) Setback Guidelines-base + modifier** Ephemeral + Intermittent stream mapping study (once complete)	Current ER Setback Guidelines map tool available now Incorporate updates as available

*Available in City of Calgary Open Data Catalogue.

**Alluvial aquifer zones directly affecting surface water should be protected using tools other than ER; these have been mapped previously at a 1:50000 scale (Alberta Research Council 2010; Moran 1984).

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[11] Please note that the Municipal Government Act is under review and will be updated. Definitions are subject to change. For more information, please visit http://mgareview.alberta.ca.

[12] AESRD (2012) – Stepping Back from the Water; UNEP (Integrated Watershed Management - Ecohydrology and Phototechnology Manual, 2004) – hill slopes with slopes greater than 15 per cent directly enclosing a stream or river are considered to be an element of a riparian area corridor.

Riparian land-use planning decision trees

The following Riparian land-use planning decision trees integrate directions and policies regarding riparian areas from a wide-range of documents, including the **South Saskatchewan Regional Plan** (2014), **Municipal Development Plan** (2009), **New Communities Planning Guidebook** (2013), **Environmental Reserve (ER) Setback Guidelines** (2007), **Riparian Areas Mapping Project** (2013), **River Flood Mitigation Panel Report** (COC, 2014), **Biophysical Impact Assessment Framework** (under review), water and watershed management plans (e.g., **Bow Basin Watershed Management Plan, Nose Creek Watershed Management Plan) and Calgary Land Use Bylaw.**

These decision trees are drafts and advisory in nature and do not preclude further changes as a result of any future federal, provincial, or municipal policy or legislation enacted to enhance flood resiliency, environmental quality or municipal authority.

Figure 13. Riparian land-use planning decision tree: step one

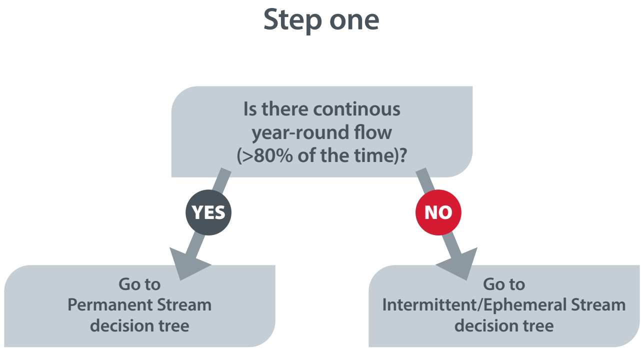


Figure 14. Riparian land-use planning decision tree: permanent streams

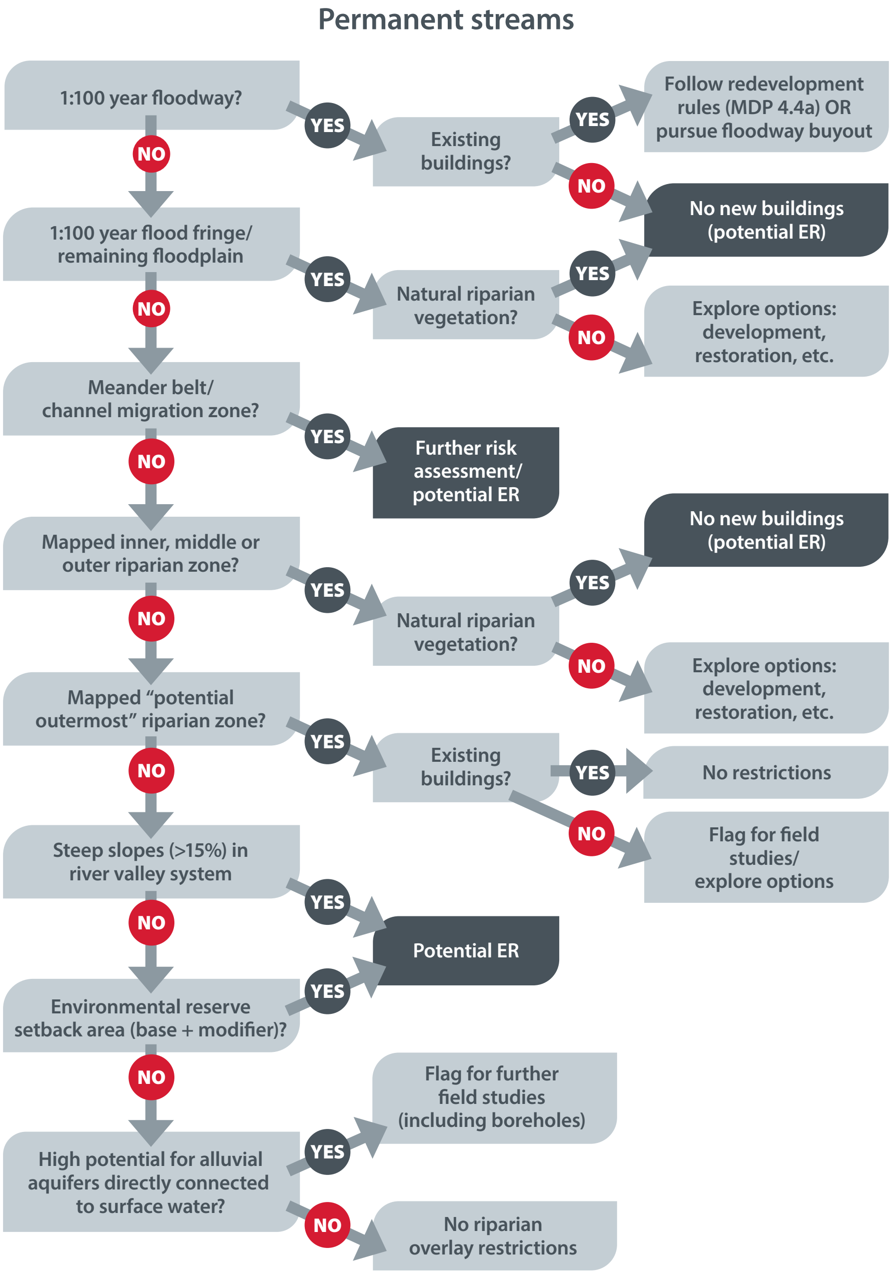
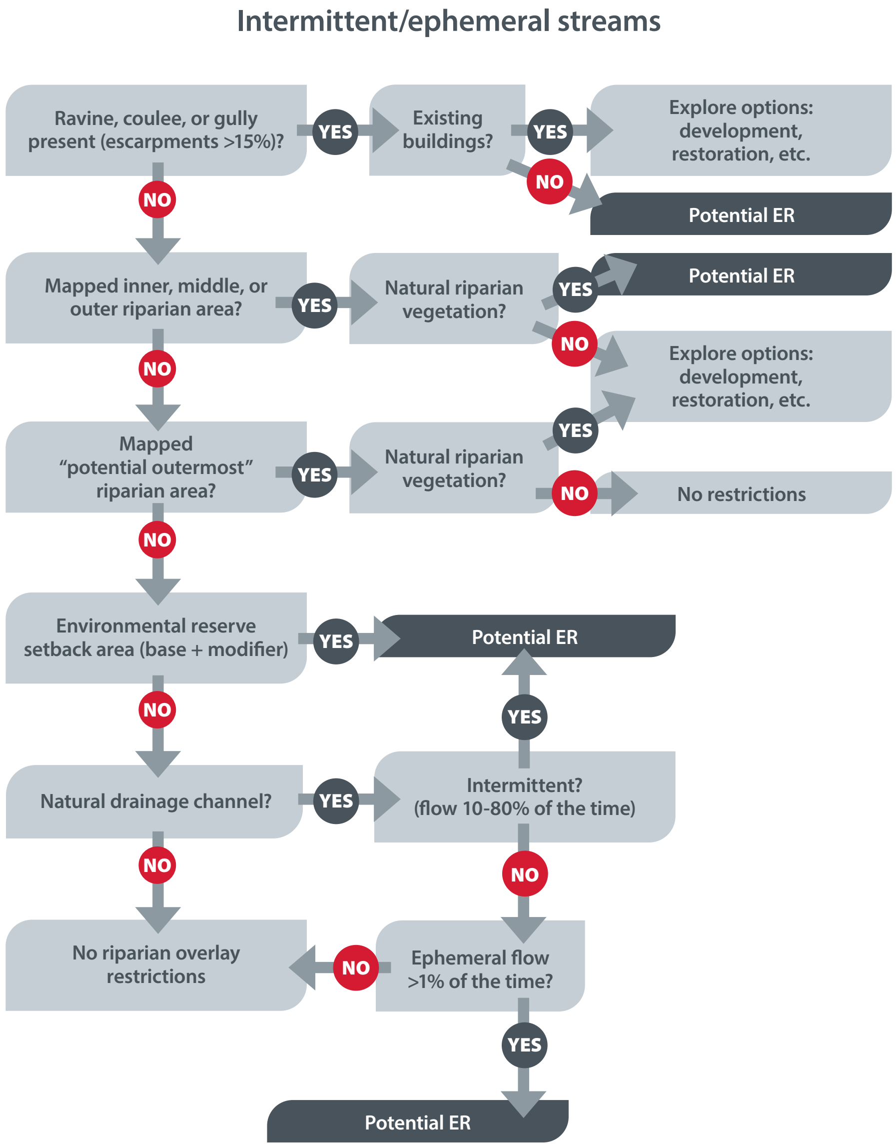


Figure 15. Riparian land-use planning decision tree: ephemeral + intermittent streams



The challenge of identifying lost or impacted riparian areas in the field

When the signature of natural riparian vegetation has been erased in the field by development or agricultural activities, care must be taken when interpreting and mapping riparian boundaries based on field data alone. If riparian restoration opportunities are being explored, broad scale riparian mapping data should complement site-specific field data. The broad scale riparian mapping data has been calibrated to include lost/developed riparian areas along major rivers and streams in Calgary.

Biophysical ecological assessments and riparian areas

Riparian area GIS mapping data and biophysical/ecological assessments Existing city-wide riparian-area mapping boundaries provide key information for initial desktop Ecological Inventory Framework or Biophysical Impact Assessment (BIA) review purposes, as required by The City of Calgary Parks. All consultants and developers should be referred to this source of reference information as early as possible in development planning processes. Any users of the data must also review the metadata, including associated data limitations (e.g., its restriction to riparian areas along major rivers and streams in Calgary). Supplementary city-wide ephemeral and intermittent stream mapping is also planned for 2016 and will be used to update data on City Online once finalized. Mapping ravine and coulee boundaries based on a systematic city-wide process is also underway.

Riparian-area field assessments Field verification of riparian-area boundaries is required, as broader-scale mapping may not capture site-specific riparian variability. In addition, many ephemeral and intermittent watercourses and associated riparian areas cannot be mapped accurately with desktop exercises alone. Field assessments combined with hydrological mapping will generally improve the accuracy of riparian-area delineation. Strong plant-taxonomy skills and hydrological knowledge, including knowledge of soils, are required to accurately delineate riparian areas in the field. Experience with identifying permanent high water, ephemeral high water (e.g., spring run-off) and high water marks associated with flood events is crucial for field delineation of riparian areas (Clare & Sass, 2012). Soil pits should be examined to determine riparian boundaries based on soil mottling or gleying, or in situations where there may be questions regarding water permanency (e.g., red indicates oxidization in areas that experience full saturation). Vegetation surveys are also critical. Where vegetation is disturbed, principles outlined in Stewart and Kantrud (Classification of Natural Ponds and Lakes in the Glaciated Prairie Region, 1971) can also be used during field assessments of riparian areas. In agricultural environments with non-native vegetation, the crop draw-down phase and presence of colonizing invasive species can also be field cues showing the presence of riparian conditions. In addition to ground-truthing the extent of the riparian area, characteristics of the site should be assessed to assign a riparian health score (Cows and Fish, 2012).

Riparian setback determination Determination of appropriate riparian setbacks should be based on the land-use planning decision trees above. Riparian setbacks must take into consideration the floodway, riparian areas, meander belts/channel migration zones, steep slopes and existing policies and guidelines, such as the ER Setback Guidelines (2007). Setbacks can also be modified and increased to preserve wildlife movement corridors, species at risk/species of conservation concern, sensitive landscape features, unstable soils, etc. Field assessments should be performed by an experienced environmental professional during the growing season, when the majority of riparian species in the proposed project site are in flower. During the design of the assessment, riparian and floodplain maps must be used to develop a sampling strategy.

Master drainage plans and riparian areas

The City of Calgary's stormwater management planning process involves the integration of plans from the watershed level down to detailed design. Watershed and water management plans provide general guidance and recommendations at the watershed level. Water management plans may include specific stormwater management and riparian-area protection requirements, including water quality and water conservation objectives, maximum allowable release rates, runoff volume-control targets, implementation of LID practices, etc.

A master drainage plan (MDP), which can be developed by The City of Calgary or the developer/consultant is prepared for a large urban drainage area and is typically serviced by a single outfall. MDPs identify the location of stormwater infrastructure (e.g., ponds, trunk sizes, servicing routes, overland drainage routes, water quality-treatment requirements).

An individual MDP must:

- Incorporate stormwater management and watershed protection requirements of the broader scale watershed or water management plan.
- Provide an acceptable level of service and meet the objectives of regional context studies, area structure plans, redevelopment plans and biophysical impact assessments. Depending on various factors, these other documents can be developed before, during or after the development of an MDP.
- Comply with The City of Calgary Stormwater Management & Design Manual and provincial requirements.

One of the technical requirements of MDPs is to confirm post-development runoff rates and volume targets. Increased stormwater runoff due to urbanization can cause channel erosion and pollution, and can have adverse impacts on aquatic species. The City has developed runoff rate volume and water quality targets for greenfield and redevelopment projects.

Technical requirements for MDP reports can be found in the Stormwater Management & Design Guidelines, as well in the Terms of Reference issued for the scope to be included in individual Master Drainage Plans. Generally, Master Drainage Plans will include the following requirements pertaining to drainage courses and associated riparian areas:

- Establish stormwater targets and objectives from relevant regional Watershed and Water Management Plans
- Refer to The City of Calgary's Riparian Action Program as well as Wetlands Management Plans and Policies for alignment and consistency purposes
- Document, including with site inspections and photos, existing wetlands and drainage pathways, as well as all perennial, intermittent, and ephemeral drainage courses, man-made drainage infrastructure, and flow directions
- Assess and align stormwater concepts with available draft or final Biophysical Impact Assessment (BIA) reports
- Evaluate the stability thresholds and conveyance characteristics of existing streams and ravines, with specific attention to those drainage courses and ravines that may convey concentrated urban runoff in the future
- Identify the extent of drainage courses deemed to be important for maintaining in a natural-like state
- As part of a planning-level hydrogeological assessment, assess groundwater impacts relevant to the preservation of existing drainage courses or wetlands in a natural-like state
- Prepare pre-development flow-duration curves for ravines and drainage courses, and verify that flow frequency curves following the introduction of controlled, treated stormwater releases do not exceed pre-development flow-frequency curves
- In consultation with Water Resources, determine requirements for sampling and monitoring of water quality (e.g., TSS, P, N, Cl, metals, hydrocarbons, PAHs, etc.) and/or water flow rate monitoring for streams within the study area
- During drainage system design, locate all stormwater infrastructure (except outfalls or perimeter rain gardens or bioswales) outside of riparian areas, floodplains, and meander belt widths
- Evaluate whether and describe how existing water bodies or potential/contested water bodies might need to be sustained by the stormwater drainage system
- Give preference to the use of native wetland and riparian vegetation in constructed wetlands and stormwater management features
- Evaluate considerations for appropriate stream setbacks addressing the following setback objectives:
  - Safe flood conveyance
  - Stream movement
  - Water quality/treatment
  - Access for maintenance
  - Habitat and wildlife movement
  - Groundwater protection
  - Geotechnical slope stability
  - The City of Calgary's existing riparian and stream mapping products, including identified riparian extents, 2007 ER Setback guideline locations, and new mapping and classification of perennial, intermittent, and ephemeral streams as they become available
  - Educational, interpretive, and recreational functions
- Identify overland drainage routes, including the use of streams as overland escape routes

Supplement Three: Riparian Monitoring Protocols

Audience: specialized technical staff and/or consultants

The Riparian Action Program (RAP) is based on an adaptive management approach that includes regular monitoring and adjustments. It is a structured, science-based process that plans for and integrates experience and research into programming along the way. Adaptive management enables continual improvement, accountability and transparency and best addresses the dynamic nature of riparian systems.

On a regular basis, for example once every five years, trained City staff and/or contractors will conduct assessments to monitor and measure indicators. City of Calgary Watershed Planning staff will assume overall responsibility for co-ordinating the monitoring of this work, as well as reporting and sharing the results more broadly.

The following supplement provides an overview of the methodologies and protocols related to each of the three program areas: riparian land-use, riparian bank health, and education and outreach.

Program area one: riparian land-use monitoring protocols

This section outlines the methodology undertaken to measure baseline (2012) land uses in riparian areas and outlines a relatively straightforward method to conduct ongoing monitoring of riparian land uses as part of future monitoring efforts. The expert conducting this work will be a senior geographic information systems (GIS) technician assigned to Water Resources (e.g., Infrastructure and Information Services – Water Design staff), under the overall direction of the assigned Watershed Planning staff.

Indicator #1: Riparian open spaces (major creeks and rivers) are mapped. The City of Calgary already has a process in place to systematically update geospatial data sets on designated land-use districts as planning and development decisions proceed, a process integrated with the Land Use Bylaw. This process is encapsulated in The City's SDE GIS layer, currently named: "CALGIS.CNTST_LANDUSE_1P2007". Although this data layer includes areas that are zoned but not yet built or developed, these areas do represent major land-use decisions and, therefore, signify the intent to allow development within them.

Therefore, for the purpose of monitoring how riparian land uses are changing along Calgary's major rivers and streams, this data layer (or future updates to it) is relatively suitable. To use this data for future monitoring purposes, the following procedure is recommended:

1. The first step in monitoring riparian land use is to clip the city land use layer to the same boundary used to measure baseline land use data. This area includes the maximum extent of those areas mapped as riparian (includes the Outer Riparian Boundary, i.e., everything classified as Inner, Middle and Outer Riparian zones) or the ER Setback buffer width, whichever is greater. This boundary is encompassed by the outer spatial extent of the O2 (2013) geodata set representing major land uses, saved on the Water Resources' server.
2. Once the land use district data has been clipped to the riparian extents as described above, the data is to be combined into the simplified categories shown in Table 12 below, based primarily on the major land use district field.

Table 14. Assumptions for grouping land uses into Developed and Undeveloped categories

<table>
<tr><th colspan="3">Developed land use categories</th></tr>
<tr><th>Commercial</th><th>Residential</th><th>Institutional</th></tr>
<tr><td>Includes all C- districts, and CC-COR, CC-MH, and CR-20 centre city districts.</td><td>Includes all R- districts (Low, Medium and High Density), Multi-Residential, and CC-MH and CC-MHX districts.</td><td>Includes all health, religious, educational institutions, mostly in the S-CI land use district.</td></tr>
<tr><th>Industrial</th><th>Mixed use</th><th>Major infrastructure</th></tr>
<tr><td>Includes all I- districts.</td><td>Includes all CC-East Village districts, CC-X.</td><td>Includes the ring road/transportation and utility corridor, Deerfoot Trail, major roadways, railways, Ogden Rail Yards, Stampede grounds, wastewater treatment plants.</td></tr>
<tr><th colspan="3">Open space (undeveloped) land use categories (for the purposes of riparian land use monitoring)</th></tr>
<tr><td>Parks, recreation + public education
- Includes all S- districts.
- Includes St. Patrick’s Island + Calgary Zoo (reclassified from FUD).
- Golf courses where symbolized differently on the map.</td><td colspan="2">Future urban development (S-FUD)
- Includes all lands on the periphery “awaiting urban development and utility servicing” (COC, 2008). It accommodates extensive agricultural uses prior to rezoning during future planning.</td></tr>
</table>

1. One drawback to the CALGIS.CNTST_LANDUSE_1P2007 data layer is the large number of Direct Control (DC) land use districts, which vary greatly in terms of actual major land use type. To provide a consistent, more useful layer for interpretation and city-wide summary purposes, it is necessary to reclassify these into one of the categories noted above prior to conducting any statistical summaries. The DC_LUD data field can be consulted, but current air photo imagery should also be examined while reclassifying DC polygons within riparian areas. During baseline data analysis conducted in 2012, all of the Direct Control –DC land use districts were reclassified to a new major land-use class identity by referencing the data set and current aerial photography imagery in the GIS. The interpreter then reclassified these DC parcels to a new major land use class identity, as per the table above.
2. Once this data processing is completed, the current riparian land use data can be summarized statistically and compared to the baseline 2012 values. Current statistics by river system must also be generated, as summarized in the “ExistingLandUse%inRiparianAreas” tab in the Excel database, saved on the Water Resources server at: riparianStatsOct2014.xlsx.
3. For the purposes of indicator monitoring, the total developed area along each river/stream should be summarized and compared to baseline values from 2012 (e.g., 27 per cent developed city-wide; 25 per cent developed along the Bow River; 38 per cent developed along the Elbow River; 33 per cent developed along Nose Creek and West Nose Creek). If desired, more detailed land use categories can be created, to track and summarize trends, but it is not necessary to address the intent of the established indicator.

Indicator #2: Conversion of riparian areas to new development along ephemeral and intermittent watercourses are monitored. This indicator methodology will require further development once an inventory and map of ephemeral and intermittent watercourses has been completed and potential limits of acceptable change related to the loss of ephemeral and intermittent watercourses are appropriately defined.

Program area two: riparian and bank-health monitoring protocols

Within Calgary, different methods have been developed and applied to assess riparian health versus bank health. The riparian health assessment is a more detailed method that includes field surveys of the entire riparian area. Bank health assessment is a rapid tool applying only to banks, using observations from
river floats.

Indicator #3: City-wide riparian health index is scored by management zone Riparian health and bank health are different indicators with their own assessment methods, and they address different components of the riparian system. The differences between these two indicators are summarized in Table 13 below.

Table 15. Riparian-health versus bank-health methodologies

	Riparian health	Bank health
Area of assessment	Focused on the entire riparian area	Focused only on banks
Method of transport	Conducted on foot across the site	Conducted from the river during river floats
Level of detail	More detailed field assessments	Reconnaissance-level, simplified field assessments
Time	More time-intensive	Less time-intensive
Cost	Higher cost	Lower cost

To date, targets have been based on the riparian health metric, as it captures the full-extent of the riparian zone and not just the bank. The riparian health metric reflects program outcomes and intent. Based on extensive discussions held during 2014, it was decided that the riparian health indicator was more appropriate for ongoing monitoring and reporting. Although it is generally advised against changing this decision for purposes of consistency, future targets for bank health could also be considered and monitored, particularly if budget or time is a limiting factor. Further explanation of bank-health monitoring protocols is available in Cows and Fish (2012).

The following section summarizes monitoring protocols, including site-specific protocols, and methods for statistically summarizing riparian health sets at city-wide scales using geographic information systems (GIS).

Riparian health monitoring Riparian health was assessed within Calgary by the Alberta Riparian Habitat Management Society (more commonly known as Cows and Fish) between 2007 and 2010. In total, 31 sites along the Bow River were assessed between 2008 and 2010; 16 sites along the Elbow River were assessed from 2007 to 2010, and 13 sites within the Nose Creek watershed were assessed between 2007 and 2009, including sites along Nose Creek (six sites), West Nose Creek (six sites) and Beddington Creek (one site). These riparian-health surveys were focused along publicly owned open spaces, including 23 city parks and several golf courses. Additionally, four sites were assessed on OLSH property along Forest Lawn Creek in 2008 and again in 2013. An additional 36 privately owned residential riverfront properties were also assessed in 2009, based on the voluntary participation of private landowners. [13] It is important to stress that this effort was not an inventory of all riparian areas within the city, but rather a sampling of a subset of riparian areas.

The methodology applied to site-level riparian-health assessments was the Riparian Health Inventory (RHI). This method was developed by Cows and Fish in collaboration with Dr. Paul Hansen and William Thompson. For stream and small river systems, RHI scores are derived from an evaluation of 11 key vegetation and soil/hydrology health parameters assessed in the field. For the Bow River, RHI scores are based on an evaluation of eight of these parameters in addition to seven others mainly related to tree cover and hydrology (see Table 14 and Table 15). The parameters assessed are largely based on visual estimates made in the field by trained observers, supplemented by measurements. The riparian health scores (ratings) are expressed both as a percentage score and in terms of one of three health categories: healthy, healthy with problems and unhealthy.

[13] However, due to confidentiality agreements with landowners at the time these surveys were conducted, the private-lands data collected can neither be used to develop riparian targets, nor integrated into a long-term monitoring program.

Table 16. Riparian health scores

Health category	Score range	Description
Healthy	80 to 100%	Little to no impairment to any riparian functions
Healthy, but with problems	60 to 79%	Some impairment to riparian functions due to human or natural causes
Unhealthy	<60%	Severe impairment to riparian functions due to human or natural causes

Table 17. Riparian health parameters assessed in the RHI methodology

Riparian health parameter assessed		Streams and small rivers	Large rivers
Vegetation	Vegetation cover	✓	
	Cottonwood and poplar regeneration		✓
	Regeneration of other tree species		✓
	Preferred shrub regeneration		✓
	Preferred tree/shrub regeneration	✓	
	Preferred tree/shrub utilisation and woody vegetation removal by other than browsing	✓	✓
	Dead/decadent woody material	✓	✓
	Total canopy cover of woody plants		✓
	Invasive plants	✓	✓
	Disturbance plants	✓	✓
Physical	Root mass protection	✓	✓
	Human-caused alteration to banks	✓	✓
	Human-caused bare ground	✓	✓
	Human-caused alteration to rest of site	✓	✓
	Floodplain accessibility		✓
	Channel incisement	✓	
	Removal or addition of water from/to river system		✓
	Control of flood peak and timing by upstream dam		✓

GPS receivers are used by surveyors to record the locations of upstream and downstream ends of the riparian polygon (site). For monitoring purposes, benchmark photographs facing upstream and downstream are taken at each end of the site.

Additional photographs are taken where warranted to document features of interest or concern (e.g., weed infestations, bank erosion). Where possible, the upstream and downstream site boundaries are placed at distinct locations or landmarks, such as a bridge or stream confluence, for ease of future monitoring. The lateral extent (outer boundary) of the riparian area was previously determined in the field by Cows and Fish, and mapped onto a 2009 orthophoto (1:3000 to 1:8000 scale). Boundaries were based on the presence of hydrophytic vegetation, hydric soils and other signs of the presence of water, seasonally or regularly, on the surface or close to it. Due to human-caused disturbance of riparian-vegetation indicators in Calgary, the lateral boundary of RHI sites were often delineated based on topographic breaks or land use/management boundaries (e.g., fence lines, paved trails, roadways). In future surveys, consideration should be given to using the mapped City of Calgary riparian boundary (outer riparian boundary) to determine the edge of the riparian area prior to conducting field surveys.

Riparian health index: baseline statistical summaries While the RHI indicator is often reported in terms of the three health categories (see Table 14 on page 75), health categories reduce data resolution and therefore can pose difficulties in effectively tracking changes over time. For example, an RHI health score of 11 per cent is clearly much worse than an RHI health score of 57 per cent, yet both would be reported as **"unhealthy."** Therefore, **average** RHI scores were the key variable selected for reporting on riparian health and its change/trend over time. Average scores allow for a more thorough integration of numbers into a single indicator and a more comprehensive understanding of the data and trends behind the resulting summaries, while reducing the number of data points for reporting and communication purposes.

The city-wide baseline average RHI riparian health score was calculated as **area-weighted** average geostatistics, where larger riparian polygons have a stronger proportional influence on the average compared to smaller polygons. The basic formula applied was:

$$(\Sigma〖((\%\text{ RHI Score of polygon}(a))\text{x }(\text{polygon area }(a)(\text{ha})))+((\%\text{ RHI Score of polygon}(b))\text{x }(\text{polygon area }(b)(\text{ha}))),\ldots.〗)/(\text{Total Area of All RHI polygons (ha)})$$

Average RHI scores for the different river systems (Bow, Elbow, Nose/West Nose Creeks, Forest Lawn Creek) were also calculated using a similar process and reported on separately [14]:

$$(\Sigma〖((\%\text{ RHI Score Bow River polygon}(a))\text{x}(\text{polygon area}(a)\ (\text{ha}))〗)+\cdots)/(\text{Total Area of RHI Identity Intersection for all Bow River Polygons (ha)})$$

Next, to summarize riparian health scores by mapped riparian management categories, the following process was applied:

1. Cows and Fish Riparian Health polygons were intersected with the Riparian Management Category Polygons in GIS (identity function).
2. Any data artefacts with no management category allocations due to small polygon mismatches on edges within the GIS, were removed from the statistical analysis.
3. For each individual management category (conservation, restoration, recreation, flood + erosion control, developed), the area-weighted average was calculated with a similar process, separated by management category:

$$(\Sigma〖((\%\text{ RHI Score Conservation polygon}(m))\text{x}(\text{polygon area}(m)\ (\text{ha}))〗)+\cdots)/(\text{Total Area of RHI Identity Intersection for all Conservation Polygons (ha)})$$

$$(\Sigma〖(\%\text{ RHI Score in each Restoration polygon}(x))\text{x}(\text{polygon area}(x)(\text{ha}))+\ \ldots..〗)/(\text{Total Area of Identity Intersection for all Restoration Polygons (ha)})$$

etc.

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[14] Again, it should be stressed that the results of this method represent only areas actually surveyed during the baseline time period, and these surveyed areas are only a sample of all riparian areas in the city, not a complete inventory.

Riparian health index: future targets To establish future riparian health targets, the following process was applied:

Baseline data were summarized city-wide, as well as for each riparian management zone and river system.

Observed changes/trends in riparian health, based on post-flood surveys conducted in 2014-2015, were calculated both city-wide and for each riparian management zone established (see table below).

Table 18. Observed changes/trends in riparian health

Riparian health index (RHI) monitoring variable	CITY WIDE	Conservation	Restoration	Recreation	Flood and erosion control
Total area assessed to date (ha)**	368	212	43	85	8
Baseline 2007-2010 riparian health inventories*					
Baseline area-weighted average RHI Score (%)	60%	65%	55%	52%	54%
2014-2015 Re-visit riparian health inventories					
2014-2015 area-weighted average RHI Score (%)	64%	69%	63%	55%	55%
Change in RHI scores from baseline	+4%	+4%	+8%	+3%	+1%
2026 Future target (based on extrapolation of trend)					
2026 future target (%)	70%	75%	74%	60%	54%
Change in RHI scores from baseline	+10%	+10%	+7%	+8%	0

*Excludes private residential sites and ELB25 (actively under renovation in 2015), ELB53 (nested within ELB26) and BOW75 (eroded entirely by the 2013 flood).

**As of Spring 2016

1. Observed improvements in riparian health scores and the reasons for those improvements, as documented in Cows and Fish (2016), were analyzed and summarized as follows:
   - City-wide, the area-weighted riparian health score improved by approximately four per cent over baseline.
   - 25 per cent of the 57 sites re-visited showed “improving” health scores (i.e., >5 per cent increase), including:
     - Several sites where recent restoration projects/plantings have improved riparian health.
     - Sites where the 2013 flood beneficially impacted riparian areas by stimulating new vegetation and/or depositing fresh sediment.
     - One site along West Nose Creek in what is now the Evanston Urban Reserve showed an improvement of the health score from 65 per cent in 2007 to 85 per cent in 2014, primarily due to a shift from in-land agricultural use to urban open space, which removed livestock trampling as a disturbance.
   - 72 per cent of re-visited sites showed a relatively static health trend (less than 5 per cent change in scores).
   - Only 2 sites (4 per cent of all sites) registered a “declining” health trend, with a greater than 5 per cent decrease in scores.
2. Building on observations, continued improving trends were predicted based on the following assumptions:
   - Post-flood natural riparian-vegetation recruitment is expected to continue.
   - Preferential targeting of priority areas for riparian health restoration projects will occur.
   - Community and public stewardship actions are expected.
   - Some flow ramping criteria applied to dam operations may be applied to help enhance recruitment.
   - Future construction and riverbank engineering projects will aim to minimize impacts and maximize bioengineering designs. However, flood protection berms and riprap installed in flood and erosion control zones are likely to have some impact on riparian health scores.

Plants slow water down and their roots grab soil, helping to reduce erosion and stabilize banks.

A sprouting willow.

Caveat on scale mismatches: RHI polygons versus management category polygons Riparian health surveys were generated based on field specialist assessments of average representative health conditions in relatively large field-surveyed polygons. When large polygons are subdivided into smaller areas based on the location of management categories, conditions in the smaller sub-areas may not necessarily represent average health scores assigned to the larger riparian polygon. Therefore, the riparian health scores assigned to the smaller polygons introduce mismatches between site-specific health conditions and the broader riparian health scores from field data. For the purposes of a city-wide assessment, this is not necessarily a major issue, and various site-specific errors will likely cancel one another out when city-wide averages are calculated, as long as the variance between polygon sizes is not large. However, the smaller the management category polygons are, the greater the likelihood that the value assigned by the field database does not accurately represent actual site conditions. This is an issue for categories represented almost entirely by small polygons, including the Flood + Erosion Control and Developed management categories. However, the total area of these polygons represents only 3.9 per cent of all riparian areas in Calgary. As such, the overall city-wide average is still considered to be a valid estimate.

Program area three: education and outreach monitoring protocols.

Indicator #4: Community is engaged with riparian areas (awareness, attitudes and actions) In partnership with a third-party research vendor, The City of Calgary conducted an online survey with a randomly selected sample of 750 adult Calgarians in 2016. The margin of error for a sample of n=750 is +/-3.6 percentage points, 19 times out of 20, and a credibility interval of +/3.7 percentage points. Quotas were set by quadrant, age and gender, and the final data was weighted to ensure it is representative of adult Calgarians based on census data. Questions will be measured bi-annually to track engagement trends within the general population.

The overall outcome of the education and outreach program is that stakeholders and citizens value riparian areas. A reasonable proxy measure for values are attitudes and actions related to riparian areas, as research shows that values underlie both (Stern, 2000; Stern, Dietz, Abel,

A healthy river depends on healthy riverbanks.

Plants help reduce the amount of sediment, pollution and nutrients reaching our rivers.

The Bow supports life in many forms.

Guagnano, & Kalof, 1999). Attitudes and actions are also derived from an awareness of the beneficial or harmful consequences to valued riparian spaces and, as such, are appropriate measures of the effectiveness of environmental education programming.

In total, three to four “ballot” questions form a baseline measure of community engagement with riparian areas. These include three questions related to awareness of healthy riparian areas and benefits, care for riparian areas and one question related to stewardship actions taken with the intent to benefit these areas. Citizen satisfaction related to The City's performance to protect and restore river areas will also be measured.

Programmers and community partners will also be asked to include these ballot questions (and a suite of standardized questions) in pre- and post-program evaluations to gauge progress before and after participating in education activities. This information will enable standardized program reporting and inform specific and broad-scale adaptations. It will also allow programmers to measure how participants trend against the general population.

Indicator #5: Community stewardship actions increase over time. While indicator data, such as polling, give us a sense of how Calgarians are progressing in terms of their levels of awareness and actions, actual community actions bring polling numbers to life and provide real examples of levels of engagement. As part of the conditions of agreement between The City of Calgary and community partners, organizations will be asked to annually report the number of stewardship events, actions and people who took part in their activities. The City will also track and report on its own stewardship programming. Partners will also be asked to report on the riparian spaces restored or stewarded by community groups or members. Similar program information is already tracked and compiled by the Water Resources education and outreach team.

Supplement Four: Riparian engagement planning

Audience: Water Resources Management, City Council, key stakeholders

To date, the project team and consultants have engaged dozens of key stakeholders both internal and external to The City of Calgary. This work has helped to identify the priorities and plans outlined within the Riparian Action Program and supported the development of new tools and frameworks related to riparian programming. Future engagement work will follow The City of Calgary's official Engage! [15] process and focus on raising awareness of the riparian program, defining roles and responsibilities and collaborating with internal and external stakeholders to develop the tools, processes and policy required to better support riparian
land-use planning, maintaining or improving riparian health and education.

The following supplement provides 1) a summary of key riparian policy gaps, 2) an overview of key engagement activities and 3) an overview of proposed future engagement.

Past stakeholder engagement

In 2013, a riparian areas workshop was held at The City of Calgary Water Centre. More than 45 attendees were present, including municipal planners and staff, regulators, watershed stewardship groups and partners. One of the workshop topics included the identification and discussion of riparian policy gaps for protection and management. Based on further consultations, key gaps were summarized, as shown in Table 17.

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15 The City's engage! policy is available at: http://www.calgary.ca/CA/city-clerks/Documents/Council-policy-library/CS009-engage.pdf

Table 19. Summary of key riparian policy gaps

Identified policy gaps	Planned policy responses/actions	
River and bank engineering design process		
Not enough guidance provided to civil and river engineers on appropriate locations for hard engineering riprap vs. bioengineering structures for stream/riverbank erosion control.	Riparian Decision Matrix for River Engineering Projects decision support tool was completed and released in October 2014. Intended to help promote more bioengineering projects by informing the scope of work for consultants designing riverbank engineering works.	✓
Land-use planning and policy		
Riparian and stream valley corridors are not fully protected in land-use planning processes.	Align plans, policies and regulations to ensure consistent, clear protection of critical riparian areas.	
The Municipal Government Act is open to interpretation on Environmental Reserve (ER) dedication for riparian areas, and ER Setback Guidelines (2007) do not protect all riparian areas.	Review the ER Setback Policy to provide greater clarity, including permitted and prohibited uses within different riparian zones.	
Multiple overlapping plans, policies and regulations create complexity and lack of clarity.*	Develop and apply clear guiding documents, flow charts and maps to ensure consistent interpretation and integration.	✓
Land Use Bylaw 1P2007 only prohibits new development in the mapped 1:100 year floodway and allows filling and development in the flood fringe and other riparian areas.	Identify riparian boundaries and adjacent setbacks in all new regional context studies, area structure plans, area redevelopment plans, outline plans, biophysical impact assessments (BIAs), master drainage plans, etc.	
Understanding riparian areas		
Long-term river landscape changes.	Identify meander belts/channel migration zones and add them to land use planning documents.	
Ephemeral and intermittent drainages: Disagreements between administration and development proponents on stream order mapping criteria and protection of ephemeral and intermittent watercourses.	Study and map ephemeral and intermittent watercourses and appropriate setbacks. Review the ER Setback Guidelines to increase clarity, using up-to-date information and data.	
No strong measures in place to consider and protect alluvial aquifer zones with strong connections to surface watercourses.	Where possible, use Environmental and Municipal Reserve dedications to protect alluvial aquifers in Local Area Plans.	

* See Supplement One of the Riparian Strategy for a full list of plans, policies and regulations related to riparian areas.

Key engagement activities

- December 2013: 23 experts engaged in a web survey.
- February 2013: 45 experts engaged in a World Café workshop.
- Spring 2014: Presentations by Water Resources at the Alberta Society of Professional Biologists conference (Edmonton, AB) and the Canadian Water Resources Association conference (Calgary, AB), as well as to Calgary River Valleys.
- 2014: More than 100 City of Calgary staff were consulted in various riparian-specific meetings and draft-document circulations. Participating departments/offices included:
  - Water Resources
  - Parks
  - Planning, Development and Assessment
  - Office of Sustainability
- 2015: More than 25 City of Calgary staff were consulted in Riparian Action Program engagement meetings to summarize program contents and report back on how their feedback was used.
- April 2015: Presentation by Water Resources at the Bow River Basin Council Science Forum, Mount Royal University, Calgary, AB.
- March 2016: 85 City staff attended presentations and workshop communicating program implementation plan to City staff
- June 2016: General citizen survey
- June - August 2016: Semi-structured interviews with watershed community groups
- September 2016: Stakeholder workshop with watershed community groups to present research and interview findings

Future engagement priorities

Future engagement work will focus on raising awareness of the riparian program, defining roles and responsibilities and collaborating with internal stakeholders to develop the internal tools, processes and policy required to support better riparian land-use planning, health and education. It is anticipated that specific work plan activities (i.e., review of the ER setback policy) will require extensive engagement with both internal and external stakeholders.

Climate Resilience Strategy

Mitigation & Adaptation Action Plans

Calgary **2018**

executive summary

The consequences of climate change are widespread and well known in Calgary, and include increasing frequency and magnitude of extreme weather events causing floods and outages. The inevitability of future climate change requires The City of Calgary (The City) to integrate climate resiliency across the organization to maintain the level of services and minimize costs.

The Climate Program evolved in several key areas over the past year including outreach and education, alignment with federal and provincial policy, risk integration into operations and services, and the development of strategies and actions. In-depth research and targeted stakeholder engagement was conducted in 2017 to establish baselines and analyze the risk and vulnerability of infrastructure, people and natural environment. Economic and greenhouse gas (GHG) modelling was also completed to identify GHG reductions and economic development opportunities. A vulnerability and risk assessment was conducted to provide the basis for City business units to identify the adaptive actions necessary to build climate resiliency for their infrastructure, operations and services.

The GHG modelling concluded that GHG emissions will increase in Calgary over time. When comparing low carbon development options with "business as usual" trends, research has found that the shift towards a lower carbon development path for Calgary is economically and technologically viable. Climate change also poses opportunities. Energy efficiency upgrades in buildings improve comfort and lower costs. These investments create jobs, especially for local businesses, while making the city more resilient to future shocks.

This report has three sections: The Climate Resilience Strategy (the Strategy), The Climate Mitigation Action Plan, and The Climate Adaptation Action Plan.

- The Strategy provides the main direction for Climate Resiliency in Calgary.
- The Climate Mitigation Action Plan identifies the role and actions of The City to ensure services, enabling activities, regulations and operations are provided to reduce emissions and enable the low carbon economy. The Plan identifies the actions in collaboration with stakeholders across the community and over the next one to two business cycles, and presents five themes (buildings and energy systems, land use and transportation, consumption and waste, natural infrastructure and leadership) that cover the largest areas of impact for emissions and energy in Calgary.
- The Climate Adaptation Action Plan identifies the risks and vulnerabilities from severe weather events and involves an iterative process of risk assessment. City business units identified a series of actions to manage the climate risks for Calgary grouped into a series of five themes (people, infrastructure, natural infrastructure, water management and governance).

The plans also contain the actions over the next ten years that will begin during the 2019 – 2022 business cycle. Alignment and integration with existing business planning processes was started in 2017 through the development of the two plans. In the spirit of One Calgary, each business unit will deliver on their clearly defined roles in the Mitigation and Adaptation Action Plans.

Climate resilience in Calgary requires combined and collaborative initiative by The City alongside a diverse cross section of industry, academia, environmental organizations and citizens. By the same token, actions to reduce GHGs and climate risks, must be taken in all parts of The City's administration. It will include finance and funding, collaboration with partners and the measurement of results.

2018 climate resilience strategy

contents

list of terms

Adaptation
The process and actions to manage the actual and projected climate impacts and risk to reduce the effects on built systems, the natural environment and people

ALT
Administrative Leadership Team

AQHI
Air Quality Health Index

BOMA
Building Owners and Managers Association

°C
Degrees Celsius

C40 Cities
The C40 Cities Climate Leadership Group connects more than 90 of the world's greatest cities, representing over 650 million people and one quarter of the global economy

CEMA
Calgary Emergency Management Agency

Climate
Weather conditions prevailing in an area in general or over a long period

Climate Risk
Risk resulting from climate change affecting natural and human systems

CO_2
Carbon dioxide is the most common heat-trapping (greenhouse) gas, released through human activities such as deforestation and burning fossil fuels, as well as natural processes such as respiration and volcanic eruptions

CO_2e
Carbon dioxide equivalent is a standard unit for measuring the contribution of different greenhouse gases such as methane and nitrous oxide, which have different warming effects on the atmosphere. The impact of each different greenhouse gas is expressed in terms of the amount of CO2 that would create the same amount of warming.

COP21
United Nations 21st Climate Change Conference of the Parties

CRAZ
Calgary Regional Airshed Zone

CTP
Calgary Transportation Plan

DALY
Disability Adjusted Life Year

ESM
Environmental & Safety Management

GHG
Greenhouse Gas is any gas in the atmosphere that absorbs infrared radiation, thereby trapping heat in the atmosphere

GHG Sink
An activity or process that tends to remove greenhouse gases from the atmosphere (e.g. planting trees)

GPC
Global Protocol for Community-Scale Greenhouse Gas Emission Inventories

IBC
Insurance Bureau of Canada

ICIP
Investing in Canada Infrastructure Plan

ICLEI
International Council for Local Environmental Initiatives

km/h
Kilometres per Hour

LRT
Light Rail Transit

MDP
Municipal Development Plan

Mitigation
The processes and actions that stabilize or reduce the greenhouse gas concentration in the atmosphere

mm
Millimetre

Mt
Megatonne

NRCan
Natural Resources Canada

NRTEE
National Round Table on the Environment and the Economy

OHS
Occupational Health and Safety

P&D
Planning and Development

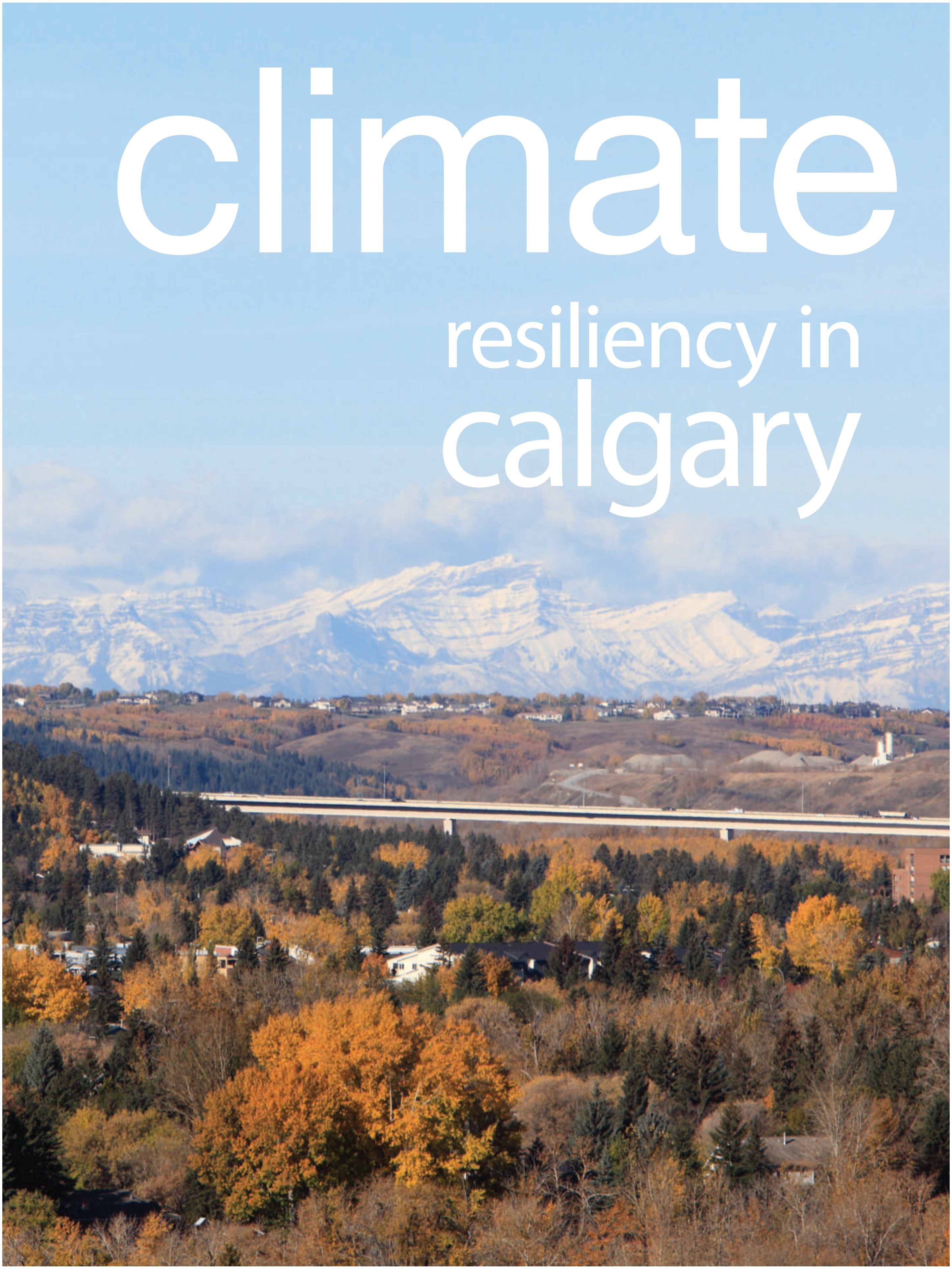
PV
Photovoltaic

RCPs
Representative Concentration Pathways are scenarios that describe alternative trajectories for carbon dioxide emissions and the resulting atmospheric concentration from the year 2000 to 2100. The RCPs describe 4 different scenarios from low to high, namely RCP 2.6, RCP 4.5, RCP 6 and RCP 8.5.

UNFCCC
United Nations Framework Convention on Climate Change

Urban Resilience
The capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow despite chronic stresses (e.g. water shortages) and acute shocks they experience (e.g. floods)

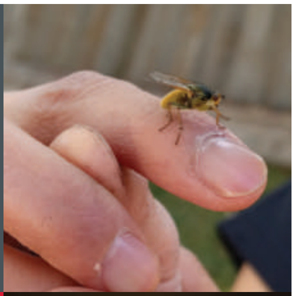
Weather
The state of the atmosphere at a place and time regarding heat, dryness, sunshine, wind, rain, etc.



climate

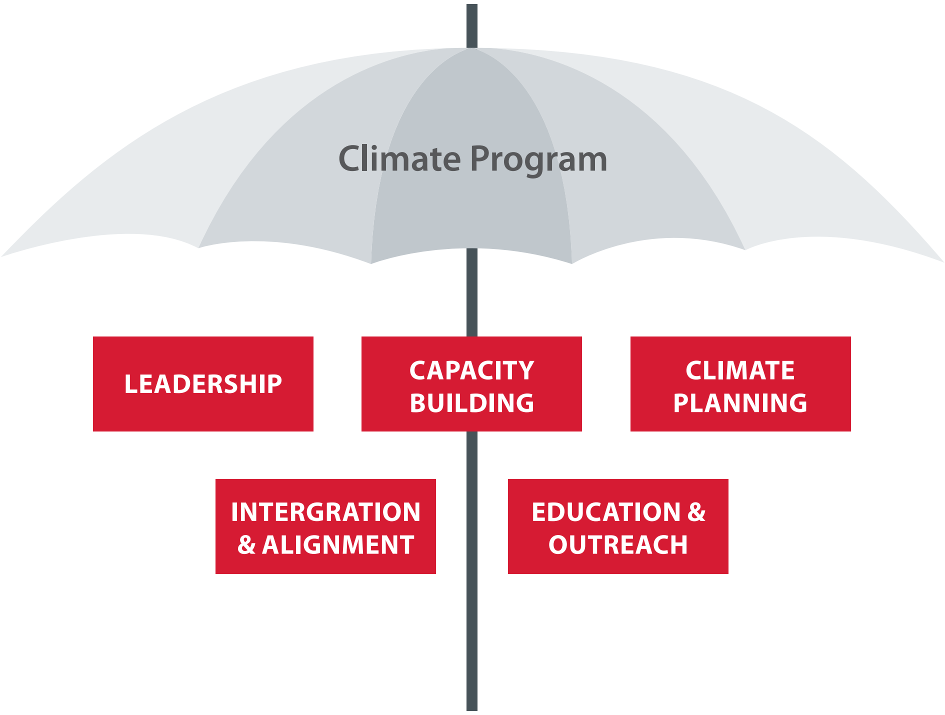
resiliency in calgary

1 the climate program



The Climate Program was developed in 2017 and is the broad administrative umbrella that provides strategic oversight to climate related activities at The City. It guides The City's compliance with current legislation, anticipated regulatory changes, and builds mitigation and adaptation considerations into existing and new plans, policies and projects. The Climate Program uses an approach that aligns with five key best practice areas in climate change planning for municipalities to ensure success (Figure 1).

FIGURE 1 – THE CLIMATE PROGRAM



a) **Leadership** – At The City, both Council and Administrative Leadership Team (ALT) are informed of the risks and opportunities related to climate change that will enable them to lead and make informed decisions. The Climate Program will, through research, communication and with corporate collaboration, ensure that Council and ALT are updated on the most relevant information available.

b) **Capacity Building** – Municipalities have competing priorities that require constant reprioritization to maximize resources and provide the services expected by the community. Staff and financial capacity should be continuously developed to ensure analysis, evaluation and recommendations are made that consider the risks of climate change and GHG emissions reductions. Vulnerability and risk assessment is done via cross-corporate collaboration. Consistent with risk management, responsibility for action lies with each business unit.

c) **Climate Planning** – Integrated long-term planning (the focus of this Strategy) provides strategic oversight to climate actions within The City and in the community. The principles will enable Council to determine the most valuable investment of the resources available to deliver services to Calgarians that will achieve Council's vision for Calgary. Climate Planning will include:

- A Strategy to guide decision-making for climate resiliency.
- A Climate Adaptation Action Plan identifying actions to reduce the impacts from the changing climate.
- A Climate Mitigation Action Plan to give direction on City and community GHG and energy management.

d) **Alignment** with various projects and processes including Connect 4, 100 Resilient Cities, City Charter and Legislative Change Strategy, to name a few, provides the legislative framework and opportunity to integrate climate resiliency into business planning and budgeting. Supporting external strategies through partner agencies such as Calgary Economic Development and industry stakeholders ensures broad alignment with economic initiatives.

e) **Public Awareness through Education and Public Outreach** provides a strong foundation for collaborative action. Public engagement and robust communications will be required to provide input into the development of a strategy that effectively coordinates the actions of both external and internal stakeholders. Research and targeted engagement will continue to occur to better understand perceptions, identify opportunities for future engagement and develop appropriate communication tools.

2 climate planning

– the climate resilience strategy

The aim of the Strategy is to maximize the resilience of Calgary in the context of a changing climate guided by local and global policy settings and specific mitigation and adaptation actions to address climate change.

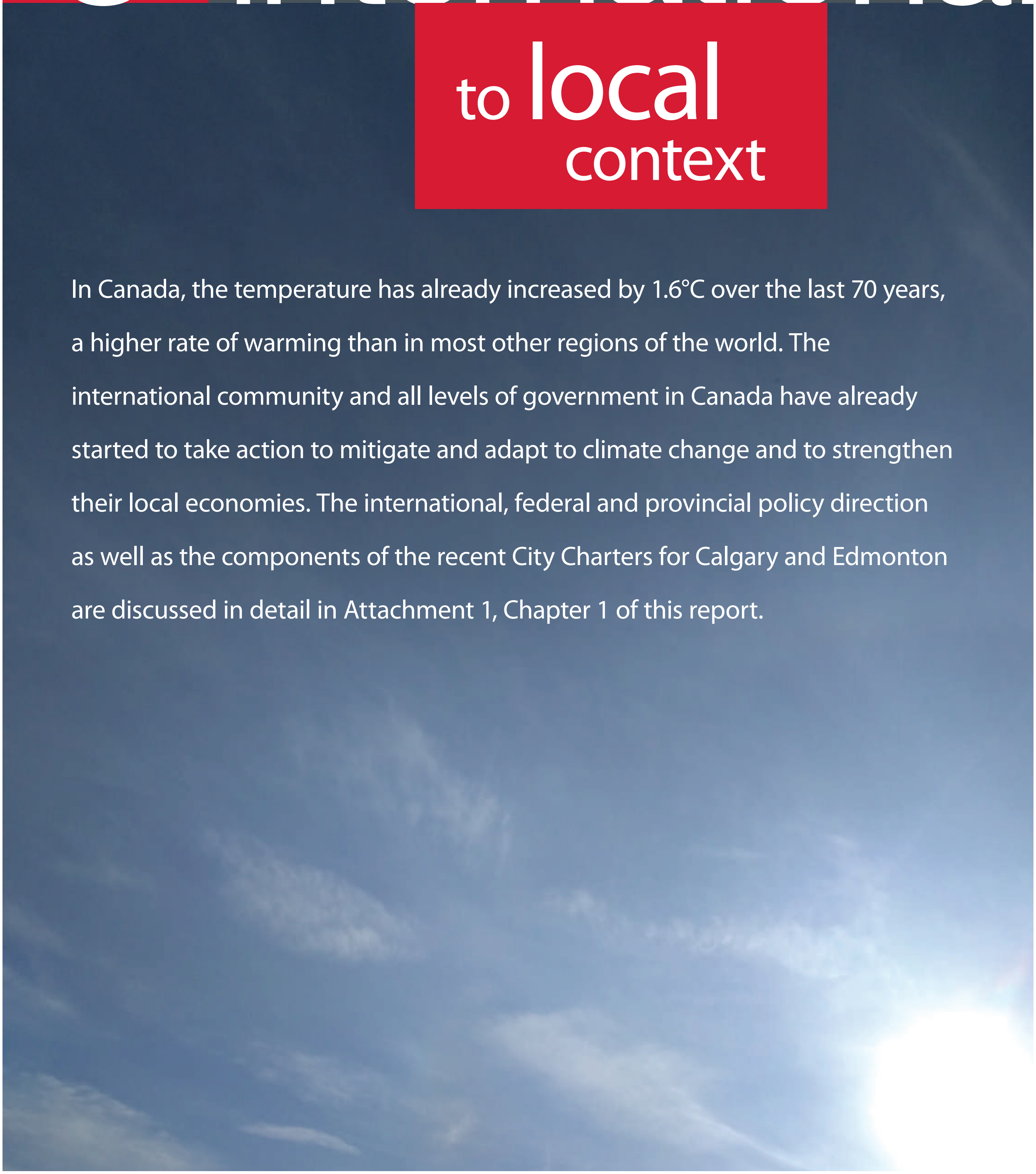
The Strategy will focus on supporting a low carbon future while reducing the impacts of a changing climate by:

- Defining The City's role in reducing GHG emissions, improving energy management, and adapting to the impacts of climate change
- Setting policy directions to guide implementation of the climate plans and actions
- Achieving long-term climate resilience objectives
- Setting out the next steps for implementation of climate resiliency by The City

The first phase (this Strategy and Plans) is to identify The City's role in ensuring continued efficient and effective services to Calgarians in a changing climate. In collaboration with the industrial, commercial and institutional sectors (Industry), it will also ensure that The City is able to foster a collaborative effort to transition to a low carbon economy.

The second phase of climate resilience is working directly with Calgarians to build capacity and provide choices to manage the impacts of severe weather events and to improve energy management and reduce emissions. It will also include the implementation of the actions identified in the first phase.

3 international to local context



In Canada, the temperature has already increased by 1.6°C over the last 70 years, a higher rate of warming than in most other regions of the world. The international community and all levels of government in Canada have already started to take action to mitigate and adapt to climate change and to strengthen their local economies. The international, federal and provincial policy direction as well as the components of the recent City Charters for Calgary and Edmonton are discussed in detail in Attachment 1, Chapter 1 of this report.

4 the challenge

The burning of fossil fuels and land use changes have released large amount of GHG's into the atmosphere that trap heat, and affect weather patterns and climate. The Earth's atmosphere today contains 40 per cent more carbon dioxide (CO_2) than 200 years ago.

Urban centres consume nearly 80 per cent of global energy and account for more than 70 per cent of global GHG emissions. The increase in GHGs is directly equated to the use of carbon-intensive energy for heating, cooling, building and transportation. Calgarians currently spend $2.6 Billion on energy each year, equating to 3 per cent of all money earned in the city. By 2030 this could rise to $6 Billion and 4 per cent of all money earned in the city through expected increases in energy prices and the growth of economic activity. Reducing emissions directly translates to reduced energy use and energy bills across the city.

As atmospheric GHG concentrations continue to rise at an increasing rate, some degree of climate change is inevitable, and extreme weather events such as droughts and rainstorms will become more frequent and intense worldwide. As a northern, cold-weather country, Canada will see its climate change more than the global average. From the Arctic sea ice cover melting, to rising sea levels on coastlines in Vancouver and Halifax, to extreme weather events experienced in Calgary – the higher rate of warming will bring unexpected changes.

The changing climate poses a serious risk to The City to deliver on its services to Calgarians. The consequences of climate change are widespread and well known in Calgary, including increasing frequency and magnitude of extreme weather events causing floods and service outages. The inevitability of future climate change means that preserving services and minimizing costs requires The City to consider and integrate climate resiliency across the organization.

5 the opportunity – climate resilience in calgary

As a member of the 100 Resilient Cities network, The City and its partners are striving to increase capacity of individuals, communities, institutions, businesses, and systems within the city to survive, adapt, and grow, no matter what kinds of chronic stresses and acute shocks are experienced. Climate resilience plays a critical part of Calgary's overarching resilience framework given how climatic disruptions impact many aspects of Calgary's operations and services.

Economic opportunities – The City, and Calgary residents and businesses could significantly enhance their energy security through investments in energy efficiency and low carbon options. Calgary's green economy is growing. There are already more than 15,000 Calgarians employed in this sector, from transportation to green buildings and energy efficiency in the commercial sector. In a recent study conducted by Calgary Economic Development, it was reported that this industry already brings in more than $3 Billion of investment into Calgary. By investing in a low carbon, cost-effective economy, we not only generate jobs, but also keep investments in energy (fuel, energy efficiency and electricity) local.

Risk management – Climate change is a risk multiplier. Floods, hail storms, extensive heat days and more frequent and intense storms all have an impact on our services and operations.

There are many reasons for an organization, particularly a municipality, to enhance resiliency and adaptive capacity in the face of climate change. Canada's National Round Table on the Environment and the Economy (NRTEE) suggested that action is justified for three reasons (adapted):

1. Doing nothing would expose an organization's assets, services, customers and employees to the full force of extreme weather events and climate change, as well as increasing GHG emissions and rising energy cost. It impedes the ability to meet organizational objectives and the expectations of investors, customers, employees and taxpayers.
2. Canadians who depend on municipal services have a growing expectation that decision-makers will take climate change into account when planning, building and operating infrastructure to maintain services into the future.

3. While significant risks will arise from climate change, adaptation measures could also create new opportunities for job growth and prosperity, such as drought resistant tree breeds, and innovative engineering solutions. Communities expect opportunities for growth and prospects to be realized.

For NRTEE, the key to success in managing risks and seizing opportunities in a changing climate is an agency's ability to raise awareness, assess and manage risks and opportunities, and build resiliency across the enterprise. While these action areas are largely internal, agencies are encouraged to also share best practices and work in partnership with external stakeholders.

The Global Commission on the Economy and Climate reported that well designed policies in resource efficiency, low carbon infrastructure investment and stimulating low carbon innovation will make growth and climate objectives mutually reinforcing both in the short and medium term. In the long term if climate change is not tackled, growth and prosperity itself will be at risk.

Being prepared is key in providing the services Calgarians need and rely on, to continue the quality of life they have here in Calgary. Strengthening the role of The City in climate resilience equips the corporation with tools and actions to address climate change risks, seize the opportunity and support the community.

6 from vision to actions

The City of Calgary has a long history of developing actions to reduce emissions and build resiliency to climate change. To manage the effects of climate change effectively, a coordinated approach is required that will result in effective management practices, business and budget prioritization and strategic oversight. From vision to actions, the strategy aligns with The City's direction toward resilience and sustainable future.

The City's **Vision** sets the primary direction for all systems, plans and actions. To build a city's resilience, systems will be designed and function in a way to withstand, respond to, and adapt more readily to shocks and stresses. The transition to a climate resilient city will require a clear view of the ideal future state.

The **Principles**, approved by Council on March 21, 2018 (C2018-0340) will guide the mainstreaming of climate-specific decision-making into policies, programs and projects. The Climate **Goals** stipulate the key aspects to achieve over time to reach the 2050 **Target** of 80 per cent reduction in GHG emissions.

Vision	A great place to make a living, a great place to make a life
Principles	Five guiding principles for climate resilience
Goals	• Reduce vulnerabilities and risks to severe weather and long-term climate effects • Improve energy use and reduce GHG emissions • Support the low carbon economy
Target	80 per cent GHG reduction by 2050

The City's role in climate change involves enabling a culture of climate resiliency actions which are supported through regulation, service provision, enabling activities, and leadership. Integrating climate specific decision-making into policies, programs and projects ensures that The City services and operations are safe guarded against risks related to climate change and make use of opportunities. Guiding Principles enable the integration of climate resilience into decision-making. They create a line of sight for Council and Administration between climate risk reduction and effective service provision.

GUIDING PRINCIPLES FOR CLIMATE RESILIENCY

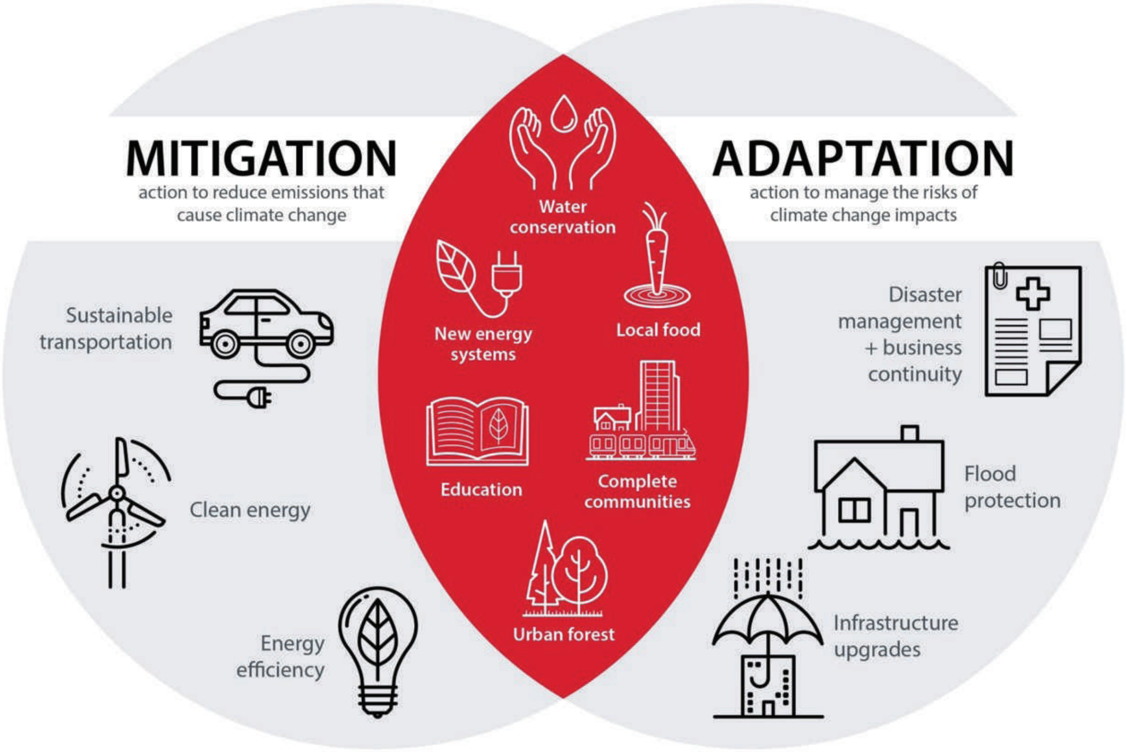
Innovation	The City will play an active role in the process of climate innovation.
Inclusiveness	The City will involve multiple stakeholders in planning and implementation at a city, regional and inter-governmental scale.
Integration	The City will integrate both mitigation and adaptation considerations in all investments to improve energy use, reduce GHG emissions, reduce disaster risks and strengthen resilience for future climate conditions.
Relevance	The City will develop locally-relevant solutions to address local climate-risks and vulnerabilities, and low carbon energy opportunities.
Commitment	The City will provide strong governance to assess and sustain progress, adequately fund and ensure ongoing meaningful partnerships.

The main climate-resilient actions, described in Figure 2, are emission reduction and managing climate risks.

- Mitigation means reducing GHG emissions through better energy management (e.g. conservation and efficiency), implementing renewable energy projects, and supporting a low carbon economy.
- Adaptation means coping with an uncertain future and taking measures to reduce the negative effects of climatic changes.

Mitigation and adaptation actions need to be designed to mutually benefit each other, as effective mitigation can reduce climate impacts and therefore reduce the level of adaptation required by communities. Many mitigation actions also help to adapt to climate change, such as natural infrastructure, naturalization of green spaces, and neighbourhood scale renewable energy generation.

FIGURE 2 – MITIGATION AND ADAPTATION



6.1 The climate mitigation action plan

The Climate Mitigation Action Plan for Calgary (Attachment 1) identifies the role and actions of The City to ensure services, enabling activities, regulations and operations are provided to reduce emissions and enable the low carbon economy. These are only the first steps. The Plan identifies the actions in collaboration with stakeholders across the community and over the next one to two business cycles, and presents five themes that cover the largest areas of impact for emissions and energy in Calgary. Ten programs focus on the specific outcomes to be pursued, and the actions are shown as the first steps in the process. The identified program areas and actions will focus on GHG emissions reductions that can be achieved in the following themes: Buildings and Energy Systems, Transportation and Land-use, Consumption and Waste, Natural Infrastructure and Leadership.

THEME		PROGRAM
	Buildings and Energy Systems	• Energy Performance standards in new and existing buildings • Energy consumption information • On-site and neighbourhood scale renewable and low carbon energy systems
	Transportation and Land Use	• Electric and low-emissions vehicles • Low or zero-emissions transportation modes • Land-use and transportation planning
	Consumption and Waste	• Consumption and waste reduction • Waste management to minimize greenhouse gas emissions
	Natural Infrastructure	• Green spaces and natural areas to support mitigation
	Leadership	• The City of Calgary as a leader in climate change mitigation

6.2 The climate adaptation action plan

The Climate Adaptation Action Plan for Calgary (Attachment 2) identifies the risks and vulnerabilities from severe weather events to City services and operations. It involves an iterative process of risk assessment. Based on the vulnerability and risk assessment done for the most severe climate impacts in Calgary, City business units identified a series of actions to manage the climate risks for Calgary. The actions are grouped into a series of five themes that reflect the interdisciplinary and comprehensive nature of climate change adaptation.

THEME	PROGRAM
People: A city where people can thrive Reducing Calgarians' vulnerability to the impacts of climate change	• Air Quality Management • Extreme Heat Management • Staff and Citizen Outreach
Infrastructure: The backbone of the city Strengthening the built environment to 'weather the storms'	• Backup Power for Critical Infrastructure • Design Standards and Practices
Natural Infrastructure: The root of resilience Maximizing the services provided by natural systems	• Natural Assets Management • Natural Assets Adaptation
Water Management: Every drop counts Preparing for increasing risks of flooding, drought and declining water quality	• River Flood Management • Stormwater Management • Long Term Water Supply
Governance: Pro-active leadership Preparing for our climate-altered future through collaborative decision making	• Budgeting and Investment Priorities • Urban Planning and Processes • Severe Weather Response and Recovery Management

A wide variety of adaptation actions, ranging from low cost and easily implementable projects, to larger and more complex projects, is to be initiated over the next five years (2018 to 2022), with feasible and "no-regret" actions first.

7 the way forward

There is a growing awareness and acknowledgement that climate resilience is the responsibility of all levels of governments, industry, businesses, and citizens working collaboratively. Climate resilience in Calgary requires combined and collaborative initiative by The City alongside a diverse cross section of industry, academia, environmental organizations and citizens. By the same token, actions to reduce GHGs and climate risks, must be taken in all parts of The City's administration. It will include finance and funding, collaboration with partners and the measurement of results.

Alignment and integration with existing business planning processes already started in 2017 through the development of the mitigation and adaptation plans. Over 200 staff were involved in developing the actions with sign-off from directors.

On May 15, 2018 (ALT2018-0537) The City's Administrative Leadership Team provided direction to Administration to support the Climate Resilience Strategy and Action Plans, and to consider them in One Calgary service plans and budgets.

Each of the Plans contain their own sections for implementation. This section outlines the overarching aspects for Climate Resilience including governance, budget and investment, timing, measurement and reporting that will be coordinated and implemented by Environment & Safety Management (ESM).

7.1 Governance

The processes utilized to develop the Climate Mitigation and Adaptation Action Plans created the foundation for implementation through a transparent and collaborative approach. The building blocks for such a collaborative approach include but are not limited to evidence-based decision making that include climate modelling and appropriate energy and GHG reduction measures, risk management and the inclusion of asset management. Meeting the climate resilience objectives will require:

- Prioritization of climate resilience as an ongoing, elevated strategic priority at The City including appropriate resources for implementation
- Alignment of City strategy, policy, regulation, and procedures
- Integrated decision making and responsibility embedded across departments
- Collaborative action from The City, industry and citizens

Building on existing models for climate governance, a group will be established to bring together key organizations and actors from across The City and from the public, private and third-party sectors. ESM will work with partners and City business units to establish the following objectives:

- Seek to be an independent voice in the city, providing authoritative advice on steps towards a low carbon, climate resilient future to inform policies and shape the actions of local stakeholders and decision makers.
- Monitor progress towards meeting The City's climate resilience goals to keep on track
- Advise on the assessment of the climate-related risks and adaptation opportunities in the city and on progress towards climate resilience.
- Foster collaboration on projects that result in measurable contributions towards meeting The City's GHG reduction targets and the delivery of enhanced climate resilience.
- Promote best practice in public engagement on climate change and its impacts to support robust decision-making.
- Act as a forum where organizations can exchange ideas, research findings, information and best practice on GHG reduction and climate resilience.
- Generate a report that will feed into the annual reporting of the Climate Resilience Strategy to Council.

ACTIONS:

Participating Business Unit:
Environmental & Safety Management

- **Work with industry to establish a Climate Resilience group that will aim to meet the above-mentioned objectives.**
- **Apply the Climate Resilience Principles as part of the implementation of actions.**

7.2 Planning and investment

There are many opportunities to embed climate resiliency measures through business planning, investment and operating cycles. Managing risks when resources are constrained involves balancing the expense of higher design standards against the costs of an asset failing. Investment decisions require integration of risk trade-offs, and may be constrained by the status of a given project (i.e. between conception and construction). It is generally easier, less costly and less disruptive to build resiliency into a capital project in the planning stages, compared to incorporating resiliency into the construction phase.

Existing infrastructure can be problematic because it has been designed and constructed for a past or present climate, and may not be resilient to future climate conditions. New infrastructure provides an opportunity to embed lifelong resiliency into its design, operation and maintenance; doing so may require designing and building to higher standards, or embedding flexibility into the design so future adjustments can be made cost-effectively when climate conditions change.

The Federal Government's "Investing in Canada Infrastructure Plan" (ICIP) is a twelve year, over $180 Billion national infrastructure funding plan that includes a proposed requirement to use a climate lens. The scope includes all the streams in ICIP, plus the Disaster Mitigation and Adaptation Fund. Under the Climate Lens, municipalities will be required to:

- Assess GHG emissions associated with the asset, including a Business-as-Usual or baseline assessment;
- Report on GHG emissions associated with the asset, including a quantification of any reductions achieved;
- Assess climate risks associated with the asset;
- Define their locally determined risk-tolerance; and
- Report on measures taken to address stated climate risks.

The City has already started to integrate the resilience decision-making into infrastructure investment. The City's capital investments should be managed in a way which provides maximum value to the community. An integrated and coordinated approach to capital planning, prioritization and funding, administered at the corporate level, refines investments, identifies efficiencies and achieves economies of scale. The City's Corporate Capital Infrastructure Investment Criteria incorporates climate resilience criteria and aligns with Federal guidelines. The work currently underway will ensure that specific criteria, including mitigation and adaptation, are applied when projects are proposed for capital investments.

ACTIONS:

Participating Business Unit:
Environmental & Safety Management

- **Evaluate and support opportunities for climate resilient budgeting, investment and efficiencies.**
- **Develop tools to support decision-making in mitigation and adaptation for business units.**

7.3 Funding

Capital and operating funding will be required to implement the Climate Plans. Several funding programs from the Provincial and Federal Governments have been used in the past to secure infrastructure investment. A range of opportunities exist for cities to collaborate and invest in climate resilience. Coordinating and directing these funding opportunities for climate resilience enables The City to target actions and work collaboratively with industry.

Regional and national governments control a range of incentives and financing that both directly and indirectly affect cities. For example, energy efficiency standards for buildings and vehicles are often defined at the national level. Similarly, financing of major municipal infrastructure investments such as mass transit projects is also often controlled by regional or national governments. These types of large infrastructure investments lay the foundation for more efficient, productive, and accessible cities.

Procurement strategies. Cities and networks of cities can influence the supply of energy efficiency or GHG reduction products and services by communicating a near-term increase in demand to manufacturers and providers. They can also collaborate with private companies to foster innovative solutions for citizens, industry or The City of Calgary.

Innovative financing approaches. Cities have developed creative ways to finance infrastructure investments including debt financing, public–private partnerships, and land value capture. Other cities are increasingly exploring green bonds.

The private sector will play a critical role in the ability of cities to achieve emission reductions and improve energy management in buildings, industrial processes, and waste, but they also stand to benefit. Many of the actions building owners can take will pay back quickly in lower utility bills, but barriers include cash constraints for the up-front investments, and split incentive problems where building owners invest but their tenants benefit. Financing solutions (both from private as well as public providers) can help overcome the initial investment hurdle.

ACTIONS:

Participating Business Unit:
Environmental & Safety Management

- **Explore innovative funding and financing opportunities**
- **Evaluate and coordinate external funding for climate resilience initiatives as per the Climate Mitigation and Adaptation Action Plans**
- **Foster new ways to procure innovation that will increase climate resilience**

7.4 Timeline

The Climate Resilience Strategy will consider a long-term view of climate change that overlaps with various business management cycles such as the four-year business planning and budget cycle, lifecycle management, maintaining the state of good repair, and capital investment planning.

Budgets and resources are applied where a combination of design and operations over the planning horizon would generate the most cost-effective outcome to reduce risk and increase resiliency and adaptive capacity. Good examples of this work would be flood resiliency and the proposed investment in corporate energy management.

Moving beyond the average lifespan of infrastructure (2100) will ensure that infrastructure investments are based on multiple bottom lines. 2050 is a key date that aligns with the international community and major private companies to reduce emissions, structure investments, measure and report. Allocating budgets and directing resources into business management cycles could follow several approaches, ranging from: incremental decisions and improvements on a continuous basis; transformative, proactive and anticipatory measures that result in an immediate upgrade in design standards; or delaying transformative change until monitoring determines that such action is necessary.

The One Calgary process (business and budget planning 2019 – 2022) describes several modules for the creation of service-based budgets and business plans. Mitigation and adaption actions were created and integrated by business units to support the service lines. Some of the climate resilience actions are currently underway such flood mitigation and electric vehicle charging network, while other actions have been newly identified based on the vulnerability and risk assessment or by industry and The City to enhance the low carbon economy and reduce GHGs. These and other ongoing actions will be included and presented by business units as part of the One Calgary process. Many actions are also being implemented as a result of anticipated Federal and Provincial guidelines and regulations.

Necessary actions from previously approved plans were initiated or continued in 2018. Major new actions will be brought to Council as part of One Calgary in November 2018 for action in the next budget cycle. The remaining new actions will require either further analysis and development of new business cases before they can proceed, or require new sources of capital or operating funding.

City business units will review new information and actions in advance of the 2023 – 2026 business cycle for potential implementation. Many actions identified in the plans will involve further engagement with internal and external stakeholders, which will be conducted by the participating business unit.

ACTIONS:

Participating Business Unit:
Environmental & Safety Management

- **Ensure the timely delivery of programs and projects**
- **Embed the Climate Resilience, Climate Mitigation and Climate Adaptation Actions in One Calgary submissions**

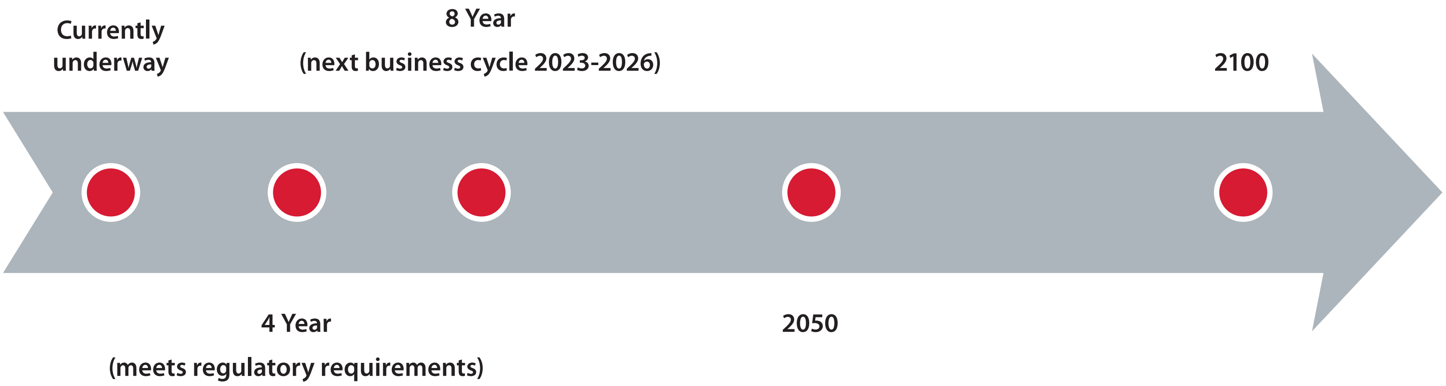
7.5 Monitoring and reporting

An important part of this Plan is to monitor, measure, report and publicly communicate Calgary's progress in implementing the actions of the Climate Resilience Strategy and Climate Mitigation and Climate Adaptation Action Plans. Efforts to build resiliency would benefit from a common reporting protocol and information repository. The City, in collaboration with its partners, will monitor progress. The City will report annually, and learn from experiences, insights, and from others. Unplanned or disruptive changes and unforeseen circumstances, such as shocks and stresses, will shape our approach, including amongst other impacts, energy price changes, climatic changes, technological developments and funding availability, all of which will be considered in future recommendations and updates.

ACTIONS:

Participating Business Unit:
Environmental & Safety Management

- **Develop and update measures for climate actions where possible with relevant agencies and partners**
- **Report annually on the progress of the Climate Plans to Council**
- **Regularly review and update Climate Plans one year in advance of the four-year budgetary cycles**
- **Include climate resilience analysis (vulnerability and emissions) as part of risk reporting**



Calgary

Climate Mitigation Action Plan
for Calgary

Attachment 1

executive summary

Calgary's local climate is already changing. The trends demonstrate that our current trajectory for greenhouse gas (GHG) emissions poses risks to our economy, environment and collective health. The longer we wait to begin decreasing emissions, the more drastic and severe the climate change impacts will become, and the more expensive it will be to reduce emissions to safe levels and recover from extreme events.

Climate mitigation is the reduction of GHG emissions through better energy management (e.g. conservation and efficiency), implementing renewable energy projects, and supporting a low carbon economy. The key purpose of the Climate Mitigation Plan is to provide direction for The City on how to address GHG emissions.

The Council approved GHG reduction targets of 20 per cent below 2005 levels by 2020 and 80 per cent below 2005 by 2050 represent the emissions reductions necessary to limit global temperature increase to less than 2°C warming. Between 2005 and 2017, Calgary's overall GHG emissions have increased. This trend indicates the need to focus on emissions in Calgary and it is one of the primary drivers for the creation of the Mitigation Action Plan for Calgary.

Within Calgary, energy use in buildings, primarily electricity, accounts for approximately 65 per cent of the GHG emissions community-wide, and this sector represents major opportunities for emission reductions. Transportation generates about a third of Calgary's GHG emissions through the use of diesel and gasoline. To reduce vehicle emissions there are three broad approaches: switch vehicle fuels to a cleaner, lower carbon vehicle fuel; switch to transportation modes that use less energy; and build city infrastructure to minimize travel distances.

Modeling by the Leeds University and the University of Calgary for the Climate Mitigation Action Plan has shown that between 2018 and 2050 Calgary could reduce its baseline emissions by 70 per cent through cost neutral investments that could be adopted at no net cost to the city's economy if the benefits from cost effective measures were captured and re-invested in further low carbon measures. An economically and technologically viable transition to a low carbon Calgary is entirely possible. Calgarians can immediately benefit from their efforts to reduce emissions. Energy efficiency upgrades in buildings save money, improve comfort, and lower housing costs for families. These investments create jobs, especially for local businesses, while making the city more resilient to future shocks.

The Climate Mitigation Action Plan actions proposed to be undertaken over the next one to two business cycles were identified in collaboration with stakeholders across the community. Five themes (buildings and energy systems, transportation and land use, consumption and waste, natural infrastructure, and leadership) cover the largest areas of impact for emissions and energy in Calgary. Ten programs focus on the specific outcomes to be pursued, and the 69 actions are the first steps in the process.

Climate change mitigation is a continuous process, with this plan acting as a starting point for The City. Successful implementation will require participation and engagement across all business units/service lines, as well as collaboration with community stakeholders in order to successfully achieve Calgary's climate resilience objectives.

Progress on the Climate Mitigation Action Plan will be reported annually. This report will be presented to Council, and will be publicly reported through the Carbon Disclosure Project.

THEME		**PROGRAM**
	Buildings and Energy Systems	1. Energy performance standards in new and existing buildings 2. Energy consumption information 3. On-site and neighbourhood scale renewable and low carbon energy systems
	Transportation and Land Use	4. Electric and low-emissions vehicles 5. Low or zero-emissions transportation modes 6. Land-use and transportation planning
	Consumption and Waste	7. Consumption and waste reduction 8. Waste management to minimize greenhouse gas emissions
	Natural Infrastructure	9. Green spaces and natural areas to support mitigation
	Leadership	10. The City of Calgary as a leader in climate change mitigation

2018 climate mitigation action plan

contents

chapter 1

climate mitigation

Scientists, business leaders and heads of government around the world are in agreement: climate change is one of the most serious challenges facing society today. Our climate is projected to become more unpredictable and extreme, posing significant risks to our communities, health and well-being, economy and the natural environment. Calgary's climate is already changing.

Climate Resilience means taking action to reduce Calgary's contribution to the problem of climate change, while also adapting our City to be better able to withstand the shocks that already know will occur. In the Climate Resilience Strategy, The City of Calgary uses new research results to better understand, reduce, and prepare for the impacts of a changing climate. This research takes a close look at the energy use forecast to 2050 and identifies cost-effective opportunities for shrinking Calgary's energy budget and GHG emissions. This new information supports better decisions about investment and the benefits we can expect through our actions.

Climate mitigation is the reduction of GHG emissions through better energy management (e.g. conservation and efficiency), implementing renewable energy projects, and supporting a low carbon economy.

Calgary and Climate Change

Over the past century, Alberta's average temperature has increased by 1.4°C, with most of that increase occurring since 1970. One or two degrees may not sound like much but prior to the industrial revolution this scale of temperature change occurred over thousands of years. A global rise of just a couple degrees has a big impact on our climate and weather.

Weather records show that the number of heat waves in the province has doubled since 1950, and this trend is forecast to increase over time. Calgary is projected to become drier during the summer, but wetter during autumn, winter and spring. During winter, precipitation could fall as heavy snow or rain, with the potential for ice storms in Calgary like those more common in eastern Canada. The potential for major river flooding, like the 2013 flood, or local flooding due to intense storms will also increase.

The trends demonstrate that our current trajectory poses risks to our economy, environment and collective health. The longer we wait to begin decreasing emissions, the more drastic and severe the climate change impacts will become, and the more expensive it will be to reduce emissions to safe levels and recover from extreme events. Over time, responding to these extreme events will undermine The City of Calgary's ability to maintain high quality services and infrastructure.

Past Work

The City has a long history of addressing climate change, from planning and preparation, to mitigation and adaptation, through to recovery. In 1994, Calgary was one of the first cities in Canada to participate in Partners for Climate Protection, a network of Canadian municipal governments committed to developing emission reduction plans.

In October 2009, Calgary was among nine members of the World Energy Cities Partnership to sign the Calgary Climate Change Accord. These cities committed to being environmental leaders and catalysts for change by utilizing official policies and plans to reduce municipal GHG emissions.

To meet the challenges of the Calgary Climate Change Accord, in November 2011, City Council adopted the Calgary Community GHG Reduction Plan. The Plan provides in-depth measurement of city-wide emissions sources and outlines actions with proven results in other jurisdictions for reducing those emissions. As part of the plan, Council also approved reduction targets of:

- 20 per cent below 2005 levels by 2020
- 80 per cent below 2005 levels by 2050

These targets apply for both corporate and community-wide GHG emissions. The plan also identified the potential for GHG reductions in Calgary, and the initial steps to make progress towards implementation.

A Changing Policy Context

The framework in which Calgary operates is in transition due to actions by governments, communities and business to limit the increase in global temperatures and adapt to a changing climate.

INTERNATIONAL POLICY DIRECTION

In December 2015 at the 21st Conference of the Parties (COP21), Canada was among 195 countries that agreed on the Paris Agreement within the United Nations Framework Convention on Climate Change. The key objectives of the Paris Agreement include:

- a goal to limit the increase in global temperatures to well below 2°C and pursue efforts to limit the rise to 1.5°C
- a commitment to achieve net-zero emissions, globally, by the second half of the century
- differentiated expectations for developed nations, including Canada, that they will reduce their emissions sooner than developing nations
- a five-year review and ratchet process which is likely to lead to more ambitious commitments from countries in the future.

FEDERAL POLICY DIRECTION

In December 2016, Canada's federal government released the Pan-Canadian Framework on Climate Change. This framework aligns Canada's actions with that of the international community through COP21. The framework recommends several policy planks that support climate change mitigation, these include:

- Model Energy Requirements for existing buildings by 2022[1]
- Model Net Zero Energy Ready Codes for Homes and Buildings by 2022[2]
- National Online Platform for Labelling and Sharing Energy Use Data[3]
- National Zero-Emissions Vehicle Strategy by 2018[4]

Additionally, the federal government also introduced a mandatory floor price on carbon of $10 per tonne of carbon dioxide equivalent (CO_2e) in 2018, rising to $50 per tonne CO_2e in 2022. A price on carbon will be imposed on those provinces that either do not adopt a carbon pricing system or fail to meet this federal minimum price of carbon.

PROVINCIAL POLICY DIRECTION

In November 2015, the Government of Alberta announced its Climate Leadership Plan. This plan focuses on reducing GHG emissions and energy use. Key elements of the plan are:

- Carbon Levy: $20 per tonne CO2e (2017), $30 per tonne CO_2e (2018)
- Financial support for energy efficiency, infrastructure GHG reduction
- Phasing out emissions from coal-generated electricity by 2030 and developing more renewable energy

Further details of the levy were provided in June of 2016 with the approval of Bill 20 – the Climate Leadership Act. The purpose of the Act is to influence the choices of energy users by imposing a price on carbon across all sectors. In addition, financial support will be provided for energy-efficiency measures, green infrastructure development and GHG emission reductions.

CITY CHARTER FOR CALGARY AND EDMONTON

The City of Calgary and the City of Edmonton have negotiated with the Government of Alberta to establish City Charters, which will be enacted as regulations under the Municipal Government Act in Spring 2018. A City Charter is a legislative tool that gives cities greater flexibility and authority intended to cover a range of issues from simple administrative efficiencies to complex regulatory changes.

The City Charters for Calgary and Edmonton will enable the cities to modify or replace provisions in the *Municipal Government Act* or any other provincial Act or regulation, where the province has specifically granted it authority to do so. City Charters also include a collaboration agreement to support ongoing, long-term coordination between the two cities and the Government of Alberta. Environment and climate change has been identified as one of three policy and planning tables for ongoing collaboration.

Within the charters, there are enabling provisions that allow The City of Calgary to enact regulations that were not previously allowed under the *Municipal Government Act* in helping to achieve climate change objectives. The Charter requires that The City undertake the creation of climate change adaptation and mitigation plans by 2020.

chapter 2

emissions inventory & projections for calgary

The City measures and reports on city-wide greenhouse gas emissions every year and follows the Global Protocol for Cities to guide our emissions reporting. This means that we report on all energy used within Calgary's boundaries in buildings (heating, cooling, lighting and power), and in the transportation systems (diesel and gasoline). The inventory also reports methane emissions from The City's waste and wastewater treatment facilities.

Current Emissions

Energy is used in Calgary by households, businesses, and organizations to heat and power buildings, to provide services, and to move goods through and around the city (see Figure 1). Within Calgary, energy use in buildings accounts for approximately 65 per cent of the GHG emissions community-wide, and this sector represents major opportunities for emission reductions. Transportation generates about a third of Calgary's GHG emissions. Waste-related emissions are a combination of organic waste decomposing in municipal landfills and wastewater processing at Calgary's wastewater treatment plants, accounting for 1 per cent of Calgary's total.

Another way to report on Calgary's emissions is by fuel type (see Figure 2). In Calgary, electricity consumption accounts for 42 per cent of total GHG emissions. While electricity in Alberta is heavily reliant upon fossil fuels, Alberta's electricity grid is projected to improve, particularly as coal-powered generation is phased out. In 2016, 47 per cent of our power was supplied from coal, 40 per cent from natural gas, and the remaining 13 per cent from renewable sources. [5]

Natural gas is the main heating fuel for almost all buildings in Calgary. Natural gas use accounts for 24 per cent of total community-wide GHG emissions.

Buildings are the source of roughly two-thirds of emissions by sector, and electricity is currently the largest contributor within those buildings. Gasoline and diesel consumption account for 20 per cent and 13 per cent of community-wide GHG emissions respectively. Taken together, vehicles contribute about a third of Calgary's overall GHG emissions.

Between 2005 and 2017, Calgary's overall GHG emissions have increased by 2.5 megatonnes (Mt) CO_2e (a 16 per cent increase). The upward trend over this period can be seen in each sector individually in Figure 3. In that time Calgary's population has grown from 955,998 to 1,246,231 and the city's overall geographic footprint has expanded. The GHG reduction targets of 20 per cent below 2005 levels by 2020 and 80 per cent below 2005 by 2050 represent the emission reductions necessary to limit global temperature increase to less than 2°C warming and have been adopted by cities around the world. In Calgary, these reductions correspond with absolute targets of 12.6 Mt CO_2e in 2020 and 3.2 Mt CO_2e in 2050. The most recent year-end data for 2017 indicates that Calgary's current GHG emissions of 18.3 Mt CO_2e are about 5.7 Mt CO_2e above the target for 2020, and 15.2 Mt CO_2e above the target set for 2050. This trend indicates the need to focus on emissions in Calgary and it is one of the primary drivers for the creation of the Mitigation Action Plan for Calgary.

CONSUMPTION-BASED EMISSIONS

Some potentially significant sources of emissions are not reported in our current inventory. Consumption-based accounting of emissions (i.e., both the direct and indirect emissions due to consumption of goods and services in a specific jurisdiction) encompasses the full lifecycle emissions of goods and services: production, pre-purchase transportation, wholesale and retail sale, use, and post-consumer disposal. For example, the emissions that are embedded in the products we use (e.g., food or clothing) are not currently accounted for in our inventory.

Research in other leading municipalities shows that consumption-based emissions can as much as double the total community-wide GHG inventory. This is significant, and actions have been identified later in this plan to begin to quantify the impact of consumption-based emissions in Calgary.

FIGURE 1 – CALGARY COMMUNITY-WIDE GHG EMISSIONS BY SECTOR (2017)

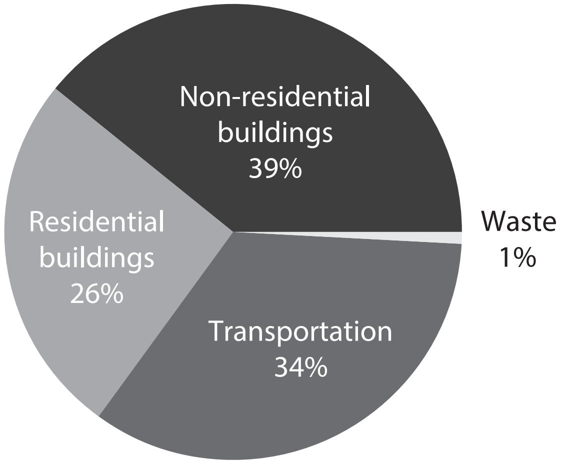


FIGURE 2 – CALGARY COMMUNITY-WIDE GHG EMISSIONS BY ENERGY TYPE (2017)

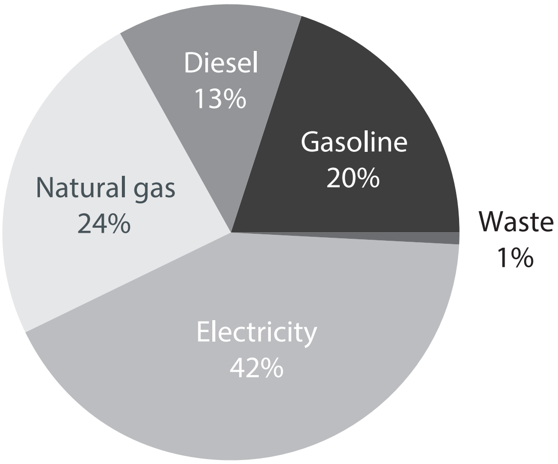
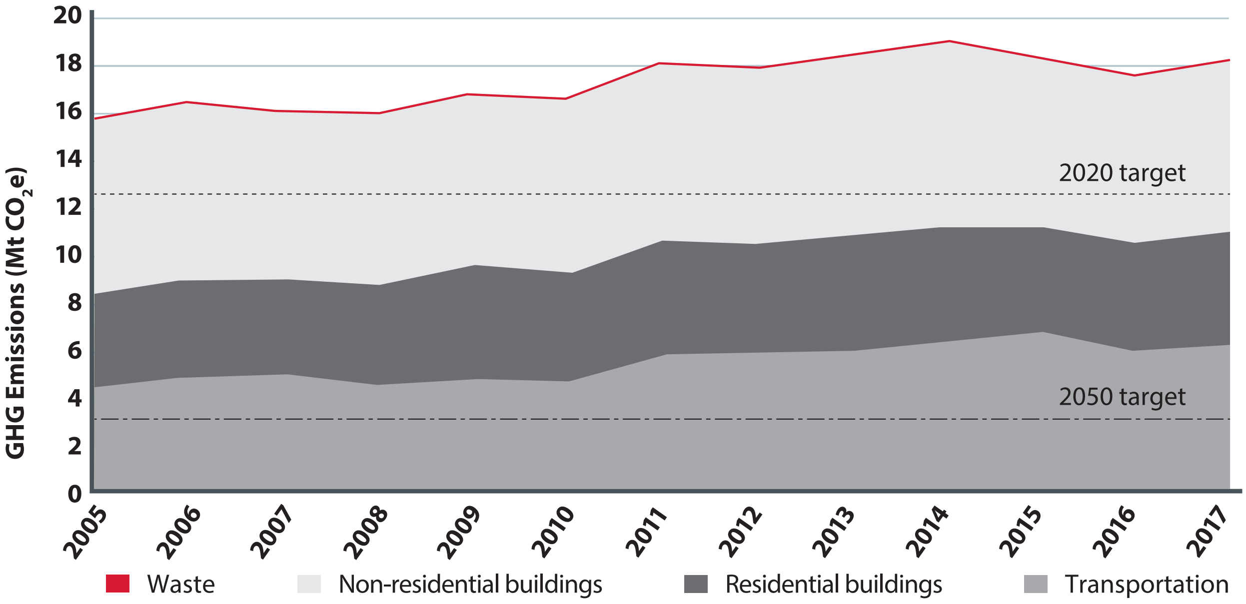


FIGURE 3 – HISTORICAL CALGARY COMMUNITY-WIDE GHG EMISSIONS (2005-2017)



The Challenge and Opportunity

Calgary is a city of more than one million people, with a gross domestic product of more than $100 Billion a year and total annual expenditure on energy of $2.6 Billion per year. On the path to GHG reductions, energy plays a dominant role. Our city's population is growing and is projected to increase by 1.3 per cent on average annually until 2050. Historically, as population grows, so too does demand for energy.

The University of Leeds and University of Calgary in 2018 published a report entitled "The Economics of Low Carbon Development: Calgary, Canada" [6]. It examines the economic case for Calgary switching to a more energy efficient and lower carbon development path, and it provides both economic and broader evaluations on the desirability of different options and pathways. The evidence base generated is intended to provide policymakers, businesses and individuals in Calgary with reliable, locally relevant evidence so that they can take informed decisions on how best to switch to a lower carbon development path.

At a macro-level, the evidence shows that there is a strong economic case for switching to a lower carbon development path in the short to medium term, and that doing this would enable Calgary to be on track by 2030, but it also highlights some significant longer-term challenges in reaching Calgary's 2050 target. Preparing to meet these challenges in the short to medium term could significantly improve the chances and reduce the costs of meeting them in the longer term.

To inform the discussion on how Calgary could shape its future energy use and GHG emissions, the report assesses a long list of the measures that a range of actors in Calgary could take. Ranging from changing light bulbs to rebuilding offices, this analysis assesses the cost and GHG implications of single actions and of programs of action that could be implemented across the city. Individually, many of these actions have only a small impact on energy use and GHG emissions. Collectively, however, the findings show that thousands of small actions, and some broader programs, could generate massive savings in cost and GHG emissions, with significant additional impacts in areas such as job creation, cleaner air, reduced energy poverty, and improved mobility.

The report highlights both the opportunity presented to Calgary, and the challenges that need to be overcome if the opportunity is to be taken. Low carbon measures can require large investments, coordination between policymakers, businesses, and individuals, and changes to the ways in which we live and work. However, the analysis shows that the benefits of many actions can far outweigh the costs. A low carbon future for Calgary will not just improve the global climate, but bring economic and social benefits to the lives of Calgarians.

The report established the following projections for Calgary:

Baseline – The baseline scenario is what Calgary's emissions are projected to be with no action beyond business-as-usual. The baseline scenario is projected out to 2050 by combining (1) data on historical trends in Calgary's prosperity, energy use and GHG emissions, (2) population and economic growth projections, (3) provincial-level GHG emissions and energy price projections to 2050, and (4) a base assumption that Calgary's Municipal Development Plan (MDP) targets are achieved.

Cost-neutral – The cost-neutral scenario identifies the GHG reductions that can be achieved with no net negative effect on the economy. This scenario assumes deployment of all measures that could be afforded if the benefits from the cost-effective measures were captured and reinvested in further low carbon options. This scenario achieves the largest GHG reductions with the internal rate of return for the scenario remaining greater than zero.

Figure 4 shows that between 2018 and 2050 **Calgary could reduce its baseline emissions by 70 per cent** through cost neutral investments that could be adopted at no net cost to the city's economy if the benefits from cost effective measures were captured and re-invested in further low carbon measures.

This would require cumulative investment of $113 Billion, generating savings of up to $5.6 Billion per year. Using net present values, the investment is paid back in 17 years with savings continuing over the lifetime of the measures still in place. Nearly 860,000 job-years could be generated by investing in cost neutral options. [7] See Table 1 below for sectoral breakdown, potential reductions and economics of Cost Neutral projections.

FIGURE 4 – CALGARY'S POTENTIAL FUTURE EMISSIONS UNDER THE BASELINE AND CARBON REDUCTION SCENARIOS

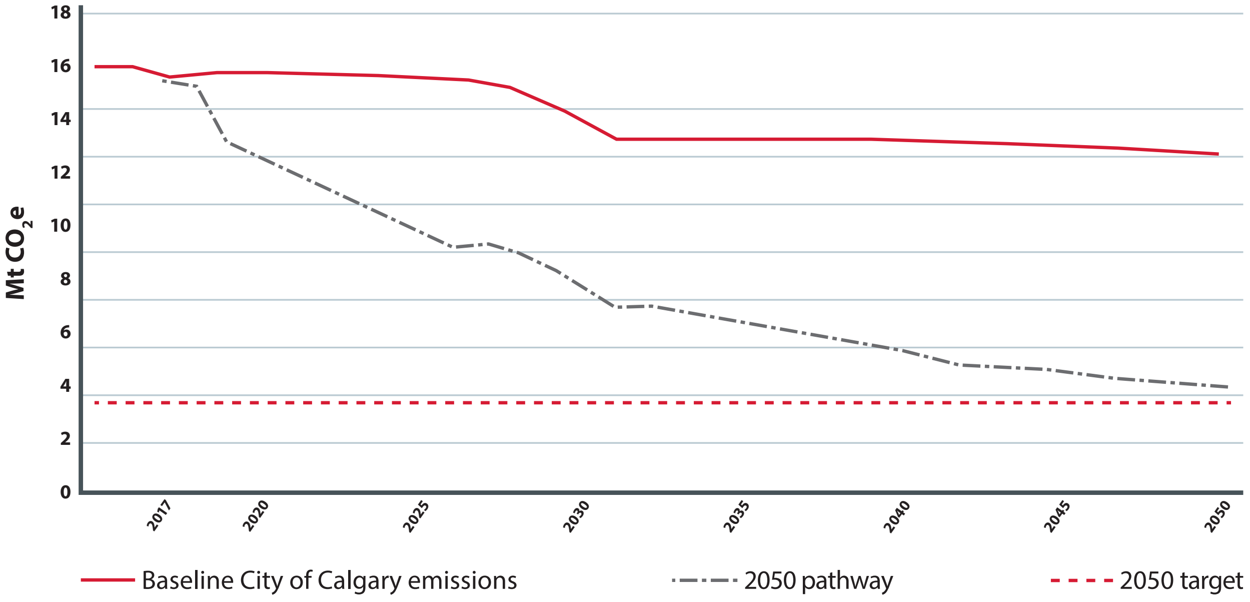


TABLE 1 – POTENTIAL REDUCTIONS AND ECONOMICS OF COST NEUTRAL PROJECTIONS

Category	Total potential GHG reductions to 2050 (Mt)	Total Investment (Billion $)	Annual Energy Savings (Billion $)	Total Job Creation Potential (Thousand job years)	Payback period on original investment (Years)
Residential	129	32.8	1.4	427	23
Commercial	76	6.9	0.5	69	13
Industrial	10	5.8	0.176	4	24
Transportation	63	59.9	3.2	291	18
Distributed Energy	24	7.5	0.27	67	15
Total Potential	**302**	**112.9**	**5.6**	**858**	**17**

When comparing low carbon development options with "business as usual" trends, the report found that the shift towards a lower carbon development path for Calgary cannot be dismissed on technical or economic grounds. An economically and technologically viable transition to a low carbon Calgary is entirely possible.

Despite the anticipated progress that will be made in reducing emissions due to the greening of Alberta's electricity sector, the strength of the local economy and sustained population growth will continue to drive emissions in Calgary. The Climate Mitigation Action Plan for Calgary is moderate in its level of ambition but it puts in place actions that will start to decouple population and economic growth from overall emissions. However, further aggressive action will be required along the way to guide Calgary to a low carbon future. Though the task of GHG reductions seems daunting, the analysis in this report has shown that it is possible to get Calgary on the right trajectory to meet our targets.

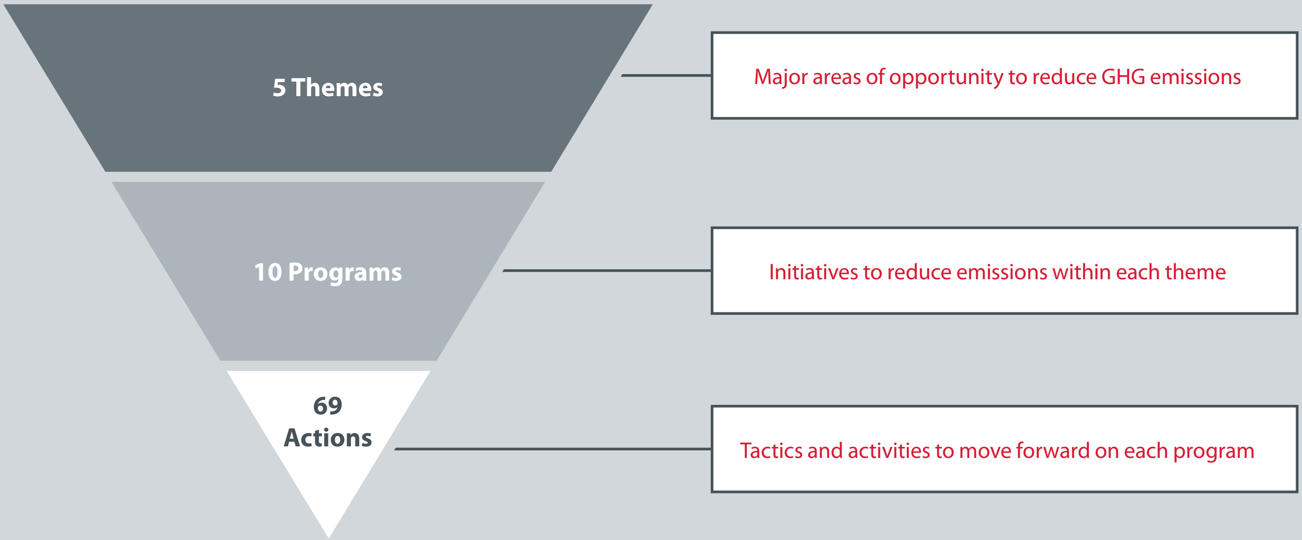
chapter 3

climate mitigation themes & actions

Setting the Path to a Low Carbon Calgary

PLAN STRUCTURE

The Climate Mitigation Action Plan for Calgary identifies the top actions to be undertaken over the next one to two business cycles to make progress to reduce emissions. Internal and external stakeholders reported to The City that these are the best opportunities to begin the transition of a low carbon future. The work is presented in five themes that cover the largest areas of impact for emissions and energy. Ten programs focus on the specific outcomes to be pursued, and the 69 actions become the first steps in the process.



5 Themes

Major areas of opportunity to reduce GHG emissions

10 Programs

Initiatives to reduce emissions within each theme

69 Actions

Tactics and activities to move forward on each program

These actions will result in both immediate and cumulative reductions in emissions from buildings, transportation, materials management, process emissions and industrial process sources. Although actions will need participation by all stakeholders across the community to achieve our GHG reduction targets, this plan focuses on actions that can be undertaken by The City directly through our roles: regulation, enabling activities, service provision, and operations. The relevant City business units identified a series of actions that will start to turn the curve on greenhouse gas emissions in Calgary.

PARTICIPATING BUSINESS UNITS

For each program, there is a list of actions with one or more Participating Business Units identified as the implementer of each action. In general, the Participating Business Unit is responsible for most actions within the program, but are also responsible for coordinating actions occurring in other business units. Each action also has a funding status and a specific timeline for implementation.

FUNDING

Each of the programs include a wide variety of mitigation actions, ranging from low cost and easily implementable projects, to larger and more complex projects. For new actions, ESM will support other City Business Units as they develop new business cases and detailed funding requirements for these actions. Approved business cases will be submitted to One Calgary budgeting process in 2018 for a coordinated allocation of corporate funding through future business plan and budget updates.

CITY ROLE

While climate change is a global issue, cities play a crucial role in tackling climate change. Each level of government has a different level of jurisdiction and different tools to turn the curve in the right direction.

This plan is focused on The City's role to reduce city-wide greenhouse gas emissions. As a municipal government, The City can directly and indirectly influence city-wide emissions in four key ways:

- **Operational Control:** This is where The City has direct ownership over the initiatives, from capital and service delivery including the type of fuel we use in City vehicles to the how we build or the reduction of energy use in buildings to the design of roads to withstand severe flooding and heat exposure.
- **Educate, Inform, and Encourage:** These are creative and intelligent programs to support improved energy management behaviours and decision-making as well as actions that provide information and choice e.g. working with the Insurance industry and other cities on best practices for industry and home owners with regards to severe weather events. Helping citizens with information on buying storm resistant shingles for their roofs.
- **Influence:** These are actions where The City can promote and support the desired energy management opportunities and climate risk reduction (e.g. collaborating with other levels of government on policy design) or programs such as energy labelling.
- **Regulation:** The City uses its jurisdictional powers to ensure a clear path toward energy management, carbon reduction, risk reduction, and societal benefits. It is also the place where The City complies with provincial and federal mandated actions such as energy labelling or energy step codes.

TARGETED STAKEHOLDER ENGAGEMENT

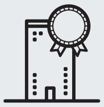
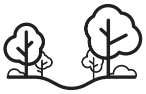
The City of Calgary established three external working groups with individuals representing industry, technical experts, academia, and the environmental sector to focus the top three areas to reduce greenhouse gas emissions in the community as listed in Table 2.

The working groups gathered for five workshops from June 2017 to May 2018 and contributed to all aspects of the Mitigation Action Plan, including shaping the technical analysis, offering stories and feedback about current challenges when working with The City to implement climate innovations, and developing the strategies, programs and actions contained within the Plan.

TABLE 2 – MEMBER COMPANIES OF THE CLIMATE CHANGE MITIGATION WORKING GROUPS

Buildings and Energy System	Land-use and Transportation	Consumption and Waste
• ATCO • Begin with Design • BILD Calgary • BOMA • Brookfield Residential • Canada Green Building Council • ENMAX Power • Flechas Architecture • KCP Energy • Mission Green Buildings • Morrison Hershfield • Pembina Institute • Southern Alberta Institute of Technology	• ATCO • BILD Calgary • Brookfield Residential • Calgary Airport Authority • Calgary Parking Authority • Canada Land Corporation • Car2Go • Electric Vehicle Association of Alberta • ENMAX Power • Federation of Calgary Communities • McElhanney Consulting Services • NAIOP • RKP Consulting • University of Calgary	• Alberta Food Processors Association • AWR Recycle • BILD Calgary • Blu Planet • Calgary Co-op • Green Calgary • Green Event Services • Leftovers YYC • Recycling Council of Alberta • University of Calgary

Themes and Programs

THEME		PROGRAM
	**Buildings and Energy Systems**	1. Energy performance standards in new and existing buildings 2. Energy consumption information 3. On-site and neighbourhood scale renewable and low carbon energy systems
	**Transportation and Land Use**	4. Electric and low-emissions vehicles 5. Low or zero-emissions transportation modes 6. Land-use and transportation planning
	**Consumption and Waste**	7. Consumption and waste reduction 8. Waste management to minimize greenhouse gas emissions
	**Natural Infrastructure**	9. Green spaces and natural areas to support mitigation
	**Leadership**	10. The City of Calgary as a leader in climate change mitigation

Buildings and Energy Systems

Energy use in buildings is the largest opportunity for GHG reductions in Calgary. From heating to cooling, from cooking to lighting, our buildings provide many energy intensive services. Natural gas and electricity used in Calgary's residential, commercial, institutional and industrial buildings make up almost 65 per cent of total emissions generated in the community. Improving the overall energy performance of buildings and making sure energy comes from clean, low-carbon sources are steps to reducing our emissions.

Investments in building energy efficiency and clean energy also present an unparalleled opportunity. By reinvesting in building stock and renewable energy systems, Calgarians will save money on utility bills, benefit from more comfortable and higher quality buildings, and support local job growth in the energy efficiency and clean energy sectors.

The actions within this theme are organized into three program areas:

- Energy performance standards
- Energy consumption information
- On-site and neighbourhood scale renewable and low carbon energy systems

Each program is explained in further detail below.

PROGRAM 1: ENERGY PERFORMANCE STANDARDS

Background

Energy performance standards refer to the minimum energy performance requirements that are regulated for new and existing buildings. Minimum energy performance standards for new buildings have been recently defined in the Energy Code, a subsection of the Alberta Building Code. This energy code has been in force since November 2016, and outlines both prescriptive and performance requirements for energy performance in new buildings. There are currently no energy performance requirements for existing buildings in any jurisdiction in Canada.

The federal government has indicated that there will be a strong push to continue to improve the energy performance standards of new buildings, and to begin to develop an energy code for existing buildings.

Natural Resources Canada has specified the following changes are expected to be brought forward in the building codes.[8] In particular:

- Winter 2018 Launch ENERGY STAR certification for commercial and institutional buildings.
- 2018 to 2019 Launch a new program to ensure that energy codes are implemented properly when they are adopted.

IMPROVE ENERGY PERFORMANCE STANDARDS IN NEW AND EXISTING BUILDINGS[11]

Building type	Total potential GHG reductions to 2050 (Mt)	Total Investment (Billion $)	Annual Energy Savings (Billion $)	Total Job Creation Potential (Thousand job years)	Payback period on original investment (Years)
Residential	129	32.8	1.4	427	23.4
Commercial	76	6.9	0.5	69	13.8
Industrial	10	5.8	0.176	4	24
Total Potential	**215**	**45.3**	**2.076**	**500**	**21.8**

- Winter 2019 Develop an online platform and framework for labelling and sharing home and building energy use data.
- Fall 2022 Publish additional tiers of Net Zero Energy Ready codes for buildings.
- Fall 2022 Publish model energy requirements for existing homes and buildings.

The provisions of the new Calgary City Charter enable The City to implement building code requirements beyond the current provincial building code. However, rather than utilizing this regulatory ability, this program focuses on supporting regulation at the provincial and federal level, and supporting energy performance beyond code through incentives and access to financing.

Why is this Priority?

Energy use in buildings makes up about 65 per cent of GHG emissions generated in the community.[9] The new provincial energy code ensures that new buildings' energy performance will improve, however, to meet our GHG reduction targets standards in Calgary must improve more quickly than the energy code currently dictates. Importantly, a significant portion of the buildings that will exist in Calgary in 2050 have already been built today. Approximately 50 per cent of buildings will still be in use in 2050, depending on Calgary's growth.[10] Energy performance of the existing building stock will need to improve through energy efficiency of equipment and conservation through improved building envelopes.

Even with a strong economic case for energy efficiency and improved energy performance, many residential and commercial building owners are not investing in better energy performance. Despite the economic benefits, there are other barriers to building or renovating buildings to improve energy performance. These actions attempt to reduce those challenges.

Potential emissions reductions and cost savings

This program examines opportunities to go beyond current energy standards for both existing and new buildings. The highlighted actions will assist to significantly reduce energy consumption by going beyond the existing energy codes, and by exploring innovative financing incentive and incentive programs.

What The City will do

The following actions have been identified as critical first steps to achieving improved energy performance standards in new and existing buildings. The actions are to:

Improve building performance requirements beyond current building code

1.1 Support the implementation of energy step codes for new buildings

Participating Business Unit: Calgary Building Services

1.2 Prepare Calgary for the implementation of a retrofit building code

Participating Business Unit: Calgary Building Services

Investigate incentives

1.3 Investigate policy approaches to provide monetary and non-monetary incentives to improve building performance.

Participating Business Unit:
Environmental & Safety Management
Calgary Building Services
Water Utility

Enable innovative financing mechanisms

1.4 Enable innovative financing mechanisms to fund improved energy performance.

Participating Business Unit:
Environmental & Safety Management

BOMA Best Certified Buildings (Commercial) also show other environmental benefits such as a 52 per cent reduction in water use, 18.7 per cent higher occupancy rate, 7 per cent higher tenant satisfaction score, and a 5.6 per cent higher lease renewal rate. [14]

PROGRAM 2: ENERGY CONSUMPTION INFORMATION

Background

Energy use is often invisible to energy users. Many citizens and commercial building managers are unaware of how much energy their everyday activities require. By making energy consumption information more readily available and easily understood, we help provide the tools to make better decisions about how energy is used in specific buildings, and we also allow better comparisons between buildings.

Currently, most people in Calgary only get information on how much energy their home or building uses through monthly utility bills. However, this information is often difficult to decipher, and may not be readily available when buying, selling or renting a home or commercial space. The difference in energy costs between buildings that appear similar on the surface can actually be quite significant. This program is focused on making energy information more readily available and more easily understood for all building types in Calgary.

Building labelling (for residential buildings) and benchmarking (for commercial buildings) are ways to make energy information publicly available. A building energy label is a way to give a score to a home's energy performance, based on an assessment. This score can be made publicly available, and can be useful in understanding the opportunities to improve the energy performance of the home, and can also be useful in comparing the energy efficiency of similar homes.

Similarly, energy benchmarking is a system for comparing the energy performance between similar buildings, for instance offices or retail stores in the commercial sector.

Other options for providing improved access to energy consumption information can include publishing energy performance maps or building information, or redesigning utility bills to promote energy conservation.

Natural Resources Canada has specified the following changes are expected to be brought forward in the building codes.[12] In particular:

- Winter 2018 Launch ENERGY STAR certification for commercial and institutional buildings.
- 2018 to 2019 Launch a new program to ensure that energy codes are implemented properly when they are adopted.
- Winter 2019 Develop an online platform and framework for labelling and sharing home and building energy use data.
- Fall 2022 Publish additional tiers of Net Zero Energy Ready codes for buildings.
- Fall 2022 Publish model energy requirements for existing homes and buildings.

The provisions of the new Calgary City Charter enable The City to implement building code requirements beyond the current provincial building code. However, rather than utilizing this regulatory ability, this program focuses on supporting regulation at the provincial and federal level, and supporting energy performance beyond code through incentives and access to financing.

Why is this Priority?

Understanding and managing the energy consumption in buildings is important for building owners and users to save energy and money in the long term, because buildings have a long service life.

Research has shown that simply increasing awareness of energy consumption can realize improved energy savings.

According to the Building Owners and Managers Association (BOMA) Best Certified Buildings (Commercial), a commercial building benchmarking program, registered buildings show on average a 15 per cent reduction in energy use. [13]

BOMA Best Certified Buildings (Commercial) also show other environmental benefits such as a 52 per cent reduction in water use, 18.7 per cent higher occupancy rate, 7 per cent higher tenant satisfaction score, and a 5.6 per cent higher lease renewal rate. [14]

Perhaps most significantly, these programs can achieve these emission reductions at a relatively low cost.

What The City will do

The following actions have been identified as critical first steps to achieving improved energy performance standards in new and existing buildings. The actions are to:

Improve building performance requirements beyond current building code

2.1 Develop a residential building labelling program for Calgary

Participating Business Unit:
Environmental & Safety Management

2.2 Develop a commercial building benchmarking program for Calgary

Participating Business Unit:
Environmental & Safety Management
Corporate Analytics & Innovation

Improve energy literacy and capacity building

2.3 Develop and publish energy consumption information for all stakeholder groups to improve energy knowledge and stakeholder capacity to capitalize on energy efficiency opportunities, and to improve The City GHG reduction program design

Participating Business Unit:
Environmental & Safety Management
Calgary Building Services

2.4 Partner with ENMAX and other energy retailers to expand the pilot of providing enhanced billing information to residential customers

Participating Business Unit:
Environmental & Safety Management

PROGRAM 3: RENEWABLE AND LOW-CARBON ENERGY SYSTEMS

Background

Reaching the city's emission reduction goals requires actions beyond increasing energy efficiency. On-site renewable energy systems and district energy systems are important strategies to transition away from fossil fuels. District energy systems, which supply heating and cooling to multiple buildings, can use waste heat and improve overall system performance. Renewables can provide a localized source of low carbon energy.

While energy efficiency measures and programs will be prioritized, replacing conventional energy sources with renewable and low carbon energy sources will eventually be required to meet The City's emissions reduction commitments. Each building owner will need to consider unique financial criteria, whether at the utility scale, neighbourhood scale, or within individual buildings. The City will encourage uptake of renewable and low carbon energy in Calgary by reducing barriers to implementation and supporting informed decision making for investment.

In 2015 to 2016, the Government of Alberta developed the Climate Leadership Plan.[15] This plan focuses on reducing GHG emissions and energy use. Key elements of the plan are:

- Carbon Levy: $20 per tonne CO2e (2017), $30 per tonne CO2e (2018)
- Financial support for energy efficiency, infrastructure carbon reduction
- By 2030, phasing out emissions from coal-generated electricity, and providing 30 per cent of Alberta's electricity from renewable sources
- The creation of Energy Efficiency Alberta that is providing subsidies for solar installations.

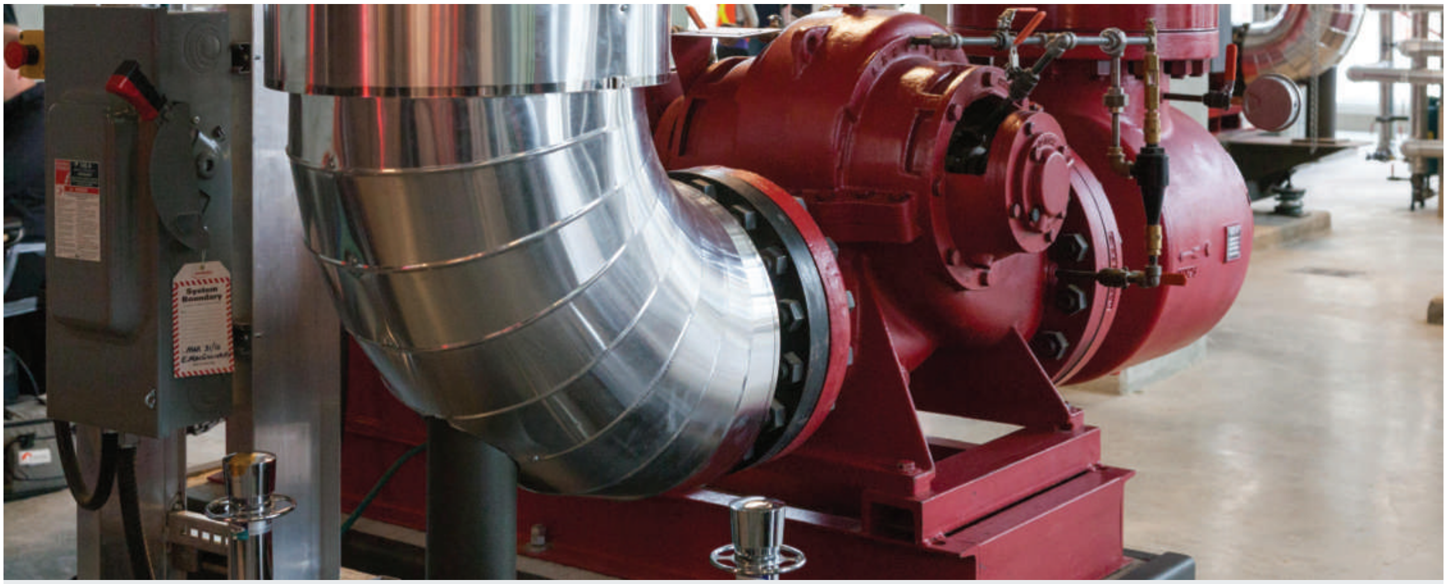
Why is this Priority?

Local and distributed low carbon and renewable energy helps to decrease GHG emissions and energy usage in buildings and neighbourhoods, thereby reducing energy costs and improving local resilience.

POTENTIAL EMISSIONS REDUCTIONS AND COST SAVINGS

Increase the implementation of on-site and neighbourhood scale renewable and low-carbon energy systems[16]

Total potential GHG reductions to 2050 (Mt)	Total Investment (Billion $)	Annual Energy Savings (Billion $)	Total Job Creation Potential (Thousand job years)	Payback period on original investment (Years)
17	7.5	0.27	67	15.0



What The City will do

The following actions have been identified as critical first steps to achieving improved energy performance standards in new and existing buildings. The actions are to:

Enable the implementation of onsite renewable and low-carbon energy systems

3.1 Develop an approach to ensure large scale developments consider the feasibility of low-carbon energy systems as part of the approvals process including: solar photovoltaics, combined heat and power, and district energy (and other technologies where appropriate)

Participating Business Unit: Community Planning
Corporate Analytics & Innovation

3.2 Support the implementation of solar photovoltaics

Participating Business Unit:
Environmental & Safety Management
Calgary Growth Strategies

3.3 Support the implementation of district energy systems

Participating Business Unit: Community Planning
Environmental & Safety Management

3.4 Support the implementation of combined heat and power

Participating Business Unit:
Environmental & Safety Management

Support alternative ownership models for renewable and low carbon energy systems

3.5 Support community ownership of renewable energy generation

Participating Business Unit:
Environmental & Safety Management

Transportation and Land-use

Where people live, work, and access amenities within Calgary impacts how they choose to get around Calgary. Currently, emissions associated with transporting people and goods account for one third of Calgary's emissions. [17] How we design our neighbourhoods and city have a significant impact on the need for energy to be used in moving goods and people around.

Emissions from the transportation sector come from the use of two main transportation fuels: diesel and gasoline. To reduce these emissions there are three broad approaches: switch vehicle fuels to a cleaner, lower carbon vehicle fuel; switch to transportation modes that use less energy; and build city infrastructure to minimize travel distances.

This theme is organized into three program areas:

- Electric and low-emissions vehicles
- Low or zero-emissions transportation modes
- Land-use and transportation planning

While reducing emissions and energy costs are the primary purpose of this plan, these initiatives can also provide a number of other community benefits. Residents who can meet many of their daily needs by walking, bicycling, or riding transit also benefit from improved health, thriving local business districts, and increased opportunities for diverse housing and jobs.

The details of these programs are outlined below.

PROGRAM 4: ELECTRIC AND LOW-EMISSIONS VEHICLES

Background

While many of the Plan's actions support the need to reduce auto travel, cars and freight vehicles will remain part of our transportation system. In addition, the number of transit vehicles and trips will grow. Therefore, it is important that we reduce the impacts of the remaining cars, buses, and trucks through cleaner vehicles and fuels.

The Government of Canada is currently in the process of creating Transportation 2030: Green and Innovative Transportation. Part of this initiative is the creation of a National Zero-Emissions Vehicle Strategy by the end of 2018. [18]

Why is this Priority?

Fuel switching for vehicles for both privately-owned and commercial fleets is the most significant opportunity to reduce emissions and energy costs in the transportation sector. Electric and hybrid vehicles are the leading technology for emissions reductions and cost savings for privately-owned vehicles, whereas commercial fleets may shift to renewable diesel, renewable compressed natural gas or electric.

Potential emissions reductions and cost savings

The most cost effective of these actions is shifting private vehicles owners to hybrid and electric vehicles.

Accelerate the shift to low emissions vehicles projections [19]

Total potential GHG reductions to 2050 (Mt)	Total Investment (Billion $)	Annual Energy Savings (Billion $)	Total Job Creation Potential (Thousand job years)	Payback period on original investment (Years)
60.3	59	3.2	291	18.4

What The City will do

The following actions have been identified as critical first steps to increase the implementation of low emissions vehicles. The key action areas are:

Support and enable the uptake of electric vehicles

4.1 Partner with the private sector and other government agencies to implement local and regional electric vehicle charging infrastructure

Participating Business Unit:
Environmental & Safety Management

4.2 Work with the private sector and non-profit organizations to develop an electric vehicle education program for the general public and businesses

Participating Business Unit:
Environmental & Safety Management

4.3 Collaborate with the City of Edmonton, the Province, local development industry and utility companies to identify and analyze options to improve access to home charging for electric vehicles

Participating Business Unit:
Environmental & Safety Management

4.4 Monitor and provide input to new electric vehicle policies and regulations developed by other orders of government

Participating Business Unit:
Environmental & Safety Management

4.5 Streamline municipal and utility processes to support public and private electric vehicle projects and reduce barriers

Participating Business Unit:
Environmental & Safety Management

4.6 Partner with post-secondary institutions and the private sector to advance research and field testing of low emission technologies, supporting infrastructure and policy direction

Participating Business Unit:
Environmental & Safety Management

Support and enable the uptake of low emissions vehicles in commercial fleets

4.7 Monitor and provide input to new medium- and heavy-duty low emission vehicle policies and regulations developed by other orders of government

Participating Business Unit: Transportation Planning

4.8 Develop a program to support the assessment of alternative fuel technologies for commercial vehicle fleets, and provide education information and emerging regulations from other orders of government

Participating Business Unit:
Environmental & Safety Management

4.9 Partner with post-secondary institutions to advance Calgary-specific research into goods movement GHG reduction and energy efficiency actions and supportive policies

Participating Business Unit:
Environmental & Safety Management

PROGRAM 5: LOW OR ZERO-EMISSIONS TRANSPORTATION MODES

Background

There are many choices for Calgarians to get around Calgary. It is The City's responsibility to provide transportation infrastructure for Calgarians that is convenient, affordable, attractive and safe. High quality transit, bike, pedestrian and car-pooling networks provide the underlying backbone of a low carbon transportation system. In recent years, The City has made much progress in this area. By continuing to prioritize safety, accessibility, and mobility for people to allow walking, cycling, and transit we can meet the needs of a growing population while significantly reducing emissions.

Why is this Priority?

Shifting Calgarians out of single-occupancy vehicles to lower or no emissions transportation modes is a key opportunity to reduce emissions. This strategy encompasses actions to directly shift Calgarians out of vehicles, or could more indirectly achieve this strategy through the development of higher-density complete communities.

Potential emissions reductions and cost savings

It is important to note that all Council approved actions in this sector such as the Calgary Transportation Plan, Route Ahead, the Cycling Strategy and the Pedestrian Strategy are included in the baseline calculations for this report. The potential GHG reductions for the aforementioned Council approved low or zero-emissions transportation modes are 15 Mt CO_2e by 2050.[20]

Accelerate the shift to low or zero-emissions transportation modes[21]

Actions Beyond Council approved actions (Municipal Development Plan, Calgary Transportation Plan, Route Ahead, Cycling Strategy, Pedestrian Strategy included in the baseline projections)	**Total potential GHG reductions to 2050 (Mt)**
Expansion of Transit (25 per cent coverage)	2.1
Carpooling	0.7
Expanded non-motorized transport (biking and walking)	0.2
Total Potential	**3.0**

What The City will do

The following actions have been identified as critical steps to shifting Calgarians to low or zero-emissions transportation modes. It should be noted that these actions have been previously approved by Council through the following strategies: Step Forward, Cycling Strategy, Complete Streets and Route Ahead Strategy. The actions are reiterated here to demonstrate the alignment with the climate change objectives of the Mitigation Action Plan. The key actions are:

Enable increased walking and cycling

5.1 Continue to implement Step Forward, the Cycling Strategy and Complete Streets

Participating Business Unit: Transportation Planning

5.2 Enhance the safety and accessibility of walking and cycling for all citizens

Participating Business Unit: Transportation Planning, Calgary Transit, Parks, Roads, Urban Strategies

5.3 Support the utilization of new and innovative bicycle technologies and programs

Participating Business Unit: Transportation Planning

Enable increased use of Calgary Transit

5.4 Continue to implement the RouteAhead 30-year strategic plan for Calgary Transit

Participating Business Unit: Calgary Transit, Green Line

5.5 Coordinate with regional transit partners to make transit service a more viable choice for regional travel

Participating Business Unit: Calgary Transit

5.6 Enable transit oriented development along the Green, Red and Blue LRT lines

Participating Business Unit: Planning & Development, Real Estate & Development Services

5.7 Increase implementation of transit priorities and yield-to-bus measures

Participating Business Unit: Calgary Transit

Enable increased use of ride-sharing, car-pooling, and working from home

5.8 Support businesses and the development industry to implement transportation demand management plans in new and existing communities or buildings

Participating Business Unit: Transportation Planning

5.9 Monitor demand for loading or special parking zones for commercial vehicles as well as demand for special parking zones for rideshare services

Participating Business Unit: Transportation Planning, Calgary Parking Authority

5.10 Pilot partner ships with alternative mobility providers to provide mobility services

Participating Business Unit: Calgary Transit

5.11 Develop a high occupancy vehicle strategy to support high-occupancy vehicles and buses, as well as consideration of electric vehicles

Participating Business Unit: Transportation Planning

PROGRAM 6: LAND-USE AND TRANSPORTATION PLANNING

Background

How we design our neighbourhoods has a significant impact on the energy needed to move goods and people around Calgary. The City can tailor plans and policies for existing and future neighbourhoods to reduce the impact of emissions and energy consumption. Through the policies of the Municipal Development Plan (MDP) and the Calgary Transportation Plan (CTP), it is possible to build low carbon planning into land uses and transportation system.

Why is this Priority?

Planning and policy decisions on land use, transportation, city infrastructure and services can exacerbate emissions and energy consumption in Calgary. Integrating climate change considerations into land-use and transportation planning decisions, strategies, plans and processes plays a crucial role in understanding the impacts of development in relation to emissions and energy use.

Potential emissions reductions and cost savings

It is important to note that all Council approved actions in this sector such as the MDP are included in the baseline calculations for this report. By 2050, if The City were to adhere to maintaining the MDP targets, Calgary could avoid 12 Mt of emissions, save $20 Billion dollars in avoided infrastructure costs and reduce energy bills by $91 Million annually.[22] The savings outlined in the table will be realized if we go beyond the current targets in the MDP.

Integrate climate change considerations into land-use and transportation planning and development decisions, strategies, plans and processes (beyond the current MDP)[23]

Total potential GHG reductions to 2050 (Mt)	Net Savings in Infrastructure (Billion $)	Annual Energy savings (Billion $)
7	9	0.046

What The City will do

The following actions have been identified as critical first steps to achieve GHG reductions in land-use and transportation planning. The key actions are:

6.1 Incorporate policies regarding climate risks and greenhouse gas reductions that may impact land use development and transportation infrastructure or services into the update of the Municipal Development Plan and Calgary Transportation Plan

Participating Business Unit: Calgary Growth Strategies Transportation Planning

6.2 Develop methodologies to integrate GHG reduction potential into growth management decisions and transportation assessments

Participating Business Unit: Calgary Growth Strategies Transportation Planning

6.3 Investigate the impact of disruptive transportation technologies on Calgary's transportation GHG emissions

Participating Business Unit: Transportation Planning

Consumption and Waste

The waste we create and how we dispose of it can have a significant impact on GHG emissions. Currently, our GHG inventory only accounts for methane emissions from our waste and wastewater facilities, which accounts for about 1 per cent of the GHG emissions in Calgary.[24] However, there are GHG emissions that are embedded in the products that we use and dispose of in Calgary. We don't currently measure these emissions, but based on analysis from other cities, embedded emissions could double the emissions that we account for in our inventory.

Recognizing that "you can't manage what you don't measure", this theme is focused on improving Calgary's measurement of consumption-based emissions, and reducing the creation of waste in the first place. Once waste creation has been minimized as much as possible, this theme area also aims to divert as much waste from our landfills as possible, particularly organic waste.

In recent years, The City has taken significant action in reducing GHG emissions from the waste sector by implementing a series of programs and actions surrounding waste reduction, recycling, GHG capture and composting. This plan aims to strengthen its commitment to reduce GHGs associated from waste emissions while starting to consider the embodied GHGs from the goods and services we consume.

Actions in this theme are organized into two key programs:

- Reduce overall consumption and waste generation
- Waste management to minimize greenhouse gas emissions

Each program is explained in further detail below.

PROGRAM 7: CONSUMPTION AND WASTE REDUCTION

Background

Traditionally, climate change mitigation plans address waste emissions (i.e., methane) by capturing or managing the emissions once they are created. This program attempts to take a more proactive approach to reducing these emissions by reducing the amount of waste that is created in the first place.

While recycling and composting are helpful steps in reducing emissions associated with the things we buy, these actions only reduce disposal emissions. The majority of GHG emissions are generated before we even purchase the products. To achieve emissions reduction goals, The City's goal is to better understand the role of individuals, businesses, governments, and other organizations to make more sustainable purchasing, production and conservation decisions.

The City uses the international standard for GHG accounting called "The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories," or the GPC. This Protocol was developed in partnership by World Resources Institute, C40 Cities Climate Leadership Group and International Council for Local Environmental Initiatives (ICLEI), and provides a robust and clear framework for calculating and reporting community-wide GHG emissions. [25]

Currently, The City reports scope 1 emissions (GHG emissions from sources located within the city boundary) and scope 2 emissions (GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and cooling within the city boundary), but does not track or report scope 3 consumption-based emissions (such as emissions from the production of goods used in Calgary, but manufactured elsewhere, or the emissions due to shipping goods to Calgary). A relatively small amount of GHG emissions come in the form of methane emissions from landfills.

Within the North American context, the City of Portland has been the first city to publish a consumption-based emissions inventory. [26]

Why is this Priority?

Consumption-based emissions (scope 3) have not been quantified or included in previous climate mitigation plans. However, this is a growing area of focus in leading municipalities, and based on initial research has the potential to represent a significant portion of Calgary's overall emissions. In Portland, Oregon, a consumption-based inventory doubled the total overall emissions in the inventory. [27]

Waste reduction and waste management is a core service that The City is responsible for providing to citizens. There are existing services that can further integrate GHG emissions considerations into how we minimize and manage waste in Calgary.

What The City will do

The following actions have been identified as critical first steps to reducing overall consumption and waste. The key actions are:

Reduce total waste generation in the residential and commercial sectors

7.1 Quantify the composition, scale and impact of consumption and waste on GHG emissions in Calgary

Participating Business Unit:
Environmental & Safety Management
Waste & Recycling Services

7.2 Implement a "pay-as-you-throw" black cart program for residential waste

Participating Business Unit: Waste & Recycling Services

7.3 Investigate options and develop a strategy for significantly reducing avoidable plastic waste and single-use items

Participating Business Unit: Waste & Recycling Services

7.4 Work with the province to move forward extended producer responsibility regulations

Participating Business Unit: Waste & Recycling Services

7.5 Focus on waste reduction in education programs for waste management

Participating Business Unit: Waste & Recycling Services

Improve access to local food

7.6 Review CalgaryEATS! Food Action Plan with enhanced climate resilience lens and develop a Food Resilience Plan

Participating Business Unit: Calgary Growth Strategies

7.7 Conduct systems-level research on climate impacts across range of food systems activities and identify critical linkages among systems components and processes

Participating Business Unit: Calgary Growth Strategies

7.8 Work with Provincial and Federal Governments and the private sector on a multi-level approach to climate programs and policies as it relates to food systems

Participating Business Unit: Calgary Growth Strategies

7.9 Raise awareness of, and address, food loss and disposal to reduce wasted food

Participating Business Unit: Calgary Growth Strategies

7.10 Promote urban and regional food production and support farmers through programs and policy

Participating Business Unit: Calgary Growth Strategies

7.11 Review and update City and institutional food procurement policies

Participating Business Unit: Calgary Growth Strategies

7.12 Support the regionalization and diversification of food supply chains

Participating Business Unit: Calgary Growth Strategies

PROGRAM 8: WASTE MANAGEMENT TO MINIMIZE GREENHOUSE GAS EMISSIONS

Background

As part of achieving our GHG emission reduction targets, our aim is to remove as much as possible GHG emissions from the waste sector. The City's goal is to avoid landfilling all recyclables, discarded food and yard organic materials, where possible. Methane is an extremely potent greenhouse gas that is produced when organic waste decomposes in anaerobic conditions. In a municipal context, methane is generated from solid waste in landfills and in wastewater treatment.

Calgary's landfills and wastewater treatment facilities represent 1 per cent of city emissions.[28] While emissions from solid waste and wastewater are the result of citizens' activities in the wider community, The City has ownership and operational control over the waste handling facilities. There are opportunities to work with the citizens of Calgary to reduce waste before it gets into the collection and landfill stream, and to convert waste streams into value-added end products such as compost and biogas for use at our facilities. The actions that relate directly to the management of City-owned water and wastewater facilities have been detailed in the Leadership theme.

Why is this Priority?

Methane is an extremely potent greenhouse gas generated by Calgary's waste management and wastewater facilities that is reported annually in Calgary's GHG Inventory.
In addition to existing mitigation efforts to reduce the environmental risk of these emissions, further reduction of organic waste disposed of in the landfills can minimize methane generation.

What The City will do

The following actions have been identified as critical first steps to reducing methane emissions from landfills. The key action is:

8.1 Continue to educate and support Calgarians to divert organic waste away from landfills through the Residential Green Cart Program, the disposal surcharge rates at City landfills, and as required for all industrial, commercial, and industrial organizations under The City's bylaws.

Participating Business Unit: Waste & Recycling Services

Natural Infrastructure

This theme focuses on gaining a greater understanding of the mitigation value of the natural environment in Calgary. It is important that this effort be conducted in unison with climate change adaptation work in order to gain a better understanding on the environmental stresses on our local environment, while building knowledge and expertise in areas that will deliver opportunities for better holistic management of our natural systems.

There is one program in this theme area:

- Conserve and manage green spaces and natural areas to support climate change mitigation

The details of this program are outlined below.

PROGRAM 9: GREEN SPACES AND NATURAL AREAS TO SUPPORT MITIGATION

Background

Natural assets include wetlands, river banks, trees and other 'green' infrastructure that provide similar services to hard infrastructure. In addition to providing a critical role in preparing for climate change, trees and other green infrastructure help by sequestering carbon dioxide and reducing building energy use through cooling and shading in summer and lessening heat loss in winter.

Protecting and maximizing the use of these natural assets can also offset costly investments in new hard infrastructure by absorbing emissions and providing additional benefits that reduce energy consumption within Calgary.

Why is this Priority?

The greenhouse gas impact of the disruption of our natural systems has not been previously included in Calgary's GHG mitigation plans. It is becoming an increasingly important area for consideration, as the conservation of natural areas, the restoration of disrupted systems, and the types of developments we permit in our city will directly impact the potential of these systems to act as a carbon sink, and to provide other environmental benefits.

The aim of these actions is to coordinate efforts across multiple City Business Units to develop processes to conserve and understand the mitigation properties of The City's natural assets in conjunction with the climate change adaptation work.

What The City will do

The following actions have been identified as critical first steps to valuing our natural systems. The key actions are:

9.1 **Develop a methodology to quantify the value of natural systems (i.e., parks, riparian areas, natural areas, urban forest, etc.) as a greenhouse gas sink, and incorporate into our annual GHG inventory reporting**

Participating Business Unit: Environmental & Safety Management

9.2 **Develop a formal working group to increase understanding of The City's natural assets for City staff and external stakeholders, including the integration of climate change mitigation considerations**

Participating Business Unit: Environmental & Safety Management

9.3 **Incorporate the value of natural systems as a greenhouse gas sink into triple bottom line analysis and other business processes where necessary**

Participating Business Unit: Water Utility

9.4 **Incorporate climate change mitigation considerations into existing strategies**

Participating Business Unit: Parks, Water Utility

9.5 **Remove regulatory policy barriers that prevent the effective conservation of wetlands in the city**

Participating Business Unit: Parks

9.6 **Continue to promote the restoration of native habitat and naturalization of existing open space to augment the ability of Parks and Open Spaces to sequester carbon**

Participating Business Unit: Parks

9.7 **Collaborate with the Province to develop a carbon offset program for natural systems**

Participating Business Unit: Environmental & Safety Management

Leadership

Demonstrating leadership is a critical role for The City. Leadership can take the form of setting an example through actions, providing information and education, or by enabling innovation and collaboration.

There is one program in this theme area:

- The City of Calgary as a leader in climate change mitigation

The details of this program are outlined below.

PROGRAM 10: THE CITY OF CALGARY AS A LEADER IN CLIMATE CHANGE MITIGATION

Background

The City of Calgary has a responsibility to "walk the talk" on climate change mitigation. We cannot expect citizens, business or other stakeholders to take action without demonstrating our commitment to action. This leadership program is focused on demonstrating how The City of Calgary is leading by example in our own operations, improving The City of Calgary's communication and engagement on climate change mitigation, as well as enabling innovation and collaboration with citizens and the private sector.

Why is this Priority?

We consistently heard from stakeholders that demonstrating leadership should be a top priority for The City of Calgary. The City is not able to achieve our climate change mitigation targets through our own activities. This Strategy is designed to better communicate climate change information and education, and to improve collaboration opportunities between The City and the private sector. This includes implementing and raising the profile of pilot projects, and creating structures to invite industry collaboration.

What The City will do

The following actions have been identified as critical first steps to demonstrating leadership on climate change mitigation. The key actions are:

Lead by example in our operations

10.1 Demonstrate leadership in the construction, operations, and maintenance of City-owned buildings, facilities, infrastructure and fleet to minimize GHG emissions by continuing the implementation of the Corporate Energy Plan 2016-2026

Participating Business Unit:
Corporate Analytics & Innovation
Transportation Department, Water Utility

10.2 Demonstrate leadership by installing low-carbon and renewable energy systems at City facilities and land

Participating Business Unit:
Corporate Analytics & Innovation
Water Utility

10.3 Update the Corporate Energy Plan to fully integrate corporate GHG management, and establish a Corporate Energy and Emissions Plan

Participating Business Unit:
Corporate Analytics & Innovation
Environmental & Safety Management

10.4 Evaluate and incorporate fully-electric, electric hybrid, and other low carbon vehicle technologies into City fleets and facilities

Participating Business Unit:
Environmental & Safety Management,
Corporate Analytics & Innovation,
Calgary Transit, Fleet Services, Waste & Recycling

Become a trusted source for Calgarians to access leading climate change mitigation information and education

10.5 Develop and implement a comprehensive climate change education program

Participating Business Unit:
Environmental & Safety Management

10.6 Integrate climate messages into existing City of Calgary public education programs

Participating Business Unit:
Environmental & Safety Management

10.7 Establish targeted and relevant communications material for key stakeholder groups

Participating Business Unit:
Environmental & Safety Management

Establish support and resources to enable innovation and collaboration by citizens, businesses, and other stakeholders

10.8 Develop and implement a public engagement plan to support the implementation of the Climate Resilience Strategy, the Mitigation Action Plan and the Adaptation Action Plan

Participating Business Unit:
Environmental & Safety Management

10.9 Establish resources to enable citizens to take action

Participating Business Unit:
Environmental & Safety Management

10.10 Develop a program to support large industrial energy users

Participating Business Unit:
Environmental & Safety Management
Calgary Building Services
Corporate Analytics & Innovation

10.11 Establish a structure and resources to enable innovation between The City and the private sector

Participating Business Unit: Calgary Approvals
Environmental & Safety Management

10.12 Establish a structure to ensure ongoing collaboration between The City, the private sector and academia

Participating Business Unit:
Environmental & Safety Management

10.13 Identify additional funding opportunities to support implementation of actions in the Mitigation Action Plan

Participating Business Unit:
Environmental & Safety Management

chapter 4

plan implementation & next steps

Implementation

Climate change mitigation is a continuous process, with this plan acting as a starting point for The City. Successful implementation will require participation and engagement across all business units/service lines, as well as collaboration with community stakeholders in order to successfully achieve Calgary's climate resilience objectives.

The Climate Mitigation Action Plan is a 'living document' where future revisions of the plan are improved by accounting for new economic realities, new and improved technologies and overall ambition on reducing emissions.

The business units identified as accountable for actions in the Plan will be leading the action implementation. The Climate Program will provide coordination among business units and deliver on selected actions on behalf of Environmental & Safety Management that are identified in the Plan. Details and prioritization of the actions may change to reflect emerging challenges and opportunities, as well as funding made available through different levels of government or partnership with the private sector and institutions.

The effectiveness of the plan implementation is dependent on the extent to which the emissions reductions and plan actions are incorporated into existing plans, policies, standards and programs. Unplanned or disruptive changes and unforeseen circumstances will also shape our approach, including technological advancements, energy price changes, grant funding, which will all be considered in future recommendations and updates as well.

Updating the Climate Mitigation Action Plan

The City should review and evaluate the effectiveness of the Climate Mitigation Action Plan every four years to guide business planning and budget decisions, incorporating the advancements in reducing GHGs and an evaluation of the effectiveness of recommended actions. This revision cycle will also satisfy the Provincial Government's requirements for updates every five years. The review and evaluation should include:

- a summary of any observed or projected changes in emissions,
- a report on successfully implemented actions,

- a dashboard on implementation progress of the ten programs,
- proposed revisions to the mitigative actions or programs given updated trends and projections,
- identification of the economics of reducing emissions,
- potential new funding sources for mitigative projects, and
- updated tracking of progress on the GHG targets to 2050.

Monitoring and Reporting

Progress on the Climate Mitigation Action Plan will be reported annually. This report will be presented to Council, and will be publicly reported through the Carbon Disclosure Project.[29]

The primary metrics used to evaluate The City's progress towards climate mitigation will be:

- impact on energy efficiency as an indicator of effective resource use,
- reduction in GHG emissions, and
- cost of energy in relation to the alternatives in Calgary.

These metrics may be used at a community or project level, and in combination or separately, depending on action being pursued. Some actions will be challenging to report on, primarily when the alternative outcome is unknowable, or the life cycle costs are estimated over a long period. Specific metrics will need to be developed for some actions to adequately report on results.

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Climate Adaptation Action Plan
for Calgary

Attachment 2

executive summary

Climate has a major influence on the way we live and Canadians and Calgarians have had plenty to “weather” as of late. In response, Calgary and cities around the world are focusing on developing policies, programs, infrastructure designs and leadership strategies to increase the climate resilience of their natural, built, socio-economic, political and administrative systems.

Climate adaptation is the process and actions to manage the actual and projected climate impacts and risk to reduce the effects on built systems, the natural environment and people. A key purpose of the Climate Adaptation Action Plan is to provide direction for The City of Calgary (The City) on how to address climate change impacts in the context of uncertainty. The Adaptation Action Plan is an essential document for communicating The City’s understanding of climate change and its commitment to improving climate resilience to protect local citizens, the environment, and the economy.

A vulnerability and risk assessment was conducted to provide the basis for City business units to identify the adaptive actions necessary to build climate resiliency for their infrastructure, operations and services. City business units identified a series of actions that should be implemented to manage the climate risks for Calgary. The wide range of actions are grouped into a series of five themes that reflect the interdisciplinary and comprehensive nature of climate change adaptation. Within each theme, two-to-three programs have been designed to ensure alignment and coordination of actions and outcomes.

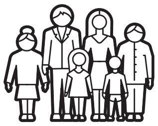
Climate change adaptation is a continuous process, with this plan acting as a starting point for Calgary. The majority of the actions in the Climate Adaptation Action Plan should be initiated within the next business cycle 2019-2022, except ongoing actions that are already underway. Successful implementation will require participation and engagement across all business units/service lines, as well as collaboration with community stakeholders in order to successfully achieve Calgary's climate resilience objectives.

The Climate Adaptation Action Plan will be updated every four years, in advance of each City business planning and budget cycle, with ongoing monitoring occurring between updates.

Climate change adaptation action plan outcomes summary

A total of 175 adaptation actions that should be initiated over next five years (2018-2022) have been identified by City business units. These actions are grouped into a series of five themes that reflect the interdisciplinary and comprehensive nature of climate change adaptation. Within each theme, two-to-three programs have been designed to ensure alignment and coordination of actions and outcomes.

The following table summarizes the outcomes for each program area:

THEME	PROGRAM
 **People:** **A city where people can thrive** Reducing Calgarians' vulnerability to the impacts of climate change	**Air Quality Management** • Reduced airborne emissions in Calgary from high-impact sources • Updated management plans to respond to high risk air quality events **Extreme Heat Management** • Extreme heat management plans and actions are in place to support citizens and outdoor city workers • Priority locations are identified for implementation of cooling and shading infrastructure or programs **Staff and Citizen Outreach** • The City staff, Civic Partners, citizens and businesses have the resources they need to take action on climate change, enabling Calgary to adapt to more extreme weather events and long term climatic changes
 **Infrastructure:** **The backbone of the city** Strengthening the built environment to 'weather the storms'	**Backup Power for Critical Infrastructure** • The City staff has identified the infrastructure that is most essential for continuity of service delivery • Back-up power requirements of these mission critical City facilities have been prioritized based on a climate change vulnerability assessment • Specific upgrades, new backup power systems, or plans to provide mobile power in response to power outages, have been identified in collaboration with partners **Design Standards and Practices** • Expansion and maintenance of detailed climate data to inform infrastructure design decisions • Updated design guidelines and practices across City business units, including infrastructure design specifications, building code and other City guidelines

THEME	PROGRAM
Natural Infrastructure: **The root of resilience** Maximizing the services provided by natural systems	**Natural Assets Management** • A coordinated approach to conserve and enhance natural assets as part of The City's ongoing asset management processes • Management and protection of natural assets and systems, such as soils and stormwater **Natural Assets Adaptation** • Increased number of healthy, well adapted natural assets in Calgary • Updated planning and development practices for soil and vulnerable locations such as river banks and flood prone areas
Water Management: **Every drop counts** Preparing for increasing risks of flooding, drought and declining water quality	**River Flood Management** • Enhanced long-term vision for flood resilience in Calgary to reflect changing climate conditions • Aligned land use planning processes with flood risks and management practices **Stormwater Management** • Assessed design guidelines for stormwater management to deal with more intense summer storms • Flood warning systems and response plans in place to address more frequent localized flooding situations **Long Term Water Supply** • Advanced drought management and response plans to manage the risk of declining water supply • Strategic investments in water supply infrastructure and water demand management programs
Governance: **Pro-active leadership** Preparing for our climate-altered future through collaborative decision making	**Budgeting and Investment Priorities** • Leaders and project managers are aware of climate change risks and potential resilience solutions • Corporate and departmental risk management and budgeting processes explicitly include climate change resilience criteria **City Planning and Processes** • City plans and policies ensure that communities, neighbourhoods, infrastructure and services are designed to respond to anticipated climate changes **Severe Weather Response and Recovery Management** • Systematically updated disaster risk reduction strategies that consider how climate change will increase the frequency and severity of extreme weather events • Civic Partners are supported by The City in developing their own response and recovery plans

2018 climate adaptation action plan

contents

chapter 1

climate adaptation

The Climate Resilience Strategy identifies a series of guiding principles that requires City policies and programs consider climate resilience (mitigation and adaptation) into all decision-making process. This will include service delivery, infrastructure, purchasing decisions and The City's regulations and policies.

The City has a long history of taking actions to reduce greenhouse gas (GHG) emissions, as well as adapting to climate change. The City's Climate Resilience Strategy continues this legacy of action by establishing a coordinated approach for City business units to act directly or to enable citizens and businesses to make Calgary a more climate resilient city. To become climate resilient, ambitious actions are required both to adapt to climate impacts, and to limit emission of greenhouse gases.

Mitigation and adaptation actions need to be designed to mutually benefit each other, as effective mitigation can reduce climate impacts and therefore reduce the level of adaptation required by communities. Many adaptation actions also help to mitigate climate change, such as natural infrastructure, naturalization of green spaces, neighborhood scale renewable energy generation, etc.

It is important to be aware that there is a significant time lag between mitigation activities and their effects on climate change. If not well planned, mitigation and adaptation measures can conflict with each other. An example would be air conditioning, which can help people to cope during a heat wave, but also increases energy use that in turn can increase energy use and GHG emissions.

Current Climate Adaptation Activities

In addition to the actions identified in this Climate Resilience Strategy, some adaptation initiatives are already underway at The City. They have not typically been called adaptation activities, but have been funded and actioned in large part to the recognition and pressures of a changing climate. Examples of such activities, broken down by the 100-Resilience Framework used by The City, include:

100-RESILIENCE FRAMEWORK CATEGORIES	PROJECTS
Infrastructure & Environment	• Flood mitigation and resiliency initiatives • Assessments of local ecology and biodiversity • Asset management and assessment, including previous work using the Engineers Canada PIEVC protocol • The City's energy efficiency initiatives • Ongoing work to better monitor weather and climate for operational applications such as high winds
Leadership & Strategy	• The City's Resilience Program • Business continuity planning • Coordinated emergency response planning and resourcing by Calgary Emergency Management Agency (CEMA) • Ongoing corporate and environmental risk management processes
Economy & Society	• Community networks of service providers and coordination of social services • Public and partner engagement on emissions reduction and adaptation • Expert stakeholder engagement on the Climate Mitigation Action Plan
Health & Wellbeing	• Participation in regional air quality management programs (e.g. Calgary Region Airshed Zone (CRAZ) Board)

Direction from Other Orders of Government

The Cities of Calgary and Edmonton have negotiated City Charters with the Government of Alberta. The City Charter is a legislative framework that gives the two cities greater flexibility and authority on a range of issues from simple administrative efficiencies to complex regulatory changes. Climate Change has been a specific focus of the Charter negotiations for the environment and energy policy areas. The Charter made the development of climate change mitigation and adaptation plans mandatory for the cities of Calgary and Edmonton. The plans must be established by December 31, 2020 and a review of the plans is required at least once every five years.

The Federal Government released the Pan-Canadian Framework on Clean Growth and Climate Change in 2016. The Framework includes a high-level discussion on climate change adaptation for Canada as a whole. The City will monitor Federal projects and subsequent guidance or direction that should be implemented at a municipal level.

Targeted Stakeholder Engagement

Development of the Climate Adaptation Action Plan was conducted by The City's Climate Program, housed within Environmental & Safety Management (ESM) business unit, with other stakeholders within The City. The following business units participated directly in the development of The City's climate adaptation actions, including development of actions specific to their areas of responsibility that will help to address the climate impacts projected for Calgary.

- Environmental & Safety Management (ESM)
- Calgary Approvals Coordination
- Calgary Building Services
- Calgary Emergency Management Agency
- Calgary Growth Strategies
- Calgary Fire Department
- Calgary Housing
- Calgary Parks
- Calgary Neighborhoods
- Calgary Recreation
- Calgary Transit
- Community Planning
- Corporate Analytics & Innovation
- Facility Management
- Finance
- Fleet Services
- Infrastructure & Resilience
- Information Technology
- Law
- Roads
- Transportation Infrastructure
- Transportation Planning
- Water Resources
- Water Services
- Waste & Recycling Services

chapter 2

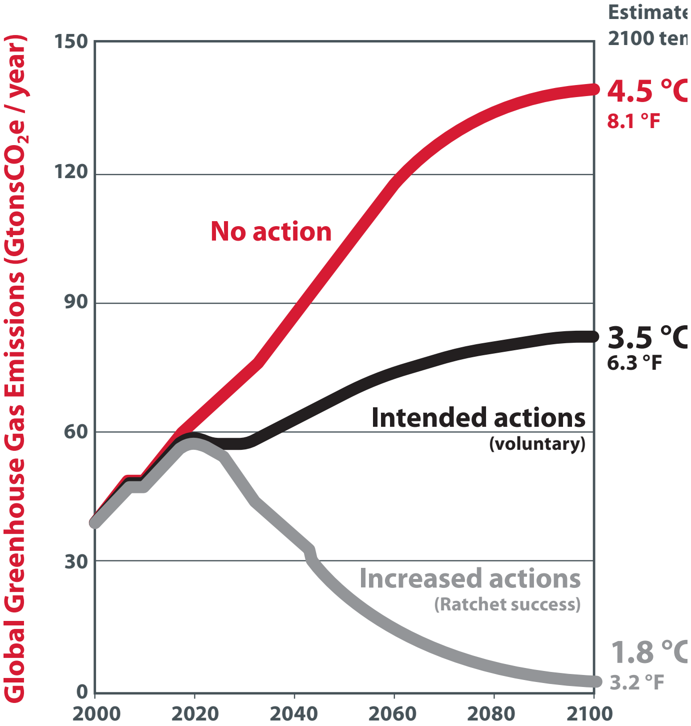
climate risks for calgary

Why Climate Adaptation?

Climate change has become one of the defining issues of our time, given the effect communities across the country continue to experience, from more extreme heat waves to increased winter storms and flooding, to advancing invasive species and vector borne diseases. In response to these changes, cities and countries around the world are focusing on developing policies, programs, infrastructure designs, and leadership strategies to increase the climate resilience of natural, built, socio-economic, political and administrative systems.

The most recent international effort to agree on climate change actions and GHG reduction targets occurred at the 2015 Paris conference (COP21). The voluntary GHG reduction commitments made by nations, shown in Figure 1, would result in average global temperature increase of approximately 3.5°C by the year 2100. This is well above the Paris Agreement's aim to keep global temperature rises this century well below 2.0°C above pre-industrial levels. Right now, global GHG emissions are trending along the highest 'No Action' line, which is projected to result in an increase of 4.5°C by 2100.

FIGURE 1 – GREENHOUSE GAS EMISSIONS (FROM FRIEDLINGSTEIN ET AL., 2014)



Adaptation is not a new concept, Canadians have developed many approaches to deal with an extremely variable climate. For example, communities in the prairie provinces have already been designed to withstand extreme differences in seasonal temperatures. However, the amount and rate of climate change is posing new challenges. Climate science now allows communities to anticipate a range of new and more extreme climate conditions, and therefore take action before the worst impacts are incurred.

Temperature increases for Calgary are projected to be higher than the global average, as northern regions are warming faster than the rest of the globe. Calgary is already facing more extreme and frequent severe weather events, and needs to pro-actively adapt to further changes.

In order to understand the specific impacts on Calgary, The City completed a vulnerability and risk assessment to analyze the major climate and weather changes expected over the next 30 to 60 years. The assessment used a combination of literature-based research, projections based on the latest climate projection models, input from City business units and analysis of local climate data.

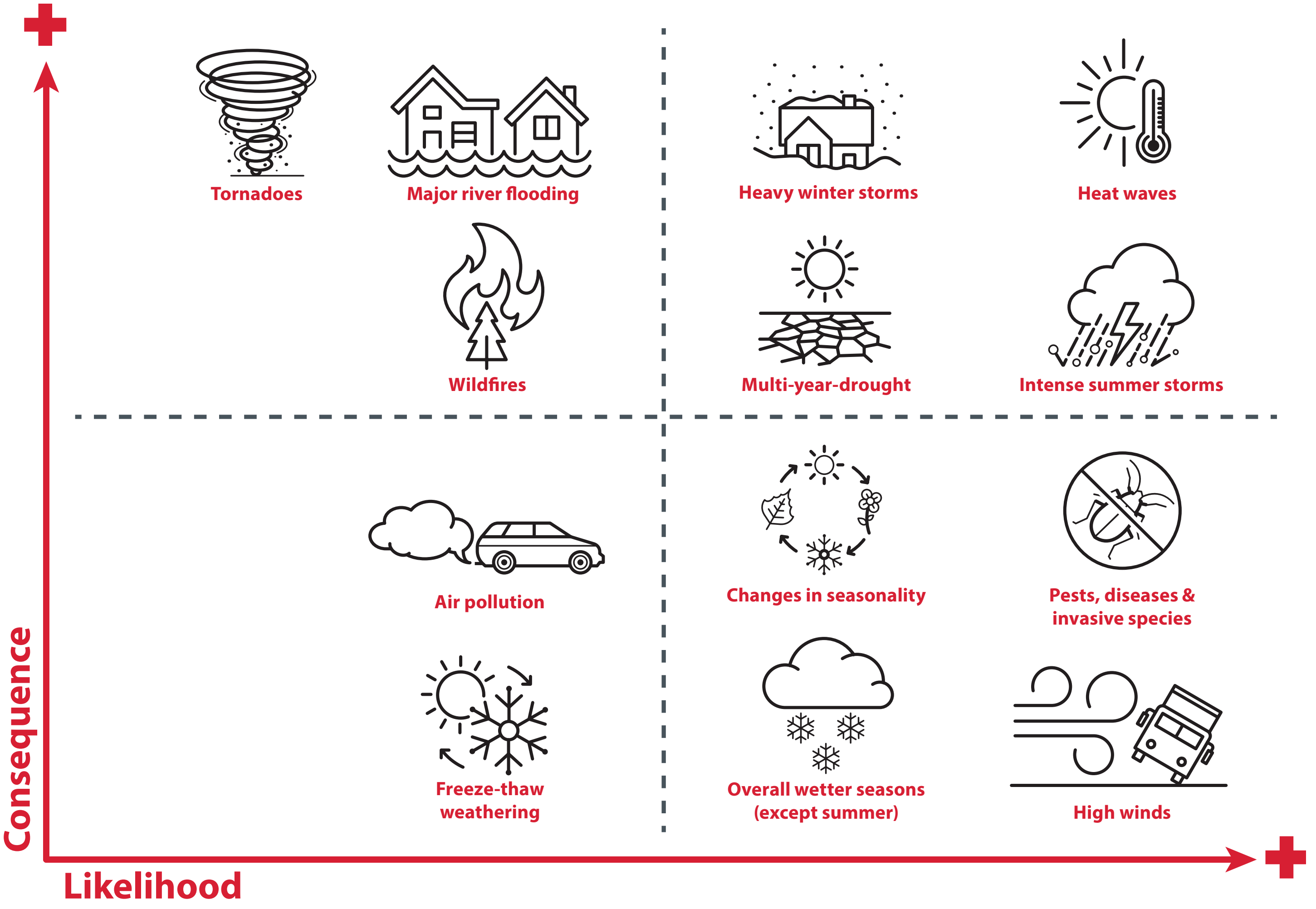
Calgary's Key Climate Risks

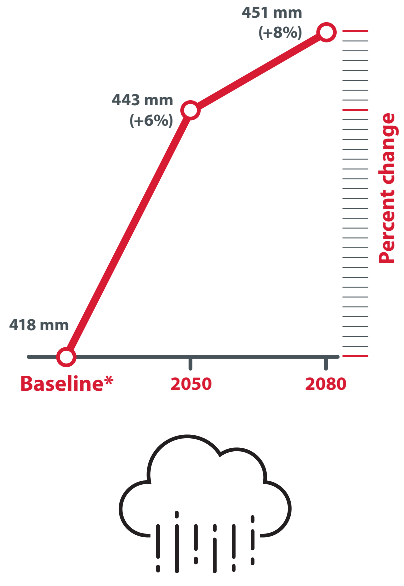
Figure 2 illustrates the projected climate and extreme weather risks identified for Calgary through the vulnerability and risk assessment process with statistical data. Risks further to the right are projected to occur more frequently (higher likelihood), while the ones closer to the top will have more significant impacts on people, infrastructure, services and natural systems (higher consequence).

For most of these climate risks, the likelihood or consequence will be worse in the decades to come than experienced in Calgary today.

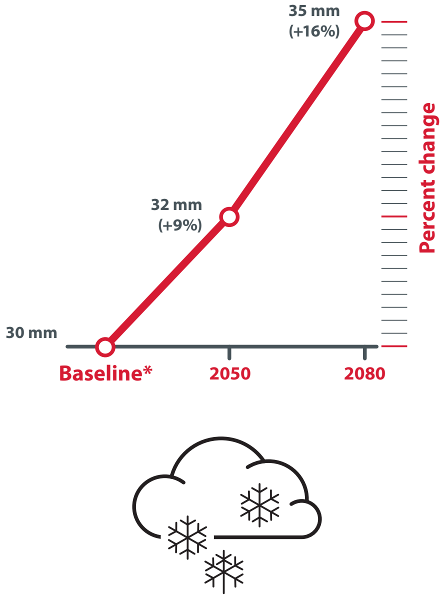
The likelihood of each climate risk was determined through an evidence-based risk assessment process, which determined

FIGURE 2 – CALGARY'S CLIMATE RISKS

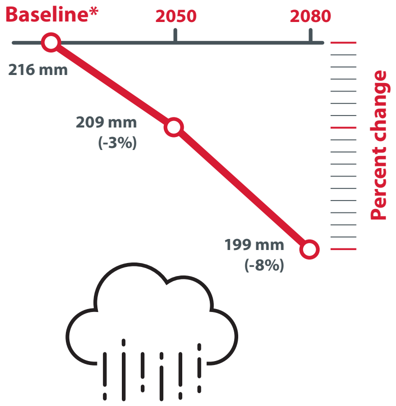




Annual precipitation



Winter precipitation



Summer precipitation

Maximum one day precipitation
32% increase by 2050s

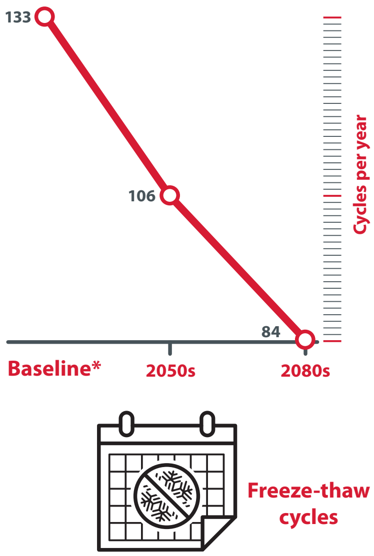
the annual frequency of an event occurring in two future time periods (centred on 2050 and 2080). The consequence of each climate risk was calculated based on The City data and staff input for the following five categories:

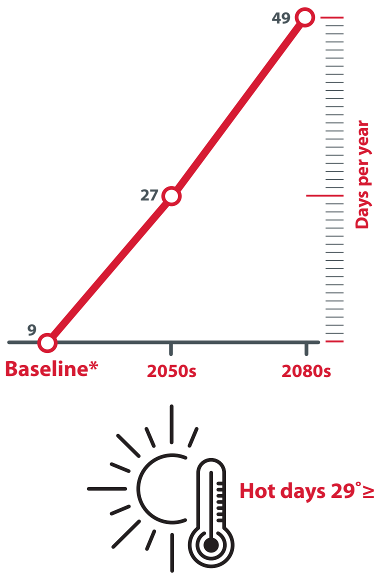
- **City asset damage** – based on an analysis of the infrastructure that would be affected by each climate risk, using historic data when available
- **City service disruption** – based on an analysis of The City services that would be affected by each climate risk, using historic data when available
- **Environmental effects** – based on the loss of rare or endangered species, transformation of landscapes and productive habitat, reduction in water supply, and decrease in water and air quality
- **Community effects** – considered access to services and community assets, along with community macroeconomic losses
- **Human health & safety (public and occupational)** – used a modified version of the disability adjusted life year (DALY) approach to determine the relative health impact of different risks

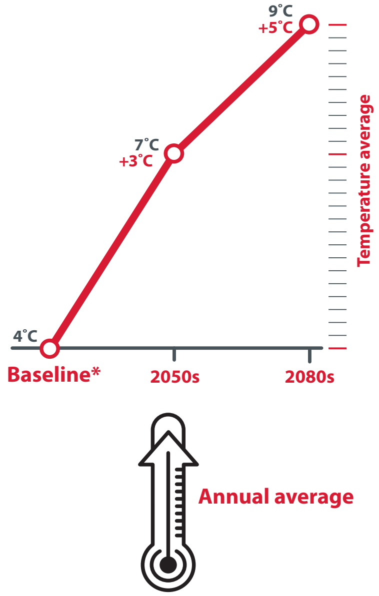
Each of the climate and extreme weather risks from Figure 2 are described in more detail below.

Projected Climate Changes for Calgary

To guide the development of the climate adaptation risks, and resulting actions, forty Global Climate Models were used to provide a highly robust characterization of the uncertainty in future projections of the high emission scenario (Representative Concentration Pathway 8.5) given the current path. Each of the Global Climate Models is a different representation of the physical processes that govern earth-atmosphere interactions (i.e., different models have different mathematical formulas and frameworks for representing physical processes). This approach was selected based on guidance from the Intergovernmental Panel on Climate Change, which suggests that, where possible, the maximum number of models should contribute to an ensemble. Projected changes for six climate variables for Calgary are shown below. These provide an indication of the impacts in the 2050s and 2080s. [30]







High Likelihood, High Consequence Risks

Heat waves

HEAT WAVES

Description: Days with temperature greater than or equal to 29°C.

Impact: Climate change will significantly impact the frequency, duration, and intensity of heat waves in Calgary. This may increase heat-related illnesses and fatalities, especially for outdoor workers, people with health conditions, children and seniors. Heat waves can also result in increased electricity demand for cooling, which can lead to brownouts during periods of peak demand, further increasing health risks. Additional impacts include reduced ground-level air quality, reduced water quality, increased odours from waste and waste facilities, and heat-expansion damage to steel structures and infrastructure such as rail tracks and roadways.

Heat Days will increase from 9 per year to an average of 27 days by the 2050s.

Examples: In 2017 Environment Canada issued several heat warnings during the summer months. During the prolonged heat waves in British Columbia (July 2009) and in Quebec (July 2010), public-health officials stated that there were an estimated 156 and 280 deaths, respectively, from heat-related causes.

INTENSE SUMMER STORMS

Intense summer storms

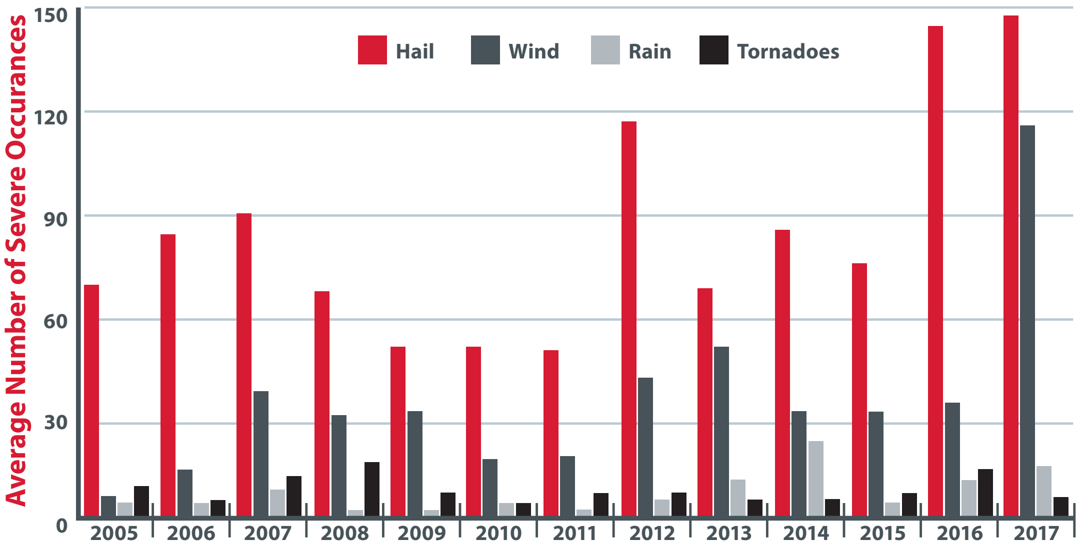
Description: Rainfall of 50 millimetres (mm) or more in an hour, often accompanied by localized flooding, damaging hail and lightning.

Impact: Summer precipitation presents a particular challenge. Even though evidence suggests that summers will become drier on average, when rainfall occurs it will more often happen as intense rainfall and thunderstorms. These storms can cause significant and costly damage when they strike homes and other buildings, can block drainage systems and cause localized flooding, or make key transportation corridors briefly impassable. Calgary and southern Alberta are also already impacted by severe hailstorms each year, as highlighted in Figure 3. Whether more intense summer storms will result in larger hail is unclear, but more frequent storms increase the risk of more frequent hail accompanying those storms.

Examples: In June 2016 Calgary experienced near record rainfall of 206.1 mm, causing an estimated $50 Million in insured property damage. In addition to the torrential rains, the whole of Alberta experienced above average 576,721 lighting strikes, compared to an average 400,000 strikes over the summer.

Between 2005 and 2016, Alberta averaged approximately 78 hail storms, 28 wind storms and 7 rain storms per year, as seen in Figure 3.

FIGURE 3 – NUMBER OF REPORTED SEVERE HAIL, WIND, RAIN AND TORNADOES EVENTS IN ALBERTA (ENVIRONMENT AND CLIMATE CHANGE CANADA, 2017)



Winter and spring precipitation will increase up to 18 per cent by the 2050s, posing concerns for river flood risks, especially when in in combination with mountain snowmelt.

HEAVY WINTER STORMS

Heavy winter storms

Description: Days with more than 10 centimetres (cm) of snow fall or freezing precipitation.

Impact: Winter is projected to have the most significant seasonal increase in precipitation for Calgary, falling as a mix of snow and rain. As the climate warms and more moisture can be held in the atmosphere, individual winter storms will become heavier with more snowfall per storm. Ice storms, like those experienced in eastern Canada today, will also begin to occur in Calgary. Ice storms in particular can damage infrastructure and cause power failures (e.g. downing of overhead power lines), increase the chance of multi-day service disruptions, and result in more injuries due to increased traffic accidents, or slipping and falling. The latter is a particular concern as Calgary's population ages and is more at risk of serious injury due to falls.

Examples: In 2014, the "*Snowtember*" event brought heavy snowfall in late summer and damaged half of the trees in the city. The 28 cm of snow that fell during Calgary's three-day September snowstorm cost the city $17.4 Million in insured costs alone – nearly as much as the entire annual snow and ice control budget.

MULTI-YEAR DROUGHT

Multi-year-drought

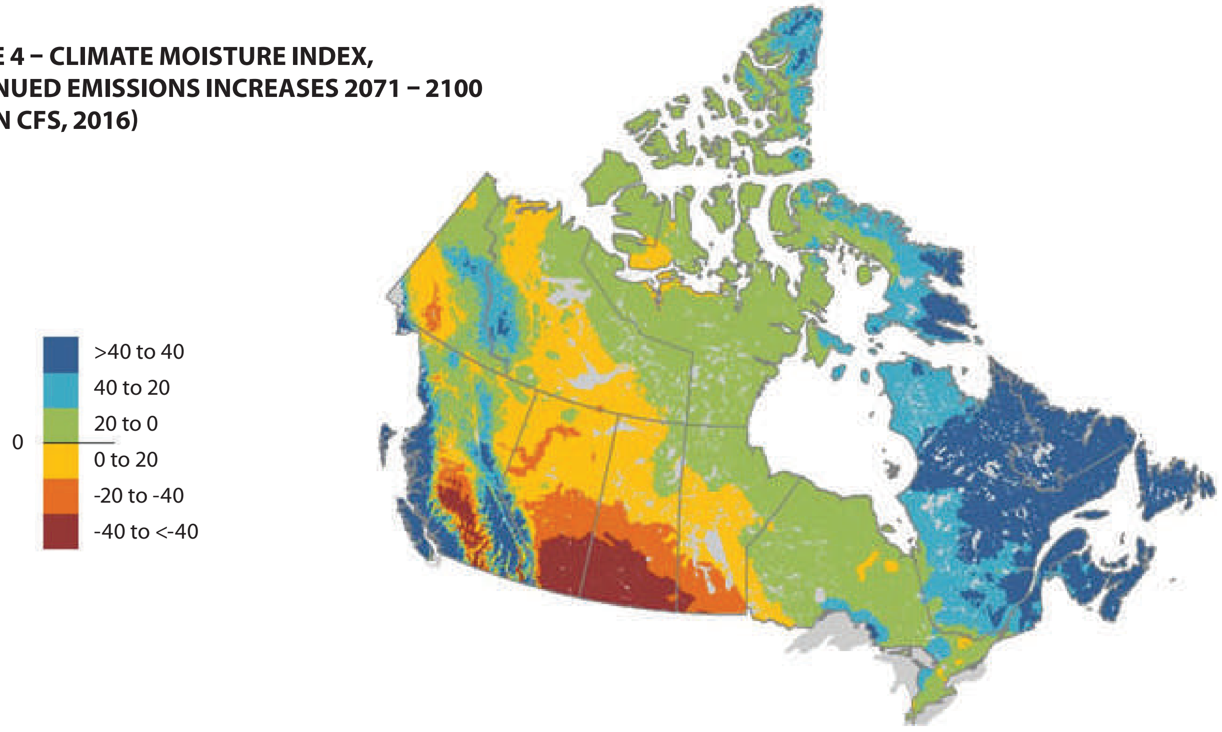
Description: Below average annual precipitation and dry conditions lasting one to three years (or more).

Impact: Although annual precipitation is generally expected to roughly remain the same in Calgary, summers are projected to be drier due to potential decrease in summer rainfall and higher evaporation rate.

The potential for multi-year drought conditions will increase as well. As precipitation becomes more sporadic and variable, annual swings in total precipitation are more likely to occur, with prolonged drought conditions for up to several years at a time.

The consequences of a multi-year drought are far reaching. In addition to the impact on local agriculture, droughts affect the health of plants, wildlife, wetlands, forests, parks, open spaces, recreational facilities and private yards. Drying out of forests increases the risk of wildfires, which impact both local air quality and even water quality if they occur upstream of the source of Calgary's water supply. Trees and plants also become more susceptible to pest and disease outbreaks (e.g. pine beetles) since lack of water can stress trees, limiting their ability to react to these attacks.

FIGURE 4 – CLIMATE MOISTURE INDEX, CONTINUED EMISSIONS INCREASES 2071 – 2100 (NRCAN CFS, 2016)



The climate moisture index by Natural Resources Canada (NRCan), shown in Figure 4, measures the difference between annual precipitation and the potential water evaporation from landscape covered by vegetation. Below the zero line (yellow, orange and red areas), the conditions may be too dry to support a forest. This projection is for the years 2071-2100 assuming the world continues to increase GHG emissions.

Examples: In 2017, much of southern Saskatchewan experienced the driest July in over 130 years of record-keeping. In Regina, less than 2 mm of rain fell that month, far below the usual average of 60 mm. For farmers in the region, the heat and dryness conditions were especially damaging because they followed a rainy spring that had been so wet they'd been unable to properly seed their fields.

Low Likelihood, High Consequence Risks

MAJOR RIVER FLOODING

Major river flooding

Description: Major river flooding events that have a five per cent, or less, chance of happening in a given year.

Impacts: Major river flooding in Calgary can be triggered by a range of climate changes including intense summer storms, rain-on-snow, ice jamming, or combinations of all these events. These events all increase river and water table levels, leading to overland or groundwater flooding. Although these floods can last only a few days, the flood impacts on people and communities can remain for months to years. Some of the more significant impacts of floods include injuries and the risk of fatalities, power outages, dislocation of residents from their homes and communities, service disruptions, stormwater backups and basement flooding, costly damage to buildings and infrastructure, and long-term changes to rivers including erosion and reduced river bank stability.

Examples: The 2013 flood washed across one-quarter of the province and through the core of Calgary. The disruptive flood cut off dozens of communities throughout the province and prompted the largest evacuation across Canada in more than 60 years with nearly 120,000 people temporarily evacuated from their homes, power shut off to the downtown core for a week. Damage losses and recovery costs from the flood exceed $6 Billion, including a record $1.72 Billion in insured losses. This included 1,000 kilometres of destroyed roads, hundreds of washed-away bridges and culverts, and thousands of damaged or destroyed cars and homes.

Wildfires

WILDFIRES

Definition: A large-scale wildfire within or adjacent to Calgary city limits, lasting several days to weeks.

Impact: Calgary is less exposed to physical damage from local wildfires than communities like Fort McMurray or Waterton due to the limited amount of forest in close proximity to the city. Calgary has experienced multiple grass fires however, such as those on Nose Hill, and some communities in Calgary adjacent to urban forests and grassland areas have an elevated risk from wildfires.

Wildfires upstream along the Elbow and Bow Rivers could also impact drinking water supply and quality for years after a fire due to wildfire's tendency to destroy natural features that assist in protecting water sources from runoff contamination (chemicals, erosion and turbidity).

Examples: In 2016, the Fort McMurray wildfire resulted in approximately $3.7 Billion in insured damage. This was more than twice the value of the previous costliest Canadian natural disaster on record. This was followed by the 2017 wildfire in and around Waterton National Park, which forced hundreds of people leave as fire burned over 38,000 hectares. In the aftermath of the 2016 Fort McMurray wildfire, the town has experienced a 50 per cent increase for water treatment expenses to avoid contamination of drinking water from post-fire pollutants washed into the river.

Tornadoes

TORNADOES

Description: Significant tornadoes are rated EF2 or stronger on the Enhanced Fujita Scale ranging from EF0 to an extreme EF5 (EF2 tornadoes have wind speeds up to 217 kilometres per hour (km/h), while EF5 tornadoes have wind speeds greater than 322 km/h).

Impact: While the probability of a tornado striking a particular site is relatively low, the consequences of a tornado depend on its location and the number of people present. Infrastructure impacts can include loss of power, severe damage to buildings and transportation corridors with possible loss of lives, as well as the potential for water service disruptions or sewage backup. Longer-term impacts could include the temporary displacement of people from their homes, injuries and deaths, loss of business revenue, and ongoing psychological trauma. Given the extreme difficulty in upgrading infrastructure to survive a tornado impact, improvements to weather monitoring and advance public warning systems are critical. Based on the available scientific data, it is not yet clear to what extent climate change could increase the frequency or severity of tornadoes in Alberta.

Examples: The most recent example of a larger scale tornado striking a large urban centre in Alberta is the 1987 Edmonton Tornado. The day came to be known as Black Friday after 27 people were killed and 300 people injured by the peak intensity EF-4 tornado that also caused more than $330 Million in damage.

High Likelihood, Low Consequence Risks

High winds

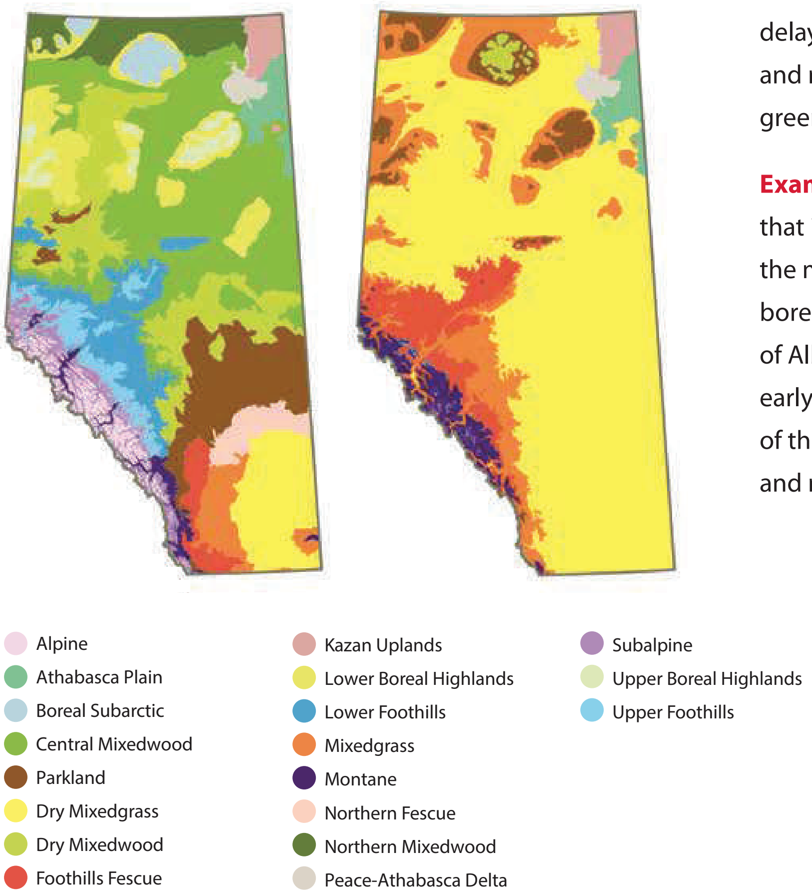
HIGH WIND EVENTS

Description: High winds producing gusts greater than or equal to 90 km/h.

Impact: High winds can damage a wide variety of infrastructure including buildings, traffic signals, streetlights, and signs and can overturn heavy vehicles. Overhead power lines are also at risk during high wind events to power interruptions or outages. Areas of the city, such as the downtown core, could also be closed periodically during extreme high wind events. Injuries or fatalities as a result of such high wind events in Calgary have been rare, but have occurred on occasion.

Examples: Recent examples include multiple events in Calgary in October, 2017 that toppled trees, downed power lines, damaged roofs, and broke windows on a number of buildings in the downtown core.

FIGURE 5 – PROJECTED CHANGE IN ALBERTA'S ECOSYSTEMS BY THE END OF THE CENTURY USING THE CURRENT EMISSION PATHWAY (NIXON ET AL., 2015), ABMI, EDMONTON



Changes in seasonality

CHANGES IN SEASONALITY, OVERALL WETTER SEASONS, AND PESTS, DISEASES & INVASIVE SPECIES

Description: A combination of above normal annual temperatures, increasing wet events with more than eight days of consecutive rainfall, and the spread of pests, diseases & invasive species that previously could not survive in the Alberta climate.

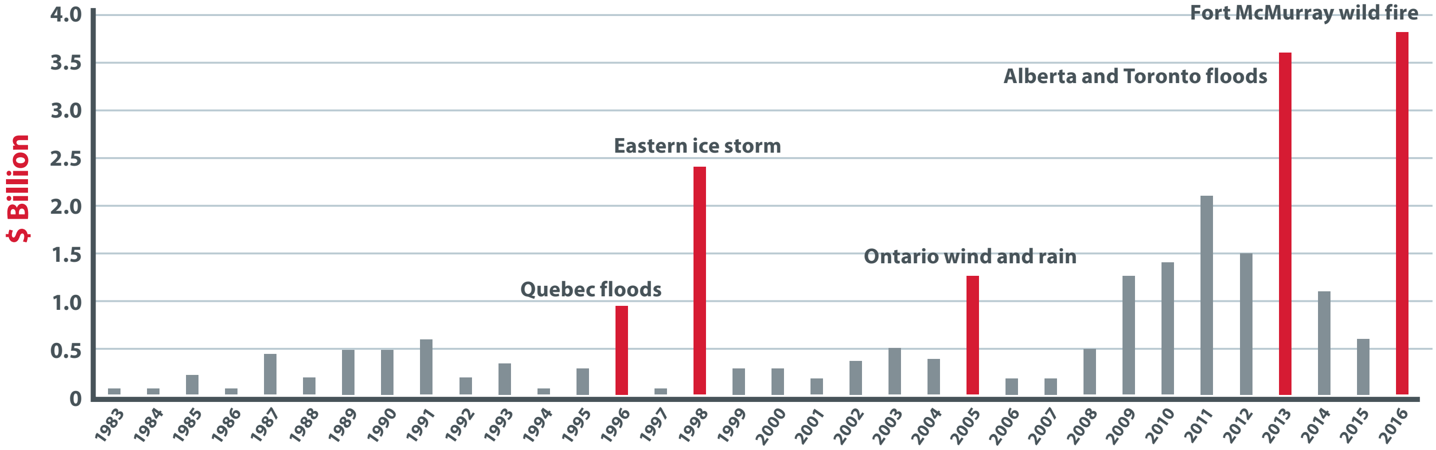
Pests, diseases & invasive species

Overall wetter seasons (except summer)

Impact: Projections indicate that average air temperatures in Calgary will increase across all of the seasons. With higher average temperatures, this can create ideal conditions for pest and disease outbreaks. This can directly impact people's health as new diseases migrate further north, as has already been seen with Lyme disease and the West Nile virus. Outdoor workers and those who enjoy outdoor activities will be most at risk. Growth of invasive species, such as the pine beetle, can wipe out entire forests, with potential impacts to the food chain and local wildlife, as well as negative impacts on forestry and tourism. Increased moisture would also lead to increased weathering of infrastructure, delays and disruptions to scheduled seasonal construction and maintenance, and increased costs for park and greenspace maintenance.

Examples: Figure 5 shows the projected rapid change that is projected for Alberta from 2015 to 2071-2100. Today the majority of central and northern Alberta is covered by boreal forest. However, projections show that the majority of Alberta would become inhospitable for such forest by as early as 2071. Grasslands, as seen in the southeast corner of the province today, are projected to expand into central and northern Alberta instead.

FIGURE 6 – CANADIAN CATASTROPHIC INSURED LOSSES (INSURANCE BUREAU OF CANADA)



Low Likelihood, Low Consequence Risks

AIR POLLUTION

Air pollution

Definition: Elevated air pollution events with an Air Quality Health Index (AQHI) value of 7 or greater.

Impact: Air quality is influenced by both human activities and natural events. Large cities like Calgary may have poor air quality due to pollution from vehicle exhaust or emissions from industry and buildings. This can cause a variety of health impacts, including worsening of respiratory diseases. In Calgary, the worst air quality conditions often occur in winter when emissions from the city become trapped by an inversion (colder, stable air is trapped at the surface with warmer air above). Inversions can inhibit the normal mixing of emissions in the atmosphere, resulting in higher ambient air concentrations for pollutants. Forest fires are also a common cause of elevated air pollution, and can impact communities hundreds of kilometers away.

Examples: In 2017, Calgary endured 321 hours of smoky conditions resulting from wildfires in the Rocky Mountains and the interior of British Columbia. This was by far the smokiest year since air-quality records began in 1953.

2017 was the smokiest year since 1953, with 321 hours of smoke due to wildfires.

FREEZE-THAW WEATHERING

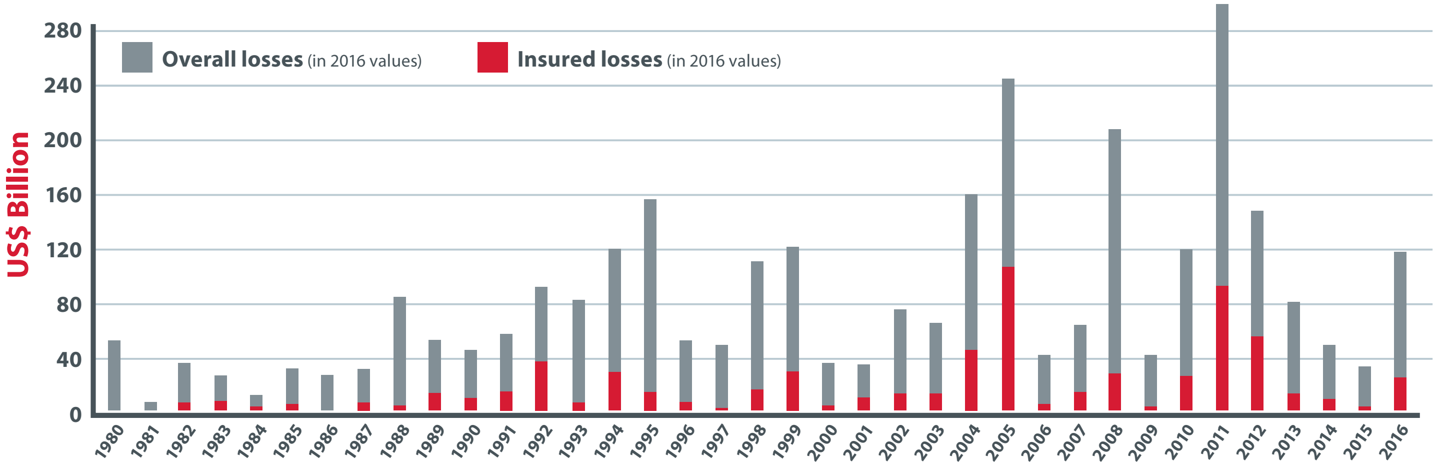
Freeze-thaw weathering

Definition: Freeze-thaw refers to the stress on infrastructure caused by repeated temperature fluctuations just above or below the freezing point. This is further exacerbated by fluctuations in wind, precipitation, ice, snow and humidity.

Impact: An assessment of these conditions from climate models suggests that freeze-thaw conditions over the course of a year will decrease over the long-term, but remain significant in mild-winter months. It remains an important risk to consider in the short and moderate term, especially in late autumn and early spring as well as during the mild-winter months. Freeze-thaw can damage a wide range of infrastructure, including roadways, pathways, light rail transit (LRT) tracks and infrastructure buried in the roadway (e.g. water pipes). Weathering is causing frequent water supply main breaks, cracks and leaks from sewer systems, and compromises stormwater drainage systems performance from either line breaks or increased gravel deposition, and disrupts water supply or sewage services.

Examples: In January 2018 many homes, business and a number of schools experienced pipe bursts inside the buildings caused by freeze-thaw and fluctuating frost depth activity. The Calgary Fire department responded to more than 100 calls within 24 hours related to burst water pipes on January 1 and 2, 2018.

FIGURE 7 – INSURED AND UNINSURED NATURAL CATASTROPHIC LOSSES WORLDWIDE (MUNICHRE NATCATSERVICE, 2017)



Source: Munich Re NatCatSERVICE Inflation adjusted via county-specific consumer price index and consideration of exchange rate fluctuations between local currency and US$.

The Costs of Climate Change

Climate change impacts are being felt in Calgary, and across Canada and internationally. These impacts will grow over time, posing significant risks to our communities, health and well-being, economy and the natural environment.

Severe weather due to climate change is already costing Canadians billions of dollars annually according to the Insurance Bureau of Canada (IBC), with record insured damages of $5 Billion reported in 2016. Figure 6 shows the growth in climate-related catastrophic insured losses in Canada between 1993 and 2016.

Canada is not alone. IBC data shows that the annual economic cost of disasters around the world has increased five-fold since the 1980s. From an average of $25 Billion a year in the 1980s, insured losses grew to an average of $130 Billion a year in the 2000s. For most extreme weather events, uninsured losses exceed the value of insured losses, further adding to the burden on communities and the economy.

Figure 7 illustrates the ratio between insured and uninsured losses adjusted for inflation and exchange rate fluctuations worldwide. In the case of Canada, floods cause annual average economic losses of more than $1.2 Billion with $800 Million of those uninsured. As a result, Canada's insurance industry is calling on governments across the country to implement expansive climate actions that will better prepare Canadians and their communities for the impacts of climate change.

In order to avoid excessive recovery and repair costs to government, residents and businesses, Calgary must adapt to the projected impacts of climate change. Investing in adaptation actions today helps to minimize both short and long-term damage and disruptions. According to the United Nations Development Programme, from a global perspective it is estimated that every dollar spent today on adaptation results in $7 saved in emergency response.

Climate impacts can cause a range of problems, including temporary loss of services, minor and major infrastructure repairs, loss of natural spaces, reduced economic growth, and a range of impacts on people and communities. More problematic for cities, is the fact that climate impacts in one area of services or operations can cascade through other interconnected city systems. Some specific examples of local and global climatic changes that could impact Calgary include:

Local	• Increasing number of heat days that affect the health and productivity of citizens, the natural environment and the lifespan of infrastructure • Infrastructure damage due to severe summer and winter storms causing financial losses, long-term physical and mental distress for individual and businesses • Crop losses for nearby farms due to pest and/ or severe weather events, • Potential tax increases to fund response & recovery costs due to increasing severe weather events • Increased insurance and maintenance costs in areas prone to stormwater and river flooding • More wildfires and air pollution during the fire season affecting the health of Calgarians and negatively impacting tourism • Melting glaciers that will reduce river flows, compromising our water supply and water quality • Increasingly disrupted and stretched municipal services, as a result of all of the above impacts
National	• Sea level rise in Canada leading to potential migration to cities such as Calgary, which would increase demands on local services and infrastructure • The spread of mountain pine beetles into Alberta increasing the threat to local forests and making them more prone to wildfires • Melting permafrost damaging infrastructure such as pipelines, buildings and roads owned by natural resources companies based in Calgary
International	• Increases in local food prices due to droughts in California or other food growing regions • Slowing of the global economy and demand for local resources and products due to damage and disruption from severe weather events • Shortages of imported products due to production and transportation interruptions caused by climatic changes • Increased migration of people due to climate change displacement, increasing demands on Canadian federal, provincial and municipal resources

chapter 3

climate adaptation themes & actions

Climate Change Adaptation Themes

Based on the vulnerability and risk assessment discussed in Chapter 2, City business units identified a series of actions that should be implemented to manage the climate risks for Calgary. The wide range of actions are grouped into a series of five themes that reflect the interdisciplinary and comprehensive nature of climate change adaptation. Within each theme, two-to-three programs have been designed to ensure alignment and coordination of actions and outcomes, as shown below.

THEME		PROGRAM
	People: **A city where people can thrive –** Reducing Calgarians’ vulnerability to the impacts of climate change	1. Air Quality Management 2. Extreme Heat Management 3. Staff and Citizen Outreach
	Infrastructure: **The backbone of the city** – Strengthening the built environment to ‘weather the storms’	4. Backup Power for Critical Infrastructure 5. Design Standards and Practices
	Natural Infrastructure: **The root of resilience** – Maximizing the services provided by natural systems	6. Natural Assets Management 7. Natural Assets Adaptation
	Water Management: **Every drop counts** – Preparing for increasing risks of flooding, drought and declining water quality	8. River Flood Management 9. Stormwater Management 10.Long Term Water Supply
	Governance: **Pro-active leadership** – Preparing for our climate-altered future through collaborative decision making	11.Budgeting and Investment Priorities 12.Urban Planning and Processes 13.Severe Weather Response and Recovery Management

The full list of recommended adaptation actions was identified during the targeted stakeholder engagement process, with selected 'priority' actions highlighted in the remainder of Chapter 3. All of the actions should be initiated over the next five years (2018–2022) in order to increase Calgary's climate resilience in response to the projected climate risks. Additional actions that were identified by City business units should be reviewed as the Climate Adaptation Action Plan is updated in advance of the 2023–2026 business cycle for potential implementation.

Climate Actions

Each of the 175 actions is attributed to one of the 13 programs which are described in the following pages. Each program includes a wide variety of adaptation actions, ranging from low cost and easily implementable projects, to larger and more complex projects. An important principle in developing the Climate Adaptation Action Plan was to focus first on feasible and "no-regret" actions.

The three to four priority actions listed in each of the programs are critical to managing climate impacts in Calgary, and lay the foundation for the rest of adaptation actions that have been identified.

Some of the adaptation actions are already underway (identified as 'ongoing'). Other actions have been newly identified based on the vulnerability and risk assessment. The City is prepared to begin implementation of some new actions immediately, with at least partial funding having been secured. The remaining new actions will require further analysis and the development of new business cases before they can proceed, or require new sources of capital or operating funding.

> Many adaptation actions identified in this plan will involve further engagement with internal and external stakeholders, which will be conducted by the Lead business unit.

Environment & Safety Management (ESM) will support other City business units as they develop new business cases and detailed funding requirements for many of the new actions. Approved business cases will be submitted to One Calgary for a coordinated allocation of corporate funding through future business plan and budget updates. ESM will also track the availability of new funding sources targeted for climate adaptation projects, and provide summary information to One Calgary and Infrastructure Calgary for consideration.

People: A city where people can thrive

Reducing Calgary's vulnerability to the impacts of climate change

Although all people will be affected to some degree by climate impacts, some groups are more at risk. Vulnerable populations, including seniors, youth and some people with chronic illnesses are all more at risk of health complications from climate impacts such as heat waves, air pollution, pests and diseases. Calgary, like other North American cities, will also see a significant increase in the number of elderly citizens over time, increasing the health impacts of climate change and putting more strain on the health care system. Some healthy adults will also be more at risk from climate risks, including outdoor workers as well as athletes and outdoor enthusiasts. For workers this may require changes to job-site practices, or even the hours scheduled for outdoor work. And for outdoor athletes and enthusiasts this may require an adjustment of training and recreational hours.

The City will need to take direct action to address health risks to citizens, particularly around air quality and heat waves. In addition, it will be important to provide education and awareness programs for citizens and businesses. Such programs will enable people to prepare themselves and take their own actions in response to climate change.

PROGRAM 1: AIR QUALITY MANAGEMENT

Air pollution

Wildfires

Heat waves

Background

Human activities, such as emissions from vehicles and buildings, and natural events like winter inversions and wildfires all affect Calgary's air quality. The impact on human health is considered 'high risk' when the Air Quality Health Index (AQHI) rises (a number used to communicate to the public how polluted the air currently is) to 7 or greater. Air quality in Calgary is generally good, with low risk to health. However, winter inversions can trap air over the city for days, allowing contaminants to accumulate and raise the AQHI. Smoke from recent wildfires have also resulted in poor air quality in Calgary.

Why is this a priority?

The number of premature deaths caused by air pollution is close to 7,700 people a year in Canada. There is a moderate likelihood that climate change is increasing the number of high risk air quality events in Calgary, as high temperatures increase the production of secondary airborne contaminants (e.g. ozone), and trap air over the city. Increased heat and drought conditions during the summer will also increase the chance of wildfire smoke from British Columbia and the United States moving into Calgary.

Anticipated outcomes

- Reduced airborne emissions in Calgary from high-impact sources.
- Updated management plans to respond to high risk air quality events.

The City is already undertaking air quality management through participation on the Calgary Region Airshed Zone (CRAZ) Board, and the Clean Air Strategic Alliance (CASA) Non-Point Source Project.

Actions in this program are closely linked to the Extreme Heat Management program, as heat waves degrade air quality. Some actions in the Low Carbon Plan will also help to improve air quality in Calgary.

Highlighted Actions

1.1 Continue to collaborate across the region and province on air quality management

Participating Business Unit:
Environmental & Safety Management

1.2 Develop messaging and response plans, in coordination with regional and provincial agencies, to provide information to Calgarians during poor air quality events

Participating Business Unit:
Environmental & Safety Management

1.3 Investigate the feasibility of implementing and enforcing bylaw restrictions or fire bans on backyard fire pits and wood burning during periods of poor air quality

Participating Business Unit:
Environmental & Safety Management

1.4 Support the adoption of electric vehicles and alternative fuels that minimize local air pollution

Participating Business Unit: Transportation

PROGRAM 2:
EXTREME HEAT MANAGEMENT

Air pollution Wildfires Heat waves Multi-year-drought

Background

Calgary typically has 8 to 9 extreme heat days per year, where the temperature is over 28°C. In the summer of 2017, Calgary experienced roughly double the number of heat warnings issued by Environment Canada. As a result of climate change, Calgary is projected to experience an average of:

- 27 annual extreme heat days by the 2050s (up to 43 days), and
- 49 annual extreme heat days by the 2080s (up to 76 days).

Why is this a priority?

Heat increases health risks for seniors, young children, and people with chronic illnesses as well as athletes and outdoor enthusiasts. Extreme heat can also cause a range of minor or serious heat-related illnesses, such as heat exhaustion, rashes and heat stroke. This is of particular concern for outdoor workers, whose ability to provide services may be negatively impacted.

During prolonged heat waves in British Columbia (July 2009) and in Quebec (July 2010), public-health officials stated that there were an estimated 156 and 280 deaths, respectively, from heat-related causes. Examples such as this, point to the need for improved private and public cooling opportunities, coordinated support for vulnerable people, and updated heat management plans.

Anticipated outcomes

- Extreme heat management plans and actions are in place to support citizens and outdoor city workers.
- Priority locations are identified for implementation of cooling and shading infrastructure or programs.

Several actions under the Infrastructure Theme also help to address the impact of extreme heat on built infrastructure.

Highlighted Actions

2.1 Ensure that heat alerts reach all Calgary Housing tenants, and provide advice on how to keep cool

Participating Business Unit: Calgary Housing

2.2 Develop corporate standard and procedures for heat management to support business units in the development of their own plans

Participating Business Unit:
Environmental & Safety Management

2.3 Install and/or enhance shade structures and water stations in public parks as a part of capital lifecycle programs

Participating Business Unit: Parks

2.4 Scope out and develop an urban heat island map to identify areas vulnerable to heat extremes, and develop measures to reduce impacts on citizens and staff

Participating Business Unit:
Environmental & Safety Management

PROGRAM 3: STAFF AND CITIZEN OUTREACH

Background

Feedback from The City-led climate change engagements and focus groups has identified a desire from Calgarians for The City to take a stronger role in fostering discussions about actions individuals, communities and businesses can take to tackle climate change.

Why is this a priority?

A key prerequisite for effective climate change adaptation and mitigation is that The City, businesses, communities and individuals work together. However, much of the climate data that is available for Calgary is not readily accessible or understandable, and many of the opportunities and benefits that can result from climate change actions have not been sufficiently communicated.

The aim of this program is to engage citizens and staff in The City-led climate change decisions and to share information on managing climate risks. The program will focus is on neighbourhood and city-wide planning processes relevant to citizens and community organisations, and on promoting learning opportunities. The program also includes public education aimed at increasing understanding of climate change so that individuals and businesses can take action on their own.

Anticipated outcomes

- The City staff, Civic Partners, citizens and businesses have the resources they need to take action on climate change, enabling Calgary to adapt to more extreme weather events and long term climatic changes.

This program will be fully integrated with outreach actions contained in the Climate Mitigation Action Plan.

Highlighted Actions

3.1 Develop and implement public and internal climate change education plans

Participating Business Unit:
Environmental & Safety Management

3.2 Develop a Climate Action Community Toolkit, and update communications plans to share climate change information with community groups, Civic Partners and private sector organizations

Participating Business Unit:
Environmental & Safety Management

3.3 Support Civic Partner's strategic and business continuity planning to address climate change risks, including sharing of The City research and plans

Participating Business Unit:
Calgary Neighbourhoods and Recreation

3.4 Coordinate with external agencies to increase safety and security checks of seniors and vulnerable tenants during extreme weather events

Participating Business Unit: Calgary Housing

Infrastructure: The backbone of the city

Strengthening our built environment to 'weather the storms'

Municipal services make use of a wide range of infrastructure, ranging from roadways and light rail transit (LRT) tracks to recreation centres and power distribution systems. Disruption or damage to this infrastructure can have significant impacts on both municipal services and citizen's daily routines.

The design parameters that go into planning and building Calgary's infrastructure are often based on historic climate and weather patterns. As the climate change intensifies, historic data is no longer a useful guide to ensure future infrastructure can withstand the impact of chronic changes or extreme weather events. These parameters must be updated to account for the latest climate projections in order to provide reliable service, and to avoid costly and frequent repairs.

Water infrastructure, including stormwater systems and water treatment plants, are particularly vulnerable to climate and extreme weather changes. As this infrastructure is critical to the health and viability of people and businesses, programs and actions specific to water are summarized in a dedicated Water Management section.

PROGRAM 4:
BACKUP POWER FOR CRITICAL INFRASTRUCTURE

Heat waves · Intense summer storms · Heavy winter storms · Major river flooding

Background

Critical infrastructure refers to facilities and equipment that are essential to providing critical services. It supports the health, safety, security, economy and overall well-being of Calgarians. The 2013 flood demonstrated how the disruption of critical infrastructure affected the community. This could range from reduced quality and strength of wireless service due to increased rainfall, all the way to a complete power outage affecting an entire community.

Why is this a priority?

For The City of Calgary, access to power is essential for maintaining services to citizens. Some facilities and infrastructure play a key role in supporting the community, such as water treatment, transportation, protective services, and public housing. Behind the scenes, data centres and repair facilities are needed as well. During some events, The City facilities are used as muster points or shelters for displaced people.

Power loss can be triggered by various types of extreme weather events. It can be a wind or ice storm bringing tree branches down on power lines, extreme heat causing a blackout, or widespread flooding damaging electrical equipment. The City should prepare for various scenarios for maintaining services.

Anticipated outcomes

- The City staff has identified the infrastructure that is most essential for continuity of service delivery.
- Back-up power requirements of these mission critical City facilities have been prioritized based on a climate change vulnerability assessment.
- Specific upgrades, new backup power systems, or plans to provide mobile power in response to power outages, have been identified in collaboration with partners.

Highlighted Actions

4.1 Assess condition of power supplies in critical City facilities with priority given to facilities serving vulnerable populations

Participating Business Unit: Facility Management

4.2 Determine backup power requirements for City systems and infrastructure in preparation for cascading power losses in the event of multiple extreme weather events

Participating Business Unit: All business units

4.3 Evaluate mobile power plants for Calgary Housing Corporation properties with ENMAX to protect tenants and buildings against freezing

Participating Business Unit: Calgary Housing

PROGRAM 5: DESIGN STANDARDS AND PRACTICES

Heat waves | Intense summer storms | Heavy winter storms | Major river flooding | High winds

Background

The City of Calgary has a wide range of standards and practices, aligned with national or international standards, which determine the design of infrastructure projects from bridges to stormwater pipes. Additional policies and bylaws influence the design of private developments like office towers and new communities.

The City's design standards and practices are based on extensive analysis, and in some cases national or provincial requirements. However, current standards and practices generally do not consider future climate, assuming instead that past climate conditions will continue into the future. Climate change fundamentally changes that assumption; therefore design standards and practices must be updated to ensure infrastructure and services can endure future climate and extreme weather events throughout their intended service life.

Why is this a priority?

Several of the climate risks for Calgary outlined in Chapter 2 impact how infrastructure or buildings need to be designed. Some examples include:

- more intense rainfall that exceeds current stormwater infrastructure capacity and can temporarily flood buildings and roadways;
- major river floods, like 2013, that can destroy riverbanks and bridges;
- increased temperatures and extreme heat that can deform infrastructure; and
- stronger winter storms that can increase roof snow loads or knock out power.

Design standards and practices must be updated to withstand these impacts to ensure reliable service, and minimize the risk of costly repairs after extreme weather events.

Anticipated outcomes

- Expansion and maintenance of detailed climate data to inform infrastructure design decisions.
- Updated design guidelines and practices across City business units, including infrastructure design specifications, building code and other City guidelines.

Highlighted Actions

5.1 Continue to drive improved energy code for buildings with additional focus on deployment of renewable energy. Work is in consultation with Provincial authorities and industry

Participating Business Unit: Calgary Building Services

5.2 Collaborate with external partners to develop regionally-appropriate climate data to inform new design standards for City infrastructure

Participating Business Unit:
Environmental & Safety Management

5.3 Facilitate a cross-corporate working group to scope out and determine a corporate approach to collaboratively update City design standards for buildings

Participating Business Unit:
Corporate Analytics & Innovation

5.4 Update design guidelines and standards for City infrastructure (such as bridges, buildings and water systems) to ensure resilience to extreme weather events and chronic climate changes

Participating Business Unit:
All capital investing business units and
Corporate Analytics & Innovation

Natural infrastructure: The root of resilience

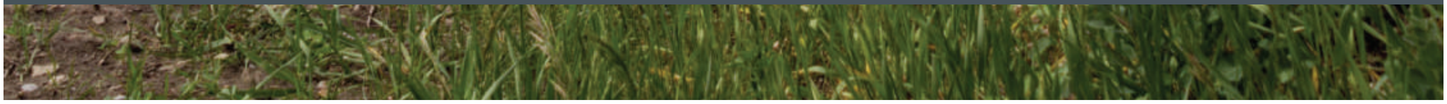
Maximizing the services provided by our natural systems

Natural assets such as bio-swales, forests, fields, green roofs, rivers, rain gardens, streams, wetlands and river banks can provide municipalities with essential services equivalent to those from many engineered assets. Some examples include water supply, water purification, flood protection, climate regulation, soil quality and stability, as well as providing landscaping and natural amenities for communities. Natural infrastructure can serve two different purposes, and in some situations can achieve both:

- everyday service provision (e.g. park space, water conveyance), and
- adaptation to climate change (e.g. tree canopy shading, absorption of storm water).

Some natural assets are best protected in place as native habitat, while others are designed and engineered to mimic natural function and processes. Both types of natural assets have multiple benefits, and have some ability to self-adapt to climate change. The functionality of traditional engineered assets tends to decline as they age. In contrast, with appropriate maintenance and rehabilitation, the functionality of natural assets can improve as they age and mature.

Infrastructure Canada has identified natural infrastructure as a critical element of climate adaptation and is a component of the effort to support Canada's ongoing transition to a clean growth economy. The Federal 2017 budget lays out the Government's plan to invest $12.9 Billion in natural infrastructure.



PROGRAM 6: NATURAL ASSETS MANAGEMENT

Intense summer storms
Major river flooding
Overall wetter seasons (except summer)
Multi-year-drought
Heat waves

Background

Natural assets include prairie, wetlands, river banks, trees and other natural infrastructure that provide similar services to hard infrastructure such as water conveyance, runoff water quality treatment or shading structure. These may be naturally occurring assets, or engineered assets that mimic nature. Natural assets have additional benefits beyond traditional service delivery, including biodiversity and providing ecosystem habitat.

Current City processes do not fully account for the benefits of natural assets, putting their maintenance and protection at risk. The operation and maintenance of natural assets is also very different from the approach taken to maintaining hard infrastructure.

Why is this a priority?

Natural assets are better able to self-adapt to changes in Calgary's climate than hard infrastructure. Protecting and maximizing the use of these natural assets can also offset costly investments in new hard infrastructure, helping Calgary to efficiently manage the risk of increasingly intense storms and flooding.

In order to maximize their benefit in managing climate risks, natural assets need to be accounted for in City asset management programs, capital funding made available, and appropriate maintenance programs put in place.

Anticipated outcomes

- A coordinated approach to conserve and enhance natural assets as part of The City's ongoing asset management processes.
- Management and protection of natural assets and systems, such as soils and stormwater.

Highlighted Actions

6.1 Continue to support and advocate for the priority protection of environmentally significant areas in accordance with the Municipal Development Plan (MDP)

Participating Business Unit: Parks

6.2 Develop a formal working group to align environmental programs, develop objectives and associated instruments for integration of natural infrastructure in the urban form

Participating Business Unit:
Environmental & Safety Management

6.3 Develop a program to increase understanding of the value of natural infrastructure for City staff and external stakeholders

Participating Business Unit:
Resilience & Infrastructure Calgary
Environmental & Safety Management

6.4 Integrate natural infrastructure into planning and corporate asset management

Participating Business Unit:
Resilience & Infrastructure Calgary
Environmental & Safety Management

PROGRAM 7: NATURAL ASSETS ADAPTATION

Intense summer storms | Multi-year-drought | Pests, diseases & invasive species | Overall wetter seasons (except summer) | Major river flooding | Heavy winter storms | High winds

Background

Based on current climate change trends, by mid-century the climate of southern Alberta is projected to become similar to Amarillo, Texas. For example, the number of extreme heat days over 28°C in Calgary is projected to increase from a current average of 9 days to 27 days per year in the 2050s and to 49 days by the 2080s on average. Although natural assets can self-adapt to climate changes better than hard infrastructure, this rate of change will still be too rapid for some local populations of species.

Why is this a priority?

If climate changes occur more quickly than some natural assets can handle, the benefits of these natural assets to Calgary may be reduced. Poorly maintained natural assets can also pose risks to Calgary. For example, unhealthy trees and shrubs pose a greater wildfire risk during extreme heat and drought conditions, or may break during extreme wind events and damage infrastructure such as power lines. In addition, natural assets under stress are more susceptible to invasive species which can be economically and ecologically damaging.

Natural asset management practices from other municipalities will not necessarily work in Calgary due to local differences in soil conditions, rainfall patterns, wind and other factors. As a result, Calgary must evaluate the best approach to help at-risk natural assets either adapt to climate changes, or even to accelerate the replacement of some species with new species better suited to our future climate.

Anticipated outcomes

- Increased number of healthy, well adapted natural assets in Calgary.
- Updated planning and development practices for soil and vulnerable locations such as river banks and flood prone areas.

Highlighted Actions

7.1 **Continue and expand naturalization programs for City Parks and green space**

Participating Business Unit: Parks

7.2 **Conduct a city-wide ecological analysis to develop a plan to build the resiliency of Calgary's natural systems**

Participating Business Unit: Parks

7.3 **Develop new guideline for soil management to provide a functional support system for healthy green spaces and natural infrastructure**

Participating Business Unit: Parks

7.4 **Implement Riparian Action Program to protect and enhance natural river areas and wetlands**

Participating Business Unit: Water Resources

Water management: Every drop counts

Preparing for increasing risks of flooding, drought and declining water quality

How and *when* we receive precipitation will change. Our future water supply will be further restricted being more prone to multi-year drought conditions. Integrated watershed management will be essential to ensure a reliable, secure and high-quality water supply for Calgary. Water supply and demand will both need to be managed effectively, and water storage capacity will be an increasing priority in response to drought and other climate impacts.

The spring season and mountain snowmelt are projected to occur earlier in the year. The growing season is also expected to become longer and hotter, putting higher demands on water supply. Warming temperatures will affect water quality, impacting the ability of water and wastewater treatment facilities to meet Calgary's needs. Precipitation will fall with more intensity, increasing the risk of river flooding as well as localized flooding overwhelming the drainage systems. Flood management will also be a priority with all citizens, businesses and governments having a role to build resilience.

PROGRAM 8:
RIVER FLOOD MANAGEMENT

Intense summer storms

Major river flooding

Overall wetter seasons (except summer)

Changes in seasonality

Background

Calgary has suffered two major flood events in recent years. In June of 2005, Calgary received what was then a record rainfall of 248 mm, resulting in flood damage to 40,000 homes costing about $75 Million. The impact of the June, 2013, flood was even more significant, with over 80,000 people temporarily evacuated from their homes, power shut off to the downtown core for a week, and over $1.72 Billion in insured losses.

With the frequency and severity of storms and flood events projected to increase, Calgary must adapt to minimize the impact of future floods.

Why is this a priority?

More intense rainfall over longer durations will increase the potential for larger river flooding events than Calgary has experienced in the past. This includes both more severe surface flooding and elevated groundwater levels that can lead to basement flooding.

The City of Calgary is already taking action to protect the communities most vulnerable to major flooding, and is working with the Province to explore upstream water storage options. Overall, Calgary is making progress to be prepared for another 2013-scale flooding event, but additional planning and investment is required to adapt to even larger flood events.

Anticipated outcomes

- Enhanced long-term vision for flood resilience in Calgary to reflect changing climate conditions.
- Aligned land use planning processes with flood risks and management practices.

Highlighted Actions

8.1 Collaborate with other levels of government to advance river flood hazard mapping to include climate change

Participating Business Unit: Water Resources

8.2 Continue to work with other levels of government on upstream storage to manage both river flood and drought risks exacerbated by climate change

Participating Business Unit: Water Resources

8.3 Develop flood damage reduction policies including consideration of appropriate land uses and long term management of flood protection infrastructure

Participating Business Unit: Calgary Growth Strategies
Water Resources

8.4 Develop cross-corporate implementation and resourcing plans for river flood response actions taking future climate extremes into account

Participating Business Unit: Water Services

PROGRAM 9: STORMWATER MANAGEMENT

Intense summer storms

Major river flooding

Overall wetter seasons (except summer)

Heavy winter storms

Background

The projected increase of intense summer storms increases the risk that local stormwater drainage systems will be overwhelmed. This will increase potential for localized surface flooding, elevated groundwater and backup of sewer systems leading to basement flooding in different communities. It will also lead to increased pollutants entering rivers and creeks. The precise location of these storms is currently impossible to forecast, so advance warning is limited but could be improved using new technologies.

Why is this a priority?

According to the Insurance Bureau of Canada, basement flooding is the number one cause of insurable damage in Canada. This tends to be worse in older, established communities where construction of stormwater ponds to manage overland flow were not common practice at that time. The risks of flooding are increasing in areas with active redevelopment due to decreased area of permeable space to absorb water, causing more surface runoff. Increased rainfall intensity due to climate change will further increase the risk for localized flooding.

Given that more frequent and severe summer storms are a high risk for Calgary, innovative solutions to manage stormwater volumes and to incorporate natural infrastructure will be required.

Anticipated outcomes

- Assessed design guidelines for stormwater management to deal with more intense summer storms.
- Flood warning systems and response plans in place to address more frequent localized flooding situations.

Highlighted Actions

9.1 Assess climate change impacts to rainfall intensity, duration and frequency to inform new development

Participating Business Unit: Water Resources

9.2 Include climate change impacts in the development of the Stormwater Management Strategy and implementation planning to guide water management in development and redevelopment areas

Participating Business Unit: Water Resources

9.3 Assess stormwater design guidelines to account for climate change in collaboration with stakeholders as part of the Stormwater Management Strategy

Participating Business Unit: Water Resources

9.4 Develop localized flood warning system and response plan to proactively deploy resources to the community and to wastewater treatment facilities.

Participating Business Unit: Water Services

PROGRAM 10:
LONG TERM WATER SUPPLY

Multi-year-drought

Wildfires

Heat waves

Pests, diseases & invasive species

Changes in seasonality

Background

A warmer global atmosphere can hold a larger amount of water vapour and can hold it for longer. This means that Calgary will be more prone to multi-year drought conditions, but when we get precipitation it will fall with great intensity and volume leading to flooding. It is both extremes of drought and flood that will be further exacerbated by climate change.

An earlier spring and warmer temperatures will result in longer growing seasons, providing opportunities for agriculture, recreation, and longer construction seasons. Warmer temperatures will also lead to rapid glacier melt decreasing the flow in mountain rivers, increases evaporation rates, and increases in river water temperatures. Collectively, these will result in decreased river water quality and volume. Therefore, the implications of long term changes to water supply and demand will need to be assessed for management of stormwater, and for operating water and wastewater treatments plants.

Why is this a priority?

Given the risk of reduced water supply during periods of peak demand, policies and programs to manage water demand across the entire Bow River watershed must be re-assessed for future climate conditions. This should include a review of water licenses, source water protection and integrated water supply management.

Citizens, business and government must work together to manage the Bow River watershed over the long-term. With climate change increasing the risk of drought, extreme temperatures and high winds, the risk of wildfires within our watershed increases and must be pro-actively managed.

Anticipated outcomes

- Advanced drought management and response plans to manage the risk of declining water supply.
- Strategic investments in water supply infrastructure and water demand management programs.

Highlighted Actions

10.1 Collaborate with other levels of government and regional stakeholders to analyze long term river flow and water quality in the Bow and Elbow Rivers

Participating Business Unit: Water Resources

10.2 Advance the Drought Management Plan to enhance response tools and minimize impacts during multi-year droughts

Participating Business Unit: Water Resources

10.3 Incorporate climate change in strategic plans and policies to manage long term water supply, wastewater treatment and stormwater management

Participating Business Unit: Water Resources

10.4 Evaluate climate change impacts to water supply and demand to inform Water Efficiency Plan and water sustainability targets

Participating Business Unit: Water Resources

Governance: Pro-active leadership

Working together to prepare for climate change now and in the future

The City has a critical role to play in adapting to climate change and preparing the community to take appropriate actions. The City must consider the implications of Calgary's urban form and growth decisions, how services delivery needs to be modified, and the coordination of response and recovery to extreme weather events such as floods or winter storms.

A key prerequisite for effective adaptation to climate change is that The City, organizations, business associations, institutions and private individuals work together. However, many decision-makers are not yet sufficiently aware of the climate adaptation actions that are required, or the associated benefits. In addition, the available information is not easily accessible, or in some cases, understandable. This can lead to climate adaptation actions being initiated too late to ensure reliable services, or being uncoordinated and not taking into account important information. The programs and actions within this thematic area are designed to maximize the coordination and effectiveness of climate adaptation actions undertaken by The City.

PROGRAM 11:
BUDGETING AND INVESTMENT PRIORITIES

Background

At The City of Calgary, capital budgets are used to construct new infrastructure, or for major reconstruction of ageing infrastructure. Operating budgets are used to cover the costs for staff to operate and maintain City infrastructure and services.

Budget and investment decisions are guided by City Council goals and a variety of technical prioritization criteria. Most capital and operating prioritization processes at The City do not currently include climate change criteria to ensure that climate risks are being properly considered in budget decisions.

Why is this a priority?

In order to minimize the disruption of City services, managing the risks associated with climate change requires adequate capital and operating budgets. This Climate Adaptation Action Plan includes a number of projects (e.g. updating infrastructure design guidelines) that are specially designed to manage climate risks. Many other proposed City projects are not directly related to climate change, but would also help to manage climate risks.

Incorporating climate change criteria into budget and investment decisions will increase funding allocated to projects that manage climate risks. This should be combined with existing economic, social or environmental criteria to ensure balanced budget priorities.

Anticipated outcomes

- Leaders and project managers are aware of climate change risks and potential resilience solutions.
- Corporate and departmental risk management and budgeting processes explicitly include climate change resilience criteria.

Highlighted Actions

11.1 Advocate for amendments to current disaster funding models with different levels of government to reflect the increased climate risks

Participating Business Unit:
Calgary Emergency Management Agency (CEMA)

11.2 Integrate climate resilience criteria within capital budget processes and funding allocation decisions

Participating Business Unit:
Resilience and Infrastructure Calgary
All asset owning business units
Environmental & Safety Management

11.3 Incorporate monitoring and tracking of corporate climate adaptation actions into existing environmental risk management monitoring processes

Participating Business Unit:
Environmental & Safety Management

11.4 Enhance awareness of leadership, project managers and business planners on climate change resilience actions and investments to manage climate risks

Participating Business Unit:
Environmental & Safety Management
Finance

PROGRAM 12:
CITY PLANNING AND PROCESSES

Background

Planning and policy decisions on land use, transportation, city infrastructure and services can help to build overall resilience to climate changes. The City can tailor plans and policies for existing and future neighbourhoods to reduce the impact of extreme weather events and long-term climatic changes that are expected to affect each area. Through the policies of the Municipal Development Plan (MDP) and the Calgary Transportation Plan (CTP), it is possible to build resiliency in planning land uses, water infrastructure and transportation connections. These plans' performance indicators will allow us to track progress toward increased resilience.

Why is this a priority?

Climate change poses a long-term risk to Calgary and its citizens. Since planning and policy decisions regarding land use, transportation, and city infrastructure shape the long-term growth of the city, these decisions can also help to manage the risks associated with climate change through proactive and responsive policies and climate-resilient design choices.

Anticipated outcomes

- City plans and policies ensure that communities, neighbourhoods, infrastructure and services are designed to respond to anticipated climate changes.

Highlighted Actions

12.1 Develop or join a community of researchers and practitioners to support information sharing on the management of climate change risks

Participating Business Unit:
Environmental & Safety Management

12.2 Update the Municipal Development Plan (MDP) and Calgary Transportation Plan (CTP) to address climate risks that may impact land development and transportation infrastructure or services

Participating Business Unit: Calgary Growth Strategies
Transportation

12.3 Align Local Area Plans policies with areas identified by Water Resources as disaster prone and undertake consultation and policy amendments to reduce potential damage to life and goods, and manage risks

Participating Business Unit: Calgary Growth Strategies
Community Planning

12.4 Conduct an ongoing evaluation of City policies against climate resiliency criteria to ensure alignment

Participating Business Unit:
Environmental & Safety Management

PROGRAM 13: SEVERE WEATHER RESPONSE AND RECOVERY MANAGEMENT

Intense summer storms
Heavy winter storms
Major river flooding
Tornadoes
High winds

Background

During an emergency, The City of Calgary's priorities are life safety, critical infrastructure, environment, and the economy. Calgary has effectively managed extreme weather events in the past, such as the 2013 flood, and is learning from those events to enhance its ability to manage extreme weather events in the future.

Climate change acts as a risk multiplier by increasing the frequency, variability, and intensity of hazards. An expected overall increase in the number of severe weather events will put further stress on operational budgets while challenging the city's ability to provide essential services, damaging critical infrastructure, and increasing the risk of injuries/fatalities. Response and recovery from extreme weather events can be very costly in terms of repair costs and staff time. The toll on citizens' physical and mental wellbeing can be severe and linger many years after the event.

Why is this a priority?

Preparing for a likely increase in the frequency, severity, and complexity of extreme weather events requires a coordinated cross-departmental and multidisciplinary approach. While the time horizons and scope are different, there is close alignment between disaster risk reduction and climate change adaptation. Climate change exacerbates weather-induced hazards, therefore, reducing disaster risk for those hazards is also a critical component of adaptation planning. Both fields are focused on assessing risk, reducing vulnerability, increasing capacity, mitigating potential damage, and enhancing resilience in order to achieve long-term sustainability goals. There is an opportunity to align disaster risk reduction and climate change adaptation in order to ensure both activities are working towards long-term societal resilience objectives.

Anticipated outcomes

- Systematically updated disaster risk reduction strategies that consider how climate change will increase the frequency and severity of extreme weather events.
- Civic Partners are supported by The City in developing their own response and recovery plans.

Highlighted Actions

13.1 Review capacity of Calgary Emergency Management Agency (CEMA) to provide local and regional support during response and recovery from identified climate impacts

Participating Business Unit:
Calgary Emergency Management Agency (CEMA)

13.2 Support Civic Partners as they build internal capacity, obtain resources and develop their own adaptive actions

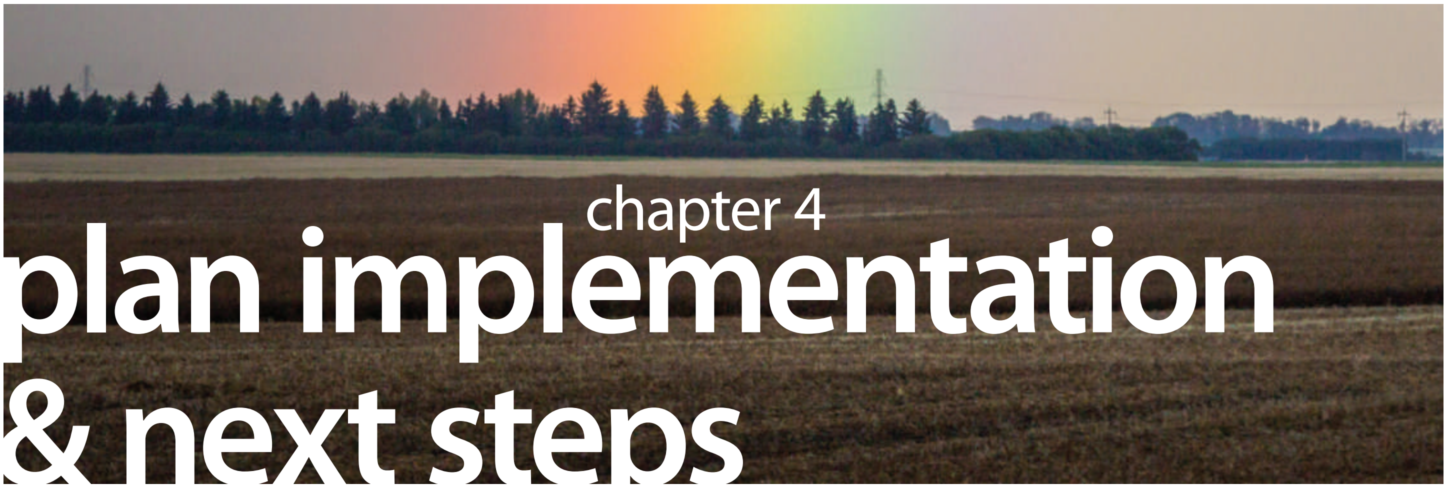
Participating Business Unit:
Calgary Neighbourhoods

13.3 Review business continuity plan and integrate identified risks of more frequent and intense extreme weather events

Participating Business Unit:
All business units

13.4 Integrate climate adaptation programming into disaster risk reduction strategies in order to increase resilience

Participating Business Unit:
Calgary Emergency Management Agency (CEMA)



chapter 4

plan implementation & next steps

Implementation

Climate change adaptation is a continuous process, with this plan acting as a starting point for Calgary. The majority of the actions in the Climate Adaptation Action Plan should be initiated within the next business cycle 2019-2022, except ongoing actions that are already underway. Successful implementation will require participation and engagement across all business units/service lines, as well as collaboration with community stakeholders in order to successfully achieve Calgary's climate resilience objectives. The Climate Adaptation Action Plan is a 'living document', much like an Emergency Response Plan, where future revisions of the plan are improved by accounting for new data, analysis on successful risk reduction measures and understanding thresholds for triggering certain damaging climate impacts.

The business units identified as accountable for actions in the Plan will be leading the action implementation. The Climate Program will provide coordination among business units and deliver on selected actions on behalf of Environmental & Safety Management that are identified in the Plan. Details and prioritization of the actions may change to reflect emerging challenges and opportunities, as well as funding made available through different levels of government or partnership with the private sector and institutions.

The effectiveness of the plan implementation is dependent on the extent to which the climate risks, impacts and actions are incorporated into existing plans, policies, standards and programs (e.g. the Municipal Development Plan (MDP)). Continued research into best practices and collaboration with external stakeholders will also help to guide successful implementation of the actions that are presented in this plan.

The City of Calgary's adaptation actions were developed by all impacted business units through a series of stakeholder workshops, and are tailored to address Calgary-specific climate risks.

Having identified the primary climate risks for Calgary, this Climate Adaptation Action Plan identifies actions that need to be undertaken by The City to increase the resilience of municipal infrastructure and services.

Updating the Climate Adaptation Action Plan

The City should review and evaluate the effectiveness of the Climate Adaptation Action Plan every four years to guide business planning and budget decisions, incorporating the latest climate data and an evaluation of the effectiveness of recommended actions. The review and evaluation should include:

- a summary of any observed or projected changes in climate risks,
- a report on successfully implemented actions,
- a dashboard on implementation progress of the 13 programs,
- proposed revisions to the adaptation actions or programs given the updated observations or projections,
- frequency of reaching specific impact thresholds
- identification of potential new funding sources for climate adaptation projects, and
- updated tracking of progress on the Core Climate Adaptation Indicators.

Monitoring and Reporting

The Climate Adaptation Action Plan will be updated every four years, in advance of each City business planning and budget cycle, with ongoing monitoring occurring between updates. The primary metric used to evaluate The City of Calgary's progress towards climate adaptation will be the percentage of climate adaptation actions identified that have been initiated within the recommended timeframes.

Successful adaptation means that some impacts are avoided or reduced, so it can be difficult to directly measure the effectiveness of pro-active adaptation actions against events that have been avoided or minimized. Climate adaptation indicators generally cannot be used independently, but must be combined to measure whether The City's actions are leading toward climate resilience on a city-wide scale. A set of potential climate adaptation indicators, linked to each of the program, are provided in Table 1, and these potential indicators can be used to evaluate whether The City's climate adaptation actions are achieving their desired goals. These should be reviewed further to establish a set of Core Climate Adaptation Indicators that can be reported to Council in advance of each business planning and budget cycle and evaluated to determine whether they will assist with implementation of the adaptation actions.

Due to the complexity of climate change adaptation, 13 indicators are not enough to fully establish whether The City is achieving comprehensive climate resilience. As a result, each business unit will monitor additional indicators specific to their actions to inform future business planning and budget recommendations.

TABLE 1 – POTENTIAL ADAPTATION INDICATORS

Themes	Programs	Core indicator	Metric
People: **A city where people can thrive**	1. Air Quality Management	Airborne emissions reduction	Per cent time Air Quality Health Index rated high risk (greater than 6)
	2. Extreme Heat Management	Heat waves	Per cent city area mapped as high risk of heat island effect
	3. Staff and Citizen Outreach	Climate literacy	Per cent increase in community awareness on climate adaptation Per cent of staff aware of climate projections Number of climate related partnership with partners

Themes	Programs	Core indicator	Metric
Infrastructure: **The backbone of the city**	4. Backup Power for Critical Infrastructure	Power supply for Critical Infrastructure	Per cent of City critical infrastructure with backup power
	5. Design Standards and Processes	Design Standards	Per cent of design standards updated to include climate change
Natural Infrastructure **The root of resilience**	6. Natural Assets Management	Natural assets	Per cent of natural assets incorporated in the City's Asset Management Plans Dollars invested in natural assets
	7. Natural Assets Adaptation	Vulnerable areas	Per cent decrease of vulnerable areas Riparian health index
Water management **Every drop counts**	8. River Flood Management	Reduce risk, resilience	Number of properties at risk of river flooding for 1-in-2, 1-in-5, 1-in-20, 1-in-100 return period
	9. Stormwater Management	Reduce risk, resilience	Number of properties at risk of localized flooding for 1-in-2, 1-in-5, 1-in-20, 1-in-100 return period
	10. Long Term Water Supply	Reduce risk, resilience	Elbow River annual low flow (cubic metres per second (m^3/s)) Nose Creek annual low flow (m^3/s)
Governance **Pro-active leadership**	11. Budgeting and Investment Priorities	Budget Integration	To be determined
	12. Urban Planning and Processes	Climate Resilience	Per cent of Local Area Plans that contain policies explicitly addressing climate risk management
	13. Severe Weather Response and Recovery Management	Business Continuity Planning	Per cent of business requirements that have an effective processes to allow business units to continue providing their services during severe weather events Total losses (in dollars) due to weather-related events incurred by The City

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Sources

30. Climate Change Adaptation Research: Vulnerabilities, Risks and Adaptation Action, Technical Report. Prepared for the City of Calgary by WaterSMART Solutions Ltd., June 2017.

September 2014

BOW RIVER AND ELBOW RIVER

Basin-Wide Hydrology Assessment and 2013 Flood Documentation

Submitted to:
Alberta Environment and Sustainable Resource Development (ESRD), Edmonton
The City of Calgary

REPORT

Report Number: 13-1326-0054-2000

Distribution:

3 Copies ESRD, Edmonton
3 Copies The City of Calgary
3 Copies Golder Associates, Calgary

A world of capabilities delivered locally

Golder Associates

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APPENDICES

1.0 INTRODUCTION

1.1 Project Background

The City of Calgary (The City), in partnership with Alberta Environment and Sustainable Resource Development (ESRD), commissioned Golder Associates Ltd. (Golder) to undertake an update of the 2010-2012 Bow and Elbow River Hydraulic Model and Flood Inundation Mapping Project. The overall scope of work includes a basin-wide flood event documentation and hydrology assessment using preliminary 2013 flow data, and a hydraulic model update incorporating surveyed 2013 high watermarks, post-flood bathymetry and topography and re-surveyed river cross sections.

In June of 2013, The City experienced a severe flood estimated to be close to the 100-year event for the Bow River and significantly higher for the Elbow River. The magnitude of 2013 flood peaks throughout the Bow and Elbow River basins, including at The City, warrant a re-analysis of the flood frequency statistics computed in 2010 (Golder, 2010). Post-flood observations on the both rivers suggest that the characteristics of the river bed and banks at many key locations were significantly altered due to erosion, scour and deposition. The hydraulic model and flood inundation mapping completed in 2012 (Golder, 2012) for the Bow and Elbow Rivers through The City, using pre-2013 flood channel bathymetry and cross section data, may not currently be as representative as desired for emergency response, and the model and mapping are being updated.

1.2 Study Scope

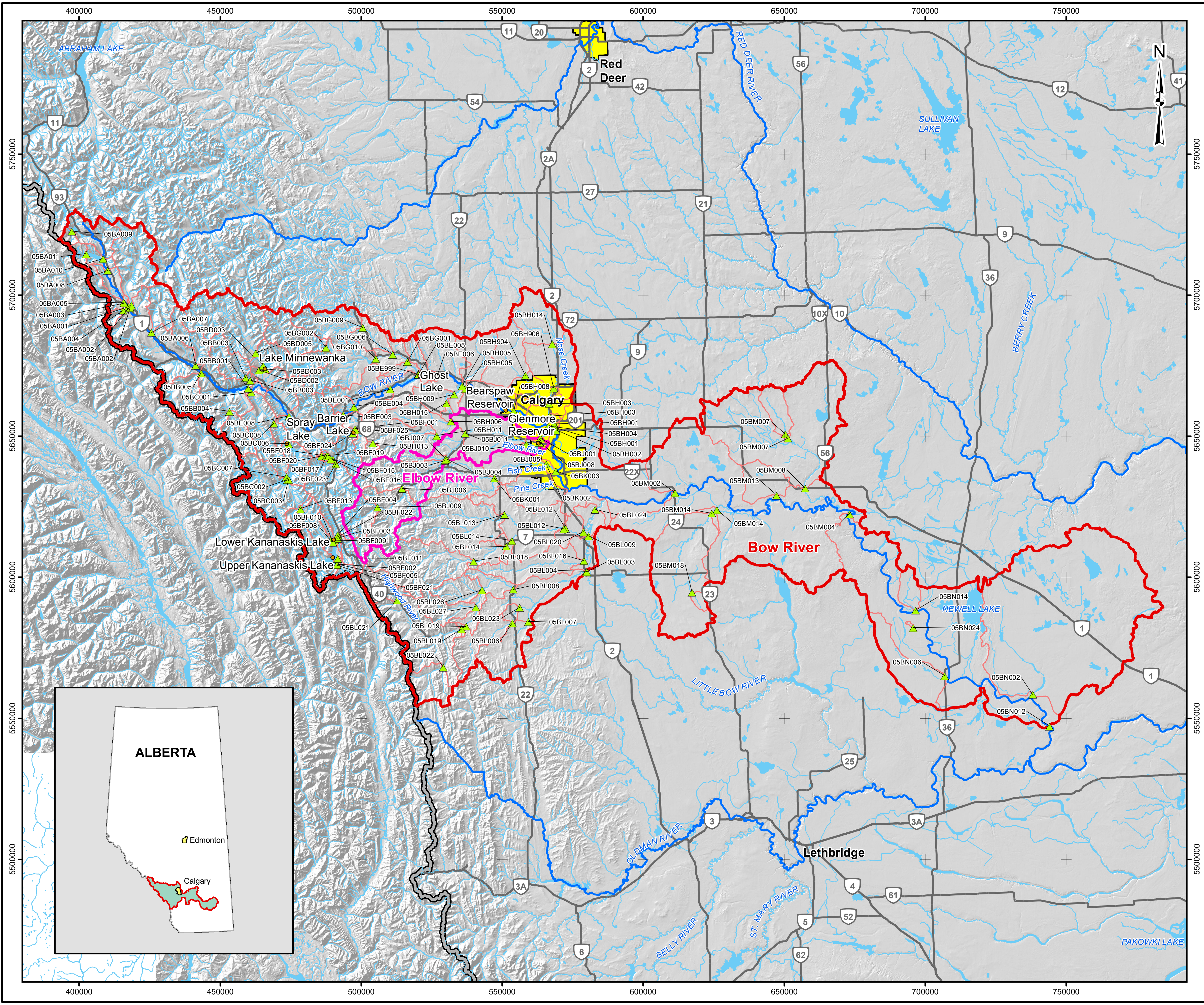
The primary objective of the project is to update the 2012 HEC-RAS hydraulic model and flood inundation mapping for the Bow and Elbow rivers through The City. Given the magnitude and impact of the 2013 flood throughout the Bow and Elbow River basins, and the critical hydrologic importance of the 2013 flood event, ESRD also required a basin-wide hydrologic assessment and a stand-alone hydrology report to put the 2013 floods into context. The scope of the basin-wide hydrologic assessment was to document the magnitudes of June 2013 flood peaks at various locations, and to undertake an updated frequency analysis to determine flood magnitudes for a range of return periods for information and use in flood inundation mapping and other projects.

The City and ESRD provided historic Water Survey of Canada (WSC) and preliminary 2012 and 2013 flow data for gauges on the Bow River, Elbow River and their tributaries. TransAlta Corporation (TransAlta) provided flow and reservoir level data up to 2013 at their hydropower developments on the Bow River and its tributaries.

It is important to note that the 2012 and 2013 flow data used in the present study are preliminary and subject to change following finalization by WSC. As such, the preliminary 2013 flood peaks and any corresponding flood frequency statistics presented in this report should be used with caution and reviewed again when final data are available. This report should be read in conjunction with “Important Information and Limitations of This Report”.

1.3 Study Area

The study area, shown in Figure 1.1, includes the Bow River and its tributaries upstream of its confluence with the Highwood River. The drainage area of Bow River at Calgary (WSC Station 05BH004) is 7,868 km^2. The upstream reach of the Bow River and its tributaries are controlled by several hydropower structures. Within the City, the Bow River is joined by several streams, including Elbow River, Nose Creek, Fish Creek and Pine Creek. The Elbow River is the most significant tributary to the Bow River within The City, and flows into the Glenmore Reservoir before discharging into the Bow River just downstream of downtown. The drainage area of the Elbow River below Glenmore Dam (WSC Station 05BJ001) is 1,236 km^2. Table 1.1 provides a summary of the basic hydrologic information available from WSC for Bow River and its tributaries within the study area.



LEGEND

▲	HYDROMETRIC STATIONS
●	STORAGE STRUCTURE
🟥	BOW RIVER BASIN
▭	ELBOW RIVER BASIN
▭	PFRA SUB-BASIN
—	MAJOR RIVER
—	PRIMARY HIGHWAY
—	WATERCOURSE
🟦	WATERBODY
▭	PROVINCIAL BOUNDARY
🟨	POPULATED PLACE

REFERENCE

HYDROMETRIC STATIONS, HYDROLOGIC REGIONS, BASIN AND SUB-BASIN DATA OBTAINED FROM PRAIRIE FARM REHABILITATION ADMINISTRATION (PRFA). BASE HYDROLOGY, POPULATED PLACES AND PROVINCIAL BOUNDARY OBTAINED FROM IHS ENERGY INC. HILLSHADE AND ROADS OBTAINED FROM GEOBASE ®.
DATUM: NAD 83 10TM AEP FOREST

40 0 40

SCALE 1:1,350,000 KILOMETRES

PROJECT

Alberta Government

BOW RIVER AND
ELBOW RIVER BASIN-WIDE HYDROLOGY

TITLE

BOW RIVER AND ELBOW RIVER BASINS

Golder Associates

PROJECT No. 13-1326-0054			SCALE AS SHOWN	REV. 0
DESIGN	AB	21 Apr. 2014	**FIGURE: 1-1**	
GIS	JE	02 Jun. 2014		
CHECK	AB	25 Jul. 2014		
REVIEW	AB	25 Jul. 2014		

I:\2013\13-1326\13-1326-0054\Mapping\MXD\Hydrology\BowRiverBasin_20140602_FINAL.mxd

Table 1.1: Summary of Existing Hydrologic Data

WSC Station ID	Station Name	Gross Drainage Area (km^2)	Period of Record	Length of Record (Years)	Type of Recorded Hydrologic Data	Condition of Recorded Hydrologic Data
05BA001	Bow River at Lake Louise	422	1910-2013	104	Flow	Natural
05BB001	Bow River at Banff	2,210	1909-2013	105	Flow	Natural
05BE004	Bow River near Seebe	5,170	1923-2011	89	Flow	Regulated
05BE006	Bow River below Ghost Dam	6,550	1933-1989	57	Flow	Regulated
05BH005	Bow River near Cochrane	7,412	1916-2013	98	Flow	Regulated
05BE005	Ghost Lake near Cochrane	6,480	1929-2013	85	Level	Regulated
05BH008	Bow River below Bearspaw Dam	7,770	1983-2013	31	Flow	Regulated
05BH004	Bow River at Calgary	7,868	1911-2013	103	Flow	Regulated
05BD003	Lake Minnewanka near Banff	647	1916-2013	98	Level	Regulated
05BC006	Spray Reservoir at Three Sister Dam	N/A	1949-2013	65	Level	Regulated
05BC002	Spray River near Spray Lakes	360	1915-1939	25	Flow	Natural
05BC001	Spray River at Banff	751	1910-2013	104	Flow	Regulated since 1951
05BF005	Upper Kananaskis Lake	151	1932-2013	82	Level	Regulated
05BF009	Lower Kananaskis Lake	359	1932-2013	82	Level	Regulated
05BF025	Kananaskis River below Barrier Dam	899	1975-2013	39	Flow	Regulated
05BF001	Kananaskis River near Seebe	933	1911-1962	52	Flow	Regulated starting 1932
05BJ004	Elbow River at Bragg Creek	791	1934-2013	80	Flow	Natural
05BJ010	Elbow River at Sarcee Bridge	1,190	1979-2013	35	Flow	Natural
05BJ005	Elbow River above Glenmore Dam	1,220	1933-1977	45	Flow	Natural
05BJ008	Glenmore Reservoir at Calgary	1,224	1976-2013	38	Level	Regulated
05BJ001	Elbow River below Glenmore Dam	1,236	1908-2013	106	Flow	Regulated since 1932
05BH003	Nose Creek at Calgary	893	1911-1986	76	Flow	Natural
05BK001	Fish Creek near Priddis	261	1957-2013	57	Flow	Natural
05BL024	Highwood River near the Mouth	3,952	1970-2013	44	Flow	Regulated
05BM002	Bow River below Carseland Dam	15,660	1956-2013	58	Flow	Regulated
05BM004	Bow River below Bassano Dam	20,250	1916, 1919-1933, 1964-2013	66	Flow	Regulated
05BN012	Bow River near the Mouth	25,280	1965-2013	49	Flow	Regulated

2.0 BASIN-WIDE HYDROLOGY

2.1 General Approach

Golder conducted a hydrologic study for ESRD (then Alberta Environment, AENV) and The City in 2010 to estimate the return period flood estimates for use in the Bow and Elbow Rivers hydraulic model, upon which the 2012 flood inundation maps are based (Golder, 2010 & 2012). According to historic records, major floods occurred on the Bow River in 1879, 1897, 1902, 1929, 1932, 1995 and 2005. Records also indicate that major floods occurred on the Elbow River in 1915, 1923, 1929, 1995, and 2005. As part of the 2010 study, the hydrology of the Bow and Elbow Rivers was examined in detail by reviewing past work (such as the 1983 Calgary Floodplain Study, AENV), utilizing the latest methods of frequency analysis, and considering changes in flows due to flow regulation by hydro infrastructure, water diversions and land use changes.

The 2010 hydrologic study computed naturalized 100-year flood flows on the Bow River above Elbow River of 1,710 m^3/s and on the Elbow River above Glenmore Reservoir of 737 m^3/s. Preliminary data for the 2013 flood event suggest that the peak flow recorded on the Bow River above Elbow River at WSC Station 05BH004 was close to the 2010 100-year flood estimate, while the peak flow on the Elbow River above Glenmore Reservoir at WSC Station 05BJ010 was significantly greater than the 2010 100-year flood estimate.

The scope of work for the present basin-wide hydrology assessment included: generation of to-2013 naturalized daily flow series' at the major storage facilities on the Bow River upstream of Bearspaw Dam and on the Elbow River at Glenmore Dam; and the estimation of 2-, 5-, 10-, 20-, 50-, 100-, 200-, 500-, and 1,000-year flood flows (corresponding to 50, 20, 10, 5, 2, 1, 0.5, 0.2 and 0.1 percent probabilities of annual exceedance, respectively) based on flood frequency analysis of naturalized and/or recorded peak flow series at relevant locations along the Bow River and its tributaries, including the Elbow River.

The general approach of the 2014 hydrology assessment was based on the methodology detailed in the 2010 hydrology report (Golder 2010) prepared for The City and ESRD as part of the 2010-2012 Bow and Elbow River Hydraulic Model and Flood Inundation Mapping Project. The flow naturalization and computation of regulated and natural flow statistics followed the same procedures as in the 2010 study. To satisfy Calgary-specific requirements, flood frequency flows were estimated for the Elbow River above and below Glenmore Dam, the Bow River above and below Bearspaw Dam, as well as above and below the Elbow River and at confluences with major tributaries, including the Highwood River, Fish Creek, Pine Creek, and Nose Creek.

The present assessment also included documentation of preliminary, recorded June 2013 flood peaks at select gauged locations within the study area, and estimation of peaks at select ungauged locations or at gauged locations with incomplete records. Corresponding return periods or frequencies of the June 2013 flood were also computed. In addition to hydrometric gauge sites and the above-noted locations within Calgary, locations of interest to ESRD included the communities of Banff, Canmore, Exshaw, Lac des Arcs, Seebe, Morley, Stoney First Nation, Ghost Lake, Cochrane, Bearspaw, Waiparous, Bragg Creek, Tsuu T'ina First Nation, Siksika First Nation and Bassano, as well as significant tributary locations. The list of selected locations included:

- Elbow River at Bragg Creek (WSC Station 05BJ004);
- Elbow River at Sarcee Bridge (WSC Station 05BJ010);
- Elbow River Inflow into Glenmore Reservoir;
- Elbow River below Glenmore Dam (WSC Station 05BJ001);

- Bow River at Lake Louise (WSC Station 05BA001);
- Bow River at Banff (WSC Station 05BB001);
- Bow River downstream of Spray River;
- Forty Mile Creek upstream of Bow River;
- Spray River at Banff (WSC Station 05BC001);
- Cougar Creek Upstream of Bow River;
- Stoneworks Creek at Highway 1;
- Exshaw Creek at Exshaw;
- Kananaskis River upstream of Bow River;
- Ghost River above Waiparous Creek (WSC Station 05BG101);
- Waiparous Creek near the Mouth (WSC Station 05BG006);
- Ghost Reservoir Inflow;
- Ghost Reservoir Outflow;
- Bow River at Cochrane (WSC Station 05BH005);
- Bearspaw Reservoir Inflow;
- Bearspaw Reservoir Outflow;
- Bow River at Calgary (WSC Station 05BH004);
- Bow River downstream of Elbow River Confluence;
- Bow River upstream of Highwood River Confluence;
- Bow River downstream of Highwood River Confluence;
- Bow River below Carseland Dam (WSC Station 05BM002);
- Bow River at Highway 547;
- Bow River at Highway 842;
- Bow River below Bassano Dam (WSC Station 05BM004);
- Bow River at Highway 539;
- Bow River at Highway 36;
- Bow River at Highway 875; and
- Bow River near the Mouth (WSC Station 05BN012) – at Highway 524.

2.2 Generation of Naturalized Daily Flow Series

The hydrology of the Bow River upstream of Calgary is influenced by the operation of several storage reservoirs on the Bow River (Bearspaw Reservoir, Ghost Lake) and its tributaries (Lake Minnewanka, Spray Lake, Barrier Lake, Lower and Upper Kananaskis Lakes), and the hydrology of the Elbow River and Bow River downstream of the Elbow River confluence is influenced by the operation of Glenmore Reservoir.

Naturalized daily flow series up to 2013 were developed at all major storage facilities on the upper Bow River, including inflows to Bearspaw Reservoir, Ghost Lake, Lake Minnewanka, Spray Lake, Barrier Lake, Lower and Upper Kananaskis Lakes, and Glenmore Reservoir on the Elbow River. The flow naturalization used the same project depletion method and the SSARR channel routing procedures as used by ESRD. The approach is explained in more detail in Appendix A of the 2010 hydrology study (Golder, 2010) and reproduced as Appendix A of this report. Naturalization of daily flows was facilitated by the Natural Flow Computation Program (NFCP) developed for the Prairie Provinces Water Board (Optimal Solutions, 2009). The annual maximum daily flows up to 2013 from each naturalized daily flow series are provided in Appendix A.

2.3 Statistical Tests on Flood Series

An in-house application of Environment Canada's Consolidated Frequency Analysis (CFA) software was used for flood frequency analyses and to conduct statistical tests for independence (not serially correlated), trend, randomness, and homogeneity. This application uses the same parametric probability distribution functions (i.e., Three-parameter Log-Normal, Extreme Value, Log-Pearson Type III and Weibull) as the CFA for fitting the flood flow series. The application incorporates modern boot strapping and two methods for parameter estimation (methods of moments and maximum likelihood), the ability to estimate confidence intervals for a flood estimate of all the standard return periods, and the Anderson-Darling methods (Stephens, 1974) to identify the best-fit probability distribution.

Table 2.1 provides the results of statistical tests on the naturalized and natural annual maximum daily flow series at various key locations on the Bow River and its tributaries. The results of statistical tests indicate that most of the recorded or naturalized daily flow maxima are independent, random, homogeneous, and do not display any significant trends. Inflows to Bearspaw Reservoir display a trend and non-homogeneity at the 1% and 5% level of significance. The non-homogeneity and trends for inflows to Bearspaw Reservoir may be due to a combination of long-term variability in the region's climate regime and alteration of flow patterns following the construction of major storage facilities on the Bow River and its tributaries. Notwithstanding the trend and non-homogeneity in the maximum annual daily flow series, the entire series for the Bow and Elbow Rivers are considered appropriate for frequency analysis.

2.4 Frequency Analysis of Naturalized Peak Flow Series

The City and ESRD provided the historic WSC and preliminary 2012 and 2013 flow data for gauges on the Bow River, Elbow River and their tributaries. TransAlta provided flow and reservoir level data at their hydropower developments on the Bow River and its tributaries. The regulated flows were naturalized and annual maximum daily flow series were developed at these locations.

The purpose of the frequency analysis of naturalized maximum daily flow series was to estimate the instantaneous flood frequency flows from 2-year to 1000-year using the naturalized daily flow series. Frequency analyses on the annual maximum daily flow series at regulated locations were completed for the Bow River above Bearspaw Dam and the Elbow River above Glenmore Reservoir. The results are provided in Table 2.2.

Table 2.1: Statistical Test of Annual Maximum Daily Flows

Station Name	Local Inflow into Lower Kananaskis	Inflow to Upper Kananaskis Lake	Inflow to Lake Minnewanka	Inflow to Spray Lake	Local Inflow to Spray River at mouth	Inflow to Barrier Lake	Bow River at Banff	Inflow to Ghost Reservoir	Inflow to Bearspaw Reservoir without Historic Data	Inflow to Glenmore Reservoir
Serial correlation coefficient test for independence										
S_1	-0.01	0.20	0.21	0.18	0.23	0.31	0.01	0.05	0.18	0.13
t	-0.06	1.20	2.10	1.82	1.84	3.06	0.13	0.45	1.79	1.36
t(α=0.05)	-1.69	1.69	1.66*	1.66*	1.67*	1.66*	1.66	1.66	1.66*	1.66
t(α=0.01)	-2.43	2.44	2.37	2.36	2.39	2.37*	2.36	2.37	2.36	2.36
Spearman rank order correlation coefficient test for no-trend										
r_s	-0.05	0.11	0.11	0.05	0.11	0.21	0.22	0.05	0.25	-0.01
t	-0.32	0.66	1.10	0.46	0.87	1.98	2.25	0.43	2.61	-0.08
t(α=0.05)	-2.03	2.03	1.99	1.98	2.00	1.99	1.98*	1.99	1.98*	-1.98
t(α=0.01)	-2.72	2.72	2.63	2.63	2.66	2.63	2.62	2.64	2.63	-2.62
Mann-Whitney split sample test for homogeneity										
Size of earlier sample	20	20	46	49	30	45	50	20	23	25
z	-0.48	-1.14	-0.44	-0.11	-1.48	-2.27	-1.40	-0.12	-3.48	-1.58
z(α=0.05)	-1.64	-1.64	-1.64	-1.64	-1.64	-1.64*	-1.64	-1.64	-1.64*	-1.64
z(α=0.01)	-2.33	-2.33	-2.33	-2.33	-2.33	-2.33	-2.33	-2.33	-2.33*	-2.33

*: Instances when the criteria for the respective statistical tests were not met.

Table 2.2: Estimated Daily Flood Flows (m^3/s) for Various Return Periods - Derived from Frequency Analysis of Natural or Naturalized Annual Maximum Daily Flows for Streams with Storage Reservoirs

Return Period (Year)	Local Inflow to Lower Kananaskis Lake	Inflow to Upper Kananaskis Lake	Inflow to Lake Minnewanka	Inflow to Spray Lake	Local Inflow to Spray River at Mouth	Inflow to Barrier Lake	Bow River at Banff	Inflow to Ghost Reservoir	Inflow to Bearspaw Reservoir without Historical Data	Inflow to Bearspaw Reservoir with Historical Data	Inflow to Glenmore Reservoir
Drainage Area (km^2)	**151**	**150**	**647**	**520**	**230**	**899**	**2,210**	**6,550**	**7,770**	**7,770**	**1,236**
2	17.4	22.4	53.6	65.2	12.0	70.8	205	348	376	354	58.5
5	21.8	28.2	80.4	87.8	20.0	113	262	471	520	592	108
10	24.7	32.5	101	107	27.0	148	296	573	641	814	156
20	27.4	36.9	124	129	35.8	188	326	688	781	1,060	218
50	30.9	42.9	158	164	50.4	250	361	869	1,000	1,420	331
100	33.5	47.7	187	196	63.8	307	385	1030	1,210	1,720	448
200	36.1	52.8	219	235	79.6	375	407	1,220	1,450	2,040	602
500	39.6	60.1	268	298	105	482	435	1,530	1,840	2,480	885
1,000	42.2	65.6	309	357	127	581	455	1,810	2,210	2,830	1,180

2.5 Routing of Naturalized Daily Flood "Hydrographs" of Various Return Periods

Synthetic inflow flood "hydrographs" at major storage facilities on the Bow River and its tributaries, including the Elbow River at Glenmore Reservoir, were developed for each return period assessed as part of the flood frequency analyses of the naturalized maximum daily flow series. The synthetic inflow "hydrographs" were developed using the same approach as in Golder (2010). The approach is summarized below:

- For a specific computed return period flood (for example, the 100-year daily flood), an analogous actual daily flow of equal or similar magnitude was identified from the naturalized daily flow series;
- The flood volumes, time to peak and the "hydrograph" time base for each selected return period daily flood "hydrograph" were determined based on a recorded naturalized (daily time step) flow series identified as being analogous for each computed return period flood; and
- A dimensionless Gamma function, with its mean, standard deviation and skewness parameters similar to those of the recorded analogous "hydrograph", was developed for each return period flood event, wherever possible.

It should be noted that these daily flood "hydrographs" are not true hydrographs, but synthetic and idealized representations of actual but unknown flood hydrographs represented as a series of average daily flows.

The flood volumes, along with the estimates of the time base of the daily flood "hydrographs" were used to scale the ordinates of the dimensionless Gamma functions such that the maximum daily flow, the time to peak and the total surrogate "event" flow volume closely matched the target values for a given return period. For example, for the 50-year daily flood inflow to Glenmore Reservoir, with a maximum daily flow of 302 m^3/s, the analogous recorded maximum daily flow of May 23, 1932 (311 m^3/s) was used as a surrogate to derive the 50-year daily flood inflow "hydrograph". The time to peak for the May 1932 flood was about two days. The mean discharge, standard deviation, hydrograph time base of about seven days, a base flow of 52 m^3/s, and a skewness coefficient of 0.582 were used to determine the parameters for the Gamma function.

It was not always possible to find a surrogate or analogous flood from naturalized, recorded daily data for each return period flood, especially for floods with return periods greater than 50 years. In addition, for some surrogate floods, it was not possible to fit the Gamma function if the skewness coefficient was either small or negative. For those cases, the shape of the Gamma function was assumed to be the same as the daily flood inflow "hydrographs" derived for a different return period. For example, for deriving the daily flood inflow "hydrographs" to Glenmore Reservoir, the only surrogate observed hydrograph that could be identified and fitted to a Gamma function was the one corresponding to the 50 year return period. Hence, the shapes of inflow "hydrographs" for other return periods were assumed to be the same as the 50 year return period.

Naturalized daily flood "hydrographs" for each return period were developed for the following hydropower developments on tributaries to the Bow River: Cascade (Lake Minnewanka), Spray Lake, Upper Kananaskis Lake, Lower Kananaskis Lake, Barrier Lake, Ghost Lake and Bearspaw Reservoir. Naturalized daily flood "hydrographs" were also developed at the WSC gauging station at Banff (WSC Station 05BB001), which records natural flows (unaffected by any man-made regulation) at a location with a drainage area of 2,210 km^2.

The naturalized daily flood "hydrographs" are provided in Appendix B of this report.

2.5.1 Estimation of Annual Peak Instantaneous Flows from Annual Maximum Flows

The maximum daily flows obtained after routing the synthetic naturalized daily inflow “hydrographs” through Bearspaw and Glenmore Reservoirs were transformed into peak instantaneous discharges using updates of the relationships established in 2010 between recorded annual maximum daily and annual maximum instantaneous flows (see Appendix B in Golder 2010). For the Bow River below Bearspaw Dam, this relationship was established in the 2010 study from recorded annual maximum daily and instantaneous flows at WSC Station 05BH004 (Bow River at Calgary) between 1915 and 2007. Based on discussions with ESRD and The City during a project meeting on May 8, 2014, it was decided that the relationship between maximum instantaneous and maximum daily should be based on relatively natural flow records of the Bow River at Calgary between 1915 and 1932, when the effects of TransAlta’s reservoirs during that period would have been minimal. The updated relationship is shown in Figure 2.1.

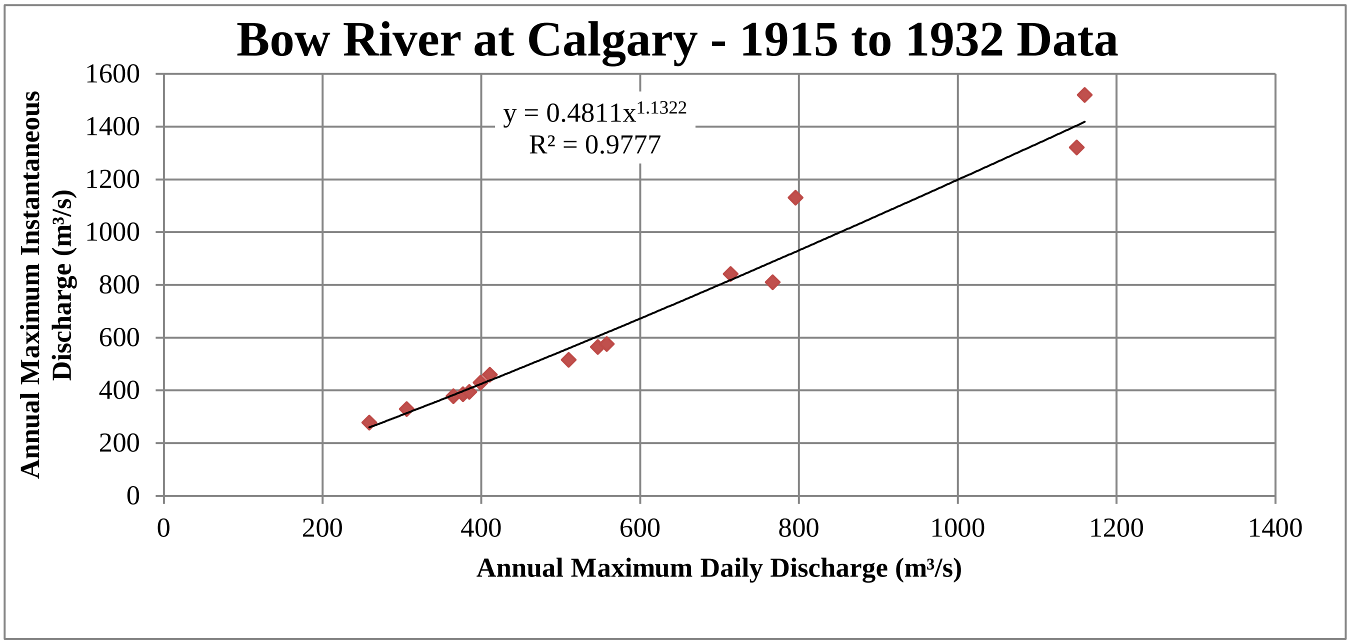


Figure 2.1: Relationship between Maximum Instantaneous and Maximum Daily Flows for the Bow River at Calgary

For the Elbow River below Glenmore Dam, the relationship was established based on recorded maximum daily and maximum instantaneous flows at WSC Station 05BJ001 (Elbow River below Glenmore Dam) and on historic large floods estimated for the Elbow River by T. Blench & Associates (Blench, 1965). The relationship was updated for this study using flow data up to 2013 and is shown in Figure 2.2.

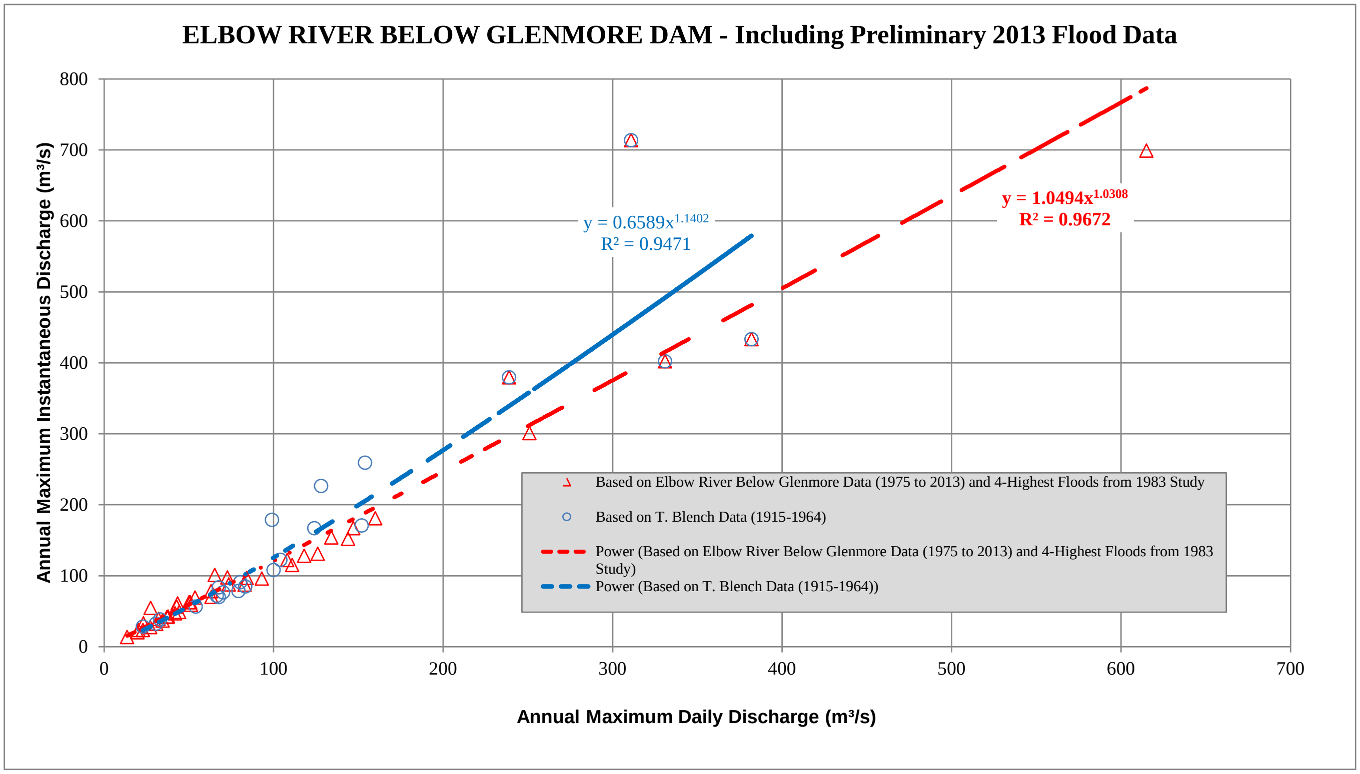


Figure 2.2: Relationships between Maximum Instantaneous and Maximum Daily Flows for the Elbow River below Glenmore Dam

2.5.2 Bow River below Bearspaw Dam

The naturalized maximum instantaneous peak flood flows on the Bow River upstream of its confluence with Elbow River corresponding to the routed naturalized daily flood inflow “hydrograph” for each return period are provided in Table 2.3. The flood routing was based on current operating rules. Table 2.3 also shows the naturalized maximum instantaneous peak flood flows for each return period obtained from the maximum daily flows (Table 2.2) using the updated maximum instantaneous-maximum daily flow relationships (Figure 2.1).

Table 2.3 shows a comparison of flood flows derived for the present hydrology assessment (with data up to 2013, including five more years of data than in the 2010 study) with those in the 2010 study (with data up to 2008).

Analyses carried out during the 2010 study indicated that Ghost Reservoir and Bearspaw Reservoir, on their own, have negligible effects (reductions of between 1% and 2%) on peak flows, as demonstrated by comparing Columns 1 and 5 in Table 2.3. Similar adjustments were made to the peak outflow values at Bearspaw Reservoir (Column 2 of Table 4) obtained during the 2014 update to develop the “Naturalized Flow Data up to 2013, Including Historic Floods, Routed through Bearspaw Reservoir” values shown in Column 6 of Table 2.3.

Table 2.3: Comparison of Instantaneous Flood Flows (m^3/s) for the Bow River Upstream of its Confluence with the Elbow River

Return Period (Years)	(1) Frequency Analyses of Naturalized Flow Data up to 2008 using Method in the 2010 Study for Incorporating Historic Floods (2010 Study)	(2) Frequency Analyses of Naturalized Flow Data up to 2013 using Method in the 2010 Study for Incorporating Historic Floods (2014 Study)	(3) Routing of Naturalized Inflow Hydrographs based on Data up to 2008 and Excluding Historic Floods through Bearspaw and Upstream Reservoirs (2010 Study)	(4) Routing of Naturalized Inflow Hydrographs based on Data up to 2013 and Excluding Historic Floods through Bearspaw and Upstream Reservoirs (2014 Study)	(5) Routing of Naturalized Inflow Hydrographs based on Data up to 2008 and Including Historic Floods Routed through Bearspaw Reservoir ONLY (2010 Study)	(6) Routing of Naturalized Inflow Hydrographs based on Data up to 2008 and Including Historic Floods Routed through Bearspaw Reservoir ONLY (2014 Study)
	(1879-2008)	(1879-2013)	(1912-2008 Excluding Historic Floods)	(1912-2013 Excluding Historic Floods)	(1879-2008)	(1879-2013)
2	423	373	494	385	418	369
5	606	666	614	487	597	659
10	774	937	751	586	763	927
20	983	1,240	842	681	970	1,230
50	1,350	1,680	969	820	1,330	1,660
100	1,710	2,040	1,070	832	1,700	2,020
200	2,170	2,420	1,210	1,050	2,160	2,390
500	2,980	2,950	1,520	1,370	2,970	2,920
1,000	3,810	3,370	1,780	1,680	3,810	3,340

A comparison of the results of the 2010 study and the 2014 update suggests the following:

- There is a significant discrepancy in the naturalized flows routed through Bearspaw Reservoir between the 2010 and 2014 analyses. The discrepancy has been traced to an error in the daily flood inflow "hydrographs" generated in 2010 for Bow River at Banff. Table 4 in Golder (2010) indicates that the 100-year and 1000-year flood flows on the Bow River at Banff (WSC Station 05BB001) were 377 and 450 m^3/s, respectively. However, the synthetic "hydrographs" shown for Bow River at Banff in Appendix B (Plot (f)) of Golder (2010) suggest that the 100-year and 1,000-year flood flows on the Bow River at Banff were 560 and 670 m^3/s, respectively. During the 2014 update, the 100-year and 1000-year flood flows on the Bow River at Banff are estimated as 385 and 455 m^3/s, respectively, and the synthetic hydrographs in Appendix B of this report reflect these values.
- The values in Column 2 of Table 2.3, obtained during the 2014 update, are generally higher than the equivalent values obtained during the 2010 study. The exceptions are for the 2-year, 50-year and 1000-year flood estimates.
- The values in Column 6 of Table 2.3, obtained during the 2014 update, are generally higher than the equivalent values obtained during the 2010 study. The exceptions are for the 2-year, 50-year and 1000-year flood estimates.
- No adjustment, using the method in USGS Bulletin 17B, of the 2014 updated flood flows (shown in Column 6 in Table 2.3) was made during the 2014 update. One of the findings of the Golder (2010) study was that once historic floods were incorporated using the approach described therein, the results from the two approaches were essentially the same.

The differences between the flood estimates reported in the 2010 study and the 2014 update study are due to (1) the significant flood event that occurred in 2013 and (2) the revised relationship between maximum instantaneous flow and maximum daily flow derived from natural flood data recorded between 1915 and 1932.

2.5.3 Elbow River below Glenmore Reservoir

Table 2.4, Columns 1 to 4, shows the return period floods (maximum daily and maximum instantaneous) obtained during the 2010 study based on return period synthetic inflow hydrographs routed through Glenmore Reservoir.

Corrections to peak flood flows routed through Glenmore Reservoir were made during the 2010 study to account for historic floods corresponding to those observed for the Bow River. The corrections were made using a similar procedure as the 1983 study by AENV since there was no historic flood recorded on the Elbow River. In the 1983 study, the frequency plot for the recorded floods for the Elbow River was shifted to mimic the shape of the frequency plots for the Bow River that included historic floods. The resulting increase/decrease in peak flood flows for the Elbow River were about 3% decrease for 2-year flood, 12% increase for 5-year, 24% increase for 10-year, 32% increase for 20-year, 42% increase for 50-year, and 47% increase for 100-year or greater return period floods. The results from the 2010 study are shown in Columns 5 and 6 in Table 2.4.

The equivalent values obtained during the 2014 update are shown in Table 2.5. The flood routing was based on current operating rules at Glenmore Reservoir. The results in Table 2.5 suggest that a significant increase in the 2014 updated flood estimates for all return periods compared to the 2010 results.

Table 2.4: Comparison of Inflows and Outflows Derived from Naturalized Synthetic Daily Flood Inflow "Hydrographs" for the Elbow River below Glenmore Dam – 2010 Study

Return Period (Years)	Based on Naturalized Recorded Flows (Inflow)		Naturalized Flows Routed through Glenmore Reservoir (Outflow)		Naturalized Flows Routed through Glenmore Reservoir and Corrected for Historic Floods (Outflow)	
	(1) Maximum Daily Discharge (m^3/s)	(2) Instantaneous Discharge (m^3/s)	(3) Maximum Daily Discharge (m^3/s)	(4) Instantaneous Discharge (m^3/s)	(5) Maximum Daily Discharge (m^3/s)	(6) Instantaneous Discharge (m^3/s)
2	55.9	66.8	45.1	53.3	43.6	51.5
5	107	132	73.7	89.1	82.2	99.4
10	154	193	126	156	156	193
20	211	267	165	206	219	274
50	302	389	245	313	349	445
100	385	501	366	476	538	699
200	481	633	477	626	701	922
500	632	841	624	830	917	1,220
1,000	766	1,030	757	1,020	1,110	1,490

Table 2.5: Comparison of Inflow and Outflow Flood Flows Derived from Naturalized Synthetic Inflow Hydrographs for the Elbow River below Glenmore Reservoir – 2014 Update

Return Period (Years)	Based on Naturalized Recorded Flows (Inflow)		Naturalized Flows Routed through Glenmore Reservoir (Outflow)		Naturalized Flows Routed through Glenmore Reservoir and Corrected for Historic Floods (Outflow)	
	(1) Maximum Daily Discharge (m^3/s)	(2) Instantaneous Discharge (m^3/s)	(3) Maximum Daily Discharge (m^3/s)	(4) Instantaneous Discharge (m^3/s)	(5) Maximum Daily Discharge (m^3/s)	(6) Instantaneous Discharge (m^3/s)
2	58.5	69.6	55.5	65.9	53.8	63.9
5	108	131	105	127	118	143
10	156	191	153	187	190	234
20	218	270	168	206	222	275
50	331	415	276	344	392	494
100	448	567	442	560	628	803
200	602	769	595	760	875	1,130
500	885	1,140	877	1,130	1,290	1,690
1,000	1,180	1,540	1,170	1,530	1,720	2,270

2.6 Peak Flow Estimates for Major Tributaries

ESRD and The City required updated flood flow estimates with return periods from the 2-year to the 1000-year for each major tributary (i.e., Nose Creek, Fish Creek, Pine Creek, and Highwood River) entering the Bow River between the Bearspaw Dam and the Highwood River confluence. A frequency analysis of the annual maximum instantaneous flow series for each tributary had been performed as part of the 2010 study. The 2010 study investigated two approaches to estimate flood flows for the lower reaches of the Bow River (the reach between its confluences with Elbow River and Highwood River), one based on coincident return period flood events and the other based on adjustments for slightly different timing of actual recorded annual flood peaks. The first approach resulted in conservative estimates of peak flows downstream of tributary confluences and was consistent with the direction provided by ESRD to assume "coincident events for all rivers and streams". The final recommended flood estimates provided in the 2010 study were based on this approach and the same approach was used for the 2014 update. The flood frequency estimates at the mouth of each major tributary to the Bow River up to the Highwood River are provided in Table 2.6 and the results for each location on the Bow River below a major tributary are provided in Table 2.7.

2.6.1 Nose Creek at Calgary

Flow records for Nose Creek at Calgary (WSC Station 05BH003) are only available for the periods from 1911 to 1919 and from 1973 to 1986. The operation of this station was discontinued after 1986. The annual series of recorded maximum instantaneous discharges, maximum daily discharges and corresponding dates are provided in Appendix B in Golder (2010). A relationship between annual maximum daily discharges and maximum instantaneous discharge was established (shown in Appendix B of Golder (2010)), to estimate annual maximum instantaneous discharge for those years where instantaneous flows were not available. The flood frequency estimates for Nose Creek at Calgary for various return periods, as estimated during the 2010 study, are provided in Table 2.6.

2.6.2 Fish Creek at the Mouth

Flow records for Fish Creek at the mouth (WSC Station 05BK003) are available only for the period from 1989 to 1993. Flood flow estimates for Fish Creek at the mouth were transferred using data recorded at Fish Creek near Priddis (WSC Station 05BK001) based on regional relationships between drainage area and return period floods.

The transfer of flood flows from the upstream station to the mouth was accomplished during the Golder (2010) study using the following steps.

1) Establish a regional relationship between drainage area and flood peaks for various return periods.

2) Establish a relationship between annual maximum daily flows and annual instantaneous flows for Fish Creek near Priddis.

3) Transfer the annual maximum daily flood flows from Fish Creek near Priddis to Fish Creek at the mouth based on the regional relationship established in Step 1.

4) Generate instantaneous flood flows for Fish Creek at the mouth based on the relationship established in Step 2.

Threepoint Creek near Millarville (WSC Station 05BL013) has a drainage area of 507 km^2. A review of recorded flow data at this hydrometric station indicated a high level of similarity with the flow regime at Fish Creek near Priddis (drainage area of 261 km^2). Over a period of 25 years (1967 to 2007) the annual maximum daily flows at the two stations occurred on the same date for 23 of these years, and for the remaining two years the maximum daily flow lagged by one day.

The similarity between these two closely located watersheds (Fish Creek and Threepoint Creek) permitted the establishment of a regional relationship that allowed for the transfer of the flood flow data from Fish Creek near Priddis (drainage area of 261 km^2) to Fish Creek at the mouth (drainage area of 442 km^2). A relationship between annual maximum daily discharges and annual maximums instantaneous discharges was established using the Fish Creek near Priddis data. This relationship was used to derive the annual maximum instantaneous discharges for Fish Creek at the mouth from the maximum daily discharge.

A frequency analysis of annual floods at WSC Station 05BK001, including the preliminary 2013 flood peak value, was carried out as part of an updated regional analysis as described in Section 2.8. The regional flood estimates derived as part of the 2010 study (Golder, 2010) are comparable to the regional flood estimates obtained as part of the 2014 study. For example, the regional equations depicted in Figure 2.3 in Section 2.8 suggest that the 20-year and 100-year flood flow from a drainage area of 442 km^2 (equal to that of Pine Creek at the mouth) are expected to be about 198 and 454 m^3/s, respectively, which are similar to the estimates of 198 and 444 m^3/s reported in the 2010 study report. Hence, the 2010 flood flow estimates for Fish Creek at the mouth were retained for this study and are reproduced in Table 2.6.

2.6.3 Pine Creek at the Mouth

AMEC completed a review and update of flood frequency estimates at several locations on Pine Creek through the Municipal District of Foothills and The City of Calgary for a flood hazard mapping study recently completed for ESRD (AMEC, 2013). AMEC provided two set of flood frequency estimates, one based on application of the HSPF model and the other based on a regression analysis of floods recorded on regional streams. Given the uncertainties associated with estimating flood discharges in Pine Creek, AMEC recommended that the more conservative HSPF estimates be used for the Pine Creek flood hazard study. The HSPF flood frequency estimates used in the flood hazard study are provided in Table 2.6 and were adopted for this study.

2.6.4 Highwood River at the Mouth

Golder completed an update of the flood frequency estimates of the Highwood River at various locations on the river including at its mouth as part of a separate study for ESRD (Golder, 2014). The Highwood River experienced extreme high flows in 2013 and several of the hydrometric stations were not functioning during the peak flow period. The 2013 flood estimates were based on hydrologic model simulations that were then adjusted with peak estimates obtained from extending the incomplete recorded flood hydrographs at those hydrometric stations. The flood frequency estimates were then updated and these values, given in Table 2.6, have been used for the 2014 updates of flood flows on the Bow River below Highwood River.

Table 2.6: Instantaneous Flood Flows (m^3/s) for Tributary Streams to the Bow River at the Mouths

Return Period (Years)	Elbow River	Nose Creek	Fish Creek	Pine Creek	Highwood River
Drainage Area (km^2)	**1,236**	**893**	**442**	**212**	**3,952**
2	63.9	6.15	39.0	3.9	205
5	143	14.2	85.7	12.9	473
10	234	23.0	134	19.8	742
20	275	35.3	198	27.3	1,210
50	494	60.2	317	38.1	1,660
100	803	88.8	444	47.0	2,210
200	1,130	130	618	56.7	2,870
500	1,690	214	946	70.8	3,980
1,000	2,270	310	1,300	82.4	4,940

Table 2.7: Instantaneous Flood Flows (m^3/s) along the Bow River – Assuming Coincident Events for all Rivers and Streams

Return Period (Years)	Bow River above Confluence with Elbow River	Bow River below Confluence with Elbow River	Bow River below Confluence with Nose Creek	Bow River below Confluence with Fish Creek	Bow River below Confluence with Pine Creek	Bow River below Confluence with Highwood River
2	369	433	439	478	482	687
5	659	802	816	902	915	1,390
10	927	1,160	1,180	1,320	1,340	2,080
20	1,230	1,500	1,540	1,740	1,770	2,980
50	1,660	2,150	2,210	2,530	2,570	4,230
100	2,020	2,820	2,910	3,360	3,400	5,610
200	2,390	3,520	3,650	4,270	4,320	7,200
500	2,920	4,610	4,820	5,770	5,840	9,820
1,000	3,340	5,610	5,920	7,220	7,300	12,240

2.7 Flood Frequency Analysis at Gauged Locations with Natural Flows

The City and ESRD provided the historic WSC and preliminary 2012 and 2013 flow data for gauges on unregulated watercourses on the Bow River, Elbow River and their tributaries. Frequency analyses of the annual flood peak series, including the preliminary 2013 flood peaks, at the various gauged locations in the Bow and Elbow River basins were carried out to estimate floods with return periods of 2, 5, 10, 20, 50, 100, 200, 500 and 1,000 years. Probability distributions considered for fitting the annual flood peak series included the Generalized Extreme Value, Log Pearson Type III, 3-parameter Log Normal and Weibull functions. The estimated flood statistics at the gauged locations are provided in Table 2.8.

2.8 Flood Frequency Estimates at Ungauged Locations

The gauged and ungauged locations on streams in the Bow and Elbow River basins where ESRD requested flood peak estimates and flood frequency statistics are listed in Section 2.1. A regional flood frequency approach was used to develop empirical relationships between drainage areas and floods of a given return period, from which flood statistics at ungauged locations could be estimated. The relationships were used to estimate the return periods of the preliminary 2013 recorded flood flows at gauged locations.

The flood frequency statistics at the ungauged locations were estimated as follows:

- Drainage areas at WSC station locations were obtained from WSC hydrometric data. Drainage areas at ungauged locations were estimated from the known drainage areas at upstream or downstream WSC stations by adding or subtracting, respectively, the estimated local areas between the WSC stations and locations of interest. All drainage areas used in the analyses are gross areas.
- The naturalized flood frequency estimates for the Bow River downstream of Spray River were estimated as follows:
    - Return period flood estimates were obtained for the Bow River at Banff from a frequency analysis of natural (unregulated) maximum instantaneous flows at WSC Station 05BB001.
    - Natural (unregulated) flows were recorded for the Spray River at Banff from 1910 to 1949 at WSC Station 05BC001.
    - The annual maximum instantaneous flows at WSC Station 05BC001 (Spray River at Banff) were about 1.15 times the corresponding annual maximum daily flows based on the only two years (1948 and 1949) that maximum instantaneous flows were available.
    - The annual maximum instantaneous flows at WSC Station 05BC001 from 1911 to 1947 were then calculated from the respective maximum daily flows using the 1.15 multiplier, and a frequency analysis carried out on the filled series from 1911 to 1949.
    - Comparison of annual maximum occurrence dates at WSC Stations 05BC001 and 05BB001 over the 1911-1949 period suggests that in most years they occurred within a day of each other. It is unlikely that the maximum instantaneous flows from the two rivers occurred at the same time. But, it is reasonable to assume that a good approximation of the maximum instantaneous flow of the Bow River below Spray River is the maximum instantaneous flow of the Bow River at Banff plus the maximum daily flow of the Spray River at Banff. The instantaneous flood frequency estimates for the Bow River below Spray River were therefore estimated as the instantaneous return period floods at WSC Station 05BB001 (Bow River at Banff) plus the maximum daily return period floods at WSC Station 05BC001 (Spray River at Banff), computed by dividing the instantaneous values by 1.15.

- Regional relationships between drainage area and floods of a range of return periods were developed for the Elbow River and tributaries of the Bow River that were not affected by flow regulation from TransAlta's operations. The at-station flood frequency estimates for various return periods were plotted against the corresponding drainage areas at the WSC stations on log-log graphs and linear lines were fitted visually for each flood return period. The basins included in the regional analysis reflect the hydrologic responses of high elevation catchment areas. The records at Bow River at Banff (WSC Station 05BB001) and Bow River at Lake Louise (WSC Station 05BA001) were removed from the regional analysis because flood flows at these locations are attenuated by Lake Louise and do not in general reflect the headwater hydrologic responses of other high elevation basins. Figure 2.3 shows the linear log-log fits to the empirical relationships between drainage area and the T-year flood estimates for the mostly headwater sub-basins with unregulated flows in the Bow and Elbow River basins.

The regional relationships between drainage area and T-year flood estimates were then used to estimate the 2 year to 1,000-year flood flows at selected ungauged locations. The estimated flood statistics at the ungauged locations are provided in Table 2.9.

Flood estimates at WSC Stations 05BM002, 05BM004 and 05BN012 were based on frequency analyses of recorded annual flood peaks. The gross drainage areas at the ungauged locations between these stations were estimated visually from a 1:1,000,000 scale map. Flood estimates at ungauged locations on the Bow River were determined by interpolation of flood flows at upstream and downstream gauged locations based on ratios of effective drainage area. The ratio of effective drainage area to gross drainage area at an ungauged location was the average of the ratios at the upstream and downstream gauged locations. This approach is basically a linear transfer of return period flood estimates at WSC Stations 05BM002, 05BM004 and 05BN012 to locations on the Bow River that are in between two adjacent stations. The approach, that essentially constrains the flood estimate at a location to a value between those at the upper and lower WSC stations, is considered reasonable as the relationship between effective runoff contributing areas and flood flows at locations in the lower reaches of the Bow River becomes complex.

Table 2.8: Regional Flood Frequency Analysis Results

WSC Station Name	**Cataract Creek near Forestry Road**	**Waiparous Creek near the Mouth**	**Trap Creek**	**Highwood River at Diebel's Ranch**	**Elbow River at Bragg Creek**	**Fish Creek near Priddis**	**Pekisko Creek**	**Threepoint Creek near Millarville**	**Elbow River at Sarcee Bridge**	**Highwood River at the Mouth**
WSC Station Number	**05BL022**	**05BG006**	**05BL027**	**05BL019**	**05BJ004**	**05BK001**	**05BL023**	**05BL013**	**05BJ010**	**05BL024**
Drainage Area (km^2)	**166**	**332**	**137**	**774**	**791**	**260**	**232**	**507**	**1,189**	**3,952**
2-year	23	29	13	78	64	27	13	42	85	205
5-year	45	70	28	143	129	66	37	111	194	473
10-year	68	117	43	210	198	108	64	185	307	742
20-year	101	179	64	300	290	169	100	281	454	1,210
50-year	164	294	105	473	462	290	168	452	708	1,660
100-year	235	409	150	663	643	431	236	619	954	2,210
200-year	335	555	213	926	883	634	323	827	1,250	2,870
500-year	534	813	336	1,440	1,320	1,050	478	1,190	1,770	3,980
1,000-year	757	1,050	474	2,000	1,780	1,530	619	1,500	2,220	4,940

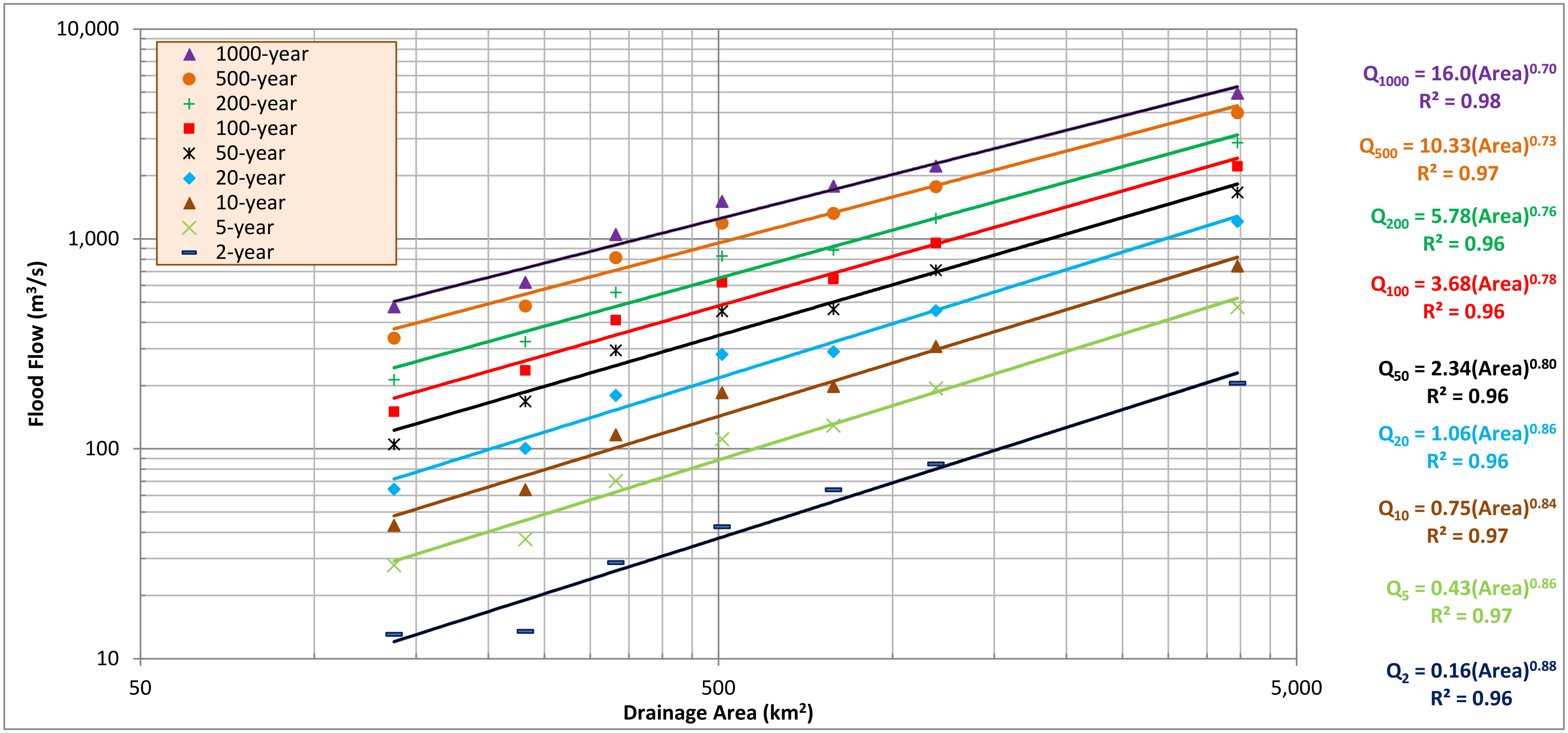


Figure 2.3: Empirical Relationships between WSC Station Drainage Areas and Return Period Flood Estimates – Bow and Elbow River Basins

Table 2.9: Updated Instantaneous Flood Frequency Estimates (Including Preliminary 2013 Flood Flows) at Gauged and Ungauged Locations

WSC Station ID	WSC Station Name or Location of Interest	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)	Flow Series Type[1] and Computed Instantaneous Flood Flows (m^3/s)										Preliminary 2013 Flood Peak (m^3/s)	Approximate Return Period of 2013 Flood Peak
				Type	1000-yr	500-yr	200-yr	100-yr	50-yr	20-yr	10-yr	5-yr	2-yr		
05BJ004	Elbow River at Bragg Creek	791	791	N	1,780	1,320	883	643	462	290	198	129	63.7	1,160 [E]	~ 300-year
05BJ010	Elbow River at Sarcee Bridge - Inflow into Glenmore Reservoir	1,189	1,189	N	2,220	1,770	1,250	954	708	454	307	194	84.6	1,240 [E]	~ 200-year
05BJ001	Elbow River below Glenmore Dam (Including Historic Floods)	1,236	1,236	NZ	2,270	1,690	1,130	803	494	275	234	143	63.9	699	~ 90-year
05BA001	Bow River at Lake Louise	422	422	N	218	184	147	125	105	84.7	71.8	60.6	47.3	61.1	~ 5-year
05BB001	Bow River at Banff	2,210	2,210	N	563	524	471	432	395	345	307	268	210	450	~ 150-year
05BC001	Spray River at Banff (1911-1949)	751	751	N	301	270	232	205	180	150	128	107	79.0	60.1	< 2-year
	Bow River downstream of Spray River	2,961	2,960	N	825	759	673	611	551	476	419	361	279	520 [R]	~ 50-year
	Forty Mile Creek upstream of Bow River	148	148	EQ	102	91	76	66	58	47	40	34	26	~ 76[a]	~ 200-year
	Cougar Creek upstream of Bow River	42.6	42.6	EQ	222	159	100	70	48	26.3	17.8	10.7	4.32	~ 70	~ 100-year
	Stoneworks Creek at Highway 1	6.17	6.17	EQ	57.2	38.9	23.0	15.3	10.1	5.02	3.49	2.03	0.793	~ 15	~ 100-year
	Exshaw Creek at Exshaw	32.3	32.3	EQ	183	130	81.1	56.1	38.3	20.8	14.1	8.42	3.39	~ 70	~ 150-year
	Kananaskis River upstream of Bow River	899	899	R	697	578	450	368	300	226	178	136	85.0	368	~ 100-year
05BG010	Ghost River above Waiparous Creek	485	485	N	1,789	1,174	670	436	282	155	95.1	55.3	20.7	350	~ 50-year
05BG006	Waiparous Creek near the Mouth	333	333	N	1,106	856	581	427	305	185	119	71.1	28.7	320	~ 50-year
	Ghost Reservoir Inflow	6,550	6,550	NZ	3,400	2,980	2,440	2,060	1,700	1,250	945	673	377	1,240	~ 25-year
	Ghost Reservoir Outflow	6,550	6,550	NZ	3,370	2,950	2,420	2,040	1,680	1,240	936	666	373	1,230	~ 25-year
05BH005	Bow River at Cochrane	7,412	7,383	NZ	3,370	2,950	2,420	2,040	1,680	1,240	936	666	373	2,050 [R]	~ 100-year
	Bearspaw Reservoir Inflow	7,770	7,740	NZ	3,370	2,950	2,420	2,040	1,680	1,240	936	666	373	1,900 [R]	~ 100-year
	Bearspaw Reservoir Outflow	7,770	7,740	NZ	3,340	2,920	2,390	2,020	1,660	1,230	927	659	369	1,880 [R]	~ 100-year
05BH004	Bow River at Calgary (IHF[d])	7,870	7,740	NZ	3,340	2,920	2,390	2,020	1,660	1,230	927	659	369	1,720[b] [R]	~ 80-year
	Bow River downstream of Elbow River Confluence (IHF)	9,100	8,950	NZ	5,610	4,610	3,520	2,820	2,150	1,500	1,160	820	433	2,420 [R]	~ 75-year
	Bow River upstream of Highwood River Confluence (IHF)	10,440	10,260	NZ	7,300	5,840	4,320	3,400	2,570	1,770	1,340	915	482	2,820 [R]	~ 75-year
	Bow River downstream of Highwood River Confluence (IHF)	14,390	14,150	NZ	12,240	9,820	7,200	5,610	4,230	2,980	2,080	1,390	687	5,820 [R]	~ 120-year
05BM002	Bow River below Carseland Dam	15,660	14,700	R	6,530	5,100	3,660	2,830	2,180	1,524	1,140	834	495	3,300 [R]	~ 120-year
	Bow River at Highway 547	16,460	15,450	R	6,870	5,370	3,860	3,000	2,310	1,610	1,210	877	514	3,300 [R]	~ 120-year
	Bow River at Highway 842	16,960	15,920	R	7,080	5,540	3,990	3,100	2,390	1,670	1,250	904	526	3,300 [R]	~ 120-year
05BM004	Bow River below Bassano Dam	20,250	17,750	R	7,910	6,220	4,500	3,500	2,710	1,890	1,410	1,010	571	3,340 [R]	~ 90-year
	Bow River at Highway 539	22,250	19,140	R	6,240	4,950	3,620	2,840	2,210	1,560	1,160	842	477	3,340 [R]	~ 150-year
	Bow River at Highway 36	23,050	19,130	R	6,240	4,950	3,620	2,840	2,210	1,560	1,170	842	478	3,340 [R]	~ 150-year
	Bow River at Highway 875	23,850	19,080	R	6,300	5,000	3,660	2,870	2,230	1,570	1,180	849	481	3,340 [R]	~ 150-year
05BN012	Bow River near the Mouth - Highway 524	25,280	19,160	R	6,210	4,930	3,610	2,830	2,200	1,550	1,160	839	476	3,610[c] [R]	~ 200-year

Notes:

1:	Series Type: N: Natural Flows; NZ: Naturalized Flows; R: Regulated Flows; EQ: Based on regional regression equations or estimated using results from other site studies.
a:	See Section 2.9.4 for discussion
b:	At the time when the report for this study was being finalized, WSC estimated this value to be 1,840 m^3/s. This estimate is not expected to change the flood frequency estimates.
c:	At the time when the report for this study was being finalized, WSC estimated this value to be 3,450 m^3/s. This estimate is not expected to change the flood frequency estimates.
d:	IHF – Including Historic Floods
E:	Estimated by WSC and may be different from preliminary recorded value. Estimate used in flood frequency analysis.
R:	Regulated Flow

2.9 Estimates of June 2013 Flood Peaks and Return Periods

One of the objectives of this study was to estimate the return period of the June 2013 flood event for streams at several locations in the Bow and Elbow River basins. The locations of interest are listed in Section 2.1. Table 2.9 provides preliminary estimates of the peak flows during the 2013 flood event, as well as flood frequency estimates that take the June 2013 flood into account. Return period estimates for the preliminary June 2013 flood peaks at each location of interest were obtained by comparing the peaks to the frequency analysis results. The preliminary June 2013 flood peak flow estimates were obtained as follows:

2.9.1 WSC Stations and Other Locations on Bow River and Elbow River

WSC and ESRD provided preliminary continuous flow records during the June 2013 flood event at hydrometric stations such as WSC Stations 05BA001, 05BH004, etc. Table 2.9 shows the maximum flow recorded at these stations. These values are considered preliminary until published by WSC.

WSC or The City provided peak flow estimates at hydrometric stations that stopped recording flows during the peak of the flood, such as WSC Stations 05BJ004, 05BJ010, etc. Such values are denoted as [E] in Table 2.9.

The June 2013 peak flow of the Bow River downstream of Spray River was estimated as the recorded instantaneous peak flow of the Bow River at Banff (WSC Station 05BB001) plus the preliminary maximum daily flow recorded of the Spray River at Banff (WSC Station 05BC001) on the same day (see Section 2.8).

2.9.2 Downstream of Hydropower Reservoirs

TransAlta provided preliminary daily discharges recorded below Barrier (Kananaskis River), Ghost (Waiparous River) and Bearspaw (Bow River) Dams. The daily outflow values were increased by ten percent to estimate peak instantaneous values, however, these estimates are considered to be preliminary and approximate.

2.9.3 Locations on Bow River Downstream of Highwood River Confluence

The peak June 2013 flood estimates at WSC Stations 05BM002, 05BM004 and 05BN012 were based on preliminary flows provided by WSC. Peak flood estimates at ungauged locations on the Bow River were then determined by interpolation of flood flows at upstream and downstream gauged locations based on ratios of effective drainage area (following the procedure described in Section 2.8 for flood frequency estimation).

2.9.4 Locations on Tributaries to Upper Reach of Bow River

The peak June 2013 flood estimates for Cougar Creek upstream of Bow River, Stoneworks Creek at Highway 1, Exshaw Creek at Exshaw, and Forty Mile Creek at Banff were of interest to ESRD. Flows on these streams are not recorded and indirect methods to estimate peak flows were required.

The standard approach taken by Golder is based on comparing the regional flood frequency estimates (using the relationships shown in Figure 2.3) with the estimated return period of the June 2013 flood in other upper Bow River tributary watersheds (see Tables 2.8 and 2.10). The regional data suggest that the return period of the June 2013 flood in the upper watersheds ranges from 100 years (Kananaskis River below Barrier Lake and upstream of Bow River), to 150 years (Bow River at Banff, WSC Station 05BB001) and even to 200 years (Redearth Creek near the Mouth, WSC Station 05BB005).

If the regional correlation was considered valid, the relationships depicted in Figure 2.3 and the drainage areas of ungauged streams at a location of interest could be used to estimate preliminary peak 2013 flood flows and corresponding return period flows.

This approach was used for obtain the Cougar, Stoneworks and Exshaw Creek peak 2013 flows and frequency statistics presented in Table 2.9, with additional details presented in the relevant sections below.

- Cougar Creek upstream of Bow River: ~ 70 m^3/s peak 2013 flow ~ 100-year flood;
- Stoneworks Creek at Highway 1: ~ 15 m^3/s peak 2013 flow ~ 100-year flood; and
- Exshaw Creek at Exshaw: ~ 70 m^3/s peak 2013 flow ~ 150-year flood.

An alternate method, also based on regional data but using a specific analogous basin, was used to obtain the Forty Mile Creek estimates presented in Table 2.9, as outlined in the relevant section below.

- Forty Mile Creek upstream of Bow River: ~ 76 m^3/s peak 2013 flow ~ 200-year flood

Several hydrologic studies were undertaken or commissioned by the provincial government, municipalities, private industry and engineering consultants to characterize the June 2103 flood. Some of these study reports were reviewed to assist in providing estimates of the June 2013 peak flows at the above four locations.

Cougar Creek upstream of Bow River

Cougar Creek is a tributary of the Bow River, located on the north side of the river at Canmore.

BGC Engineering Inc. (BGC) recently carried out a forensic analysis of the June 19-21, 2013 debris flood event on Cougar Creek for the Town of Canmore (BGC, 2013a), and provided an assessment of short-term flood mitigation measures. BGC reviewed available photographs taken during the June 2013 flood event and past flooding events as part of their forensic analysis to develop a short-term mitigation design flow. As part of their analysis, BGC provided an estimate of the peak flow during the flood event.

BGC noted that the 100-year flood for Cougar Creek just upstream of its confluence with the Bow River (drainage area estimated to be about 42.6 km^2 at this location) had been previously been estimated at about 16 m^3/s by AMEC (AMEC, 2003 & 2007). However, photographs and videos reviewed by BGC suggested that the peak flow of the 2013 debris flood was much greater than 16 m^3/s. Photographs of the inlet of the Elk Run Boulevard culvert showed the culvert at about two-thirds capacity at the peak of the flood. CH2M HILL (CH2M HILL, 1993) indicated that this culvert has a capacity of 160 m^3/s, suggesting that the 2013 peak flow may have been in excess of 100 m^3/s. However, based on their analysis, BGC suggested that the extent of aggradation at the culvert inlet during the peak of the flood was not known and the wingwalls had been outflanked, reducing the hydraulic efficiency of the culvert. They noted that it was likely that the peak flow was coincident with a reduced culvert capacity.

Therefore, for the purposes of the short-term mitigation design, BGC tentatively assigned a peak flow of 64 m^3/s to the 2013 event. This is four times the previous 100-year flood estimate. BGC is currently conducting hydraulic modelling of the culvert inlet, with various assumed channel geometries, to develop a range of potential peak flows. Results of that sensitivity analysis were not available at the time of writing their 2013 report.

A return period of about 100 years is considered an appropriate estimate of the 2013 flood at Cougar Creek. This corresponds to an approximate 2013 peak flow of about 70 m^3/s for a drainage area of 42.6 km^2, based on the flood frequency estimates provided in Table 2.9. This estimate is close to BGC's preliminary estimate.

Stoneworks Creek at Highway 1

Stoneworks Creek is a tributary of the Bow River, located on the north side of the river at Canmore. The drainage area is estimated to be about 6.17 km^2 at a location just upstream of Highway 1.

BGC recently conducted a preliminary hazard assessment of Stoneworks Creek, including documentation of damage from the June 2013 flood for the Town of Canmore (BGC, 2013b). BGC postulates that the June 2013 event that impacted the Stoneworks Creek alluvial fan is best described as a debris flood rather than a flood.

Referencing a 2009 Stantec design brief, BGC (2013b) describes flows in Stoneworks Creek being routed to upstream of a 1200 mm diameter culvert named Culvert 4, which would convey flows up to a 10-year flood, with higher flows being directed to a 900 mm diameter culvert named Culvert 8. The 100-year flood would see Culvert 8 receiving approximately 65 percent of the total flow, and Culvert 4 receiving the remaining 35 percent. Culvert 4 was noted to have sufficient capacity (2 m^3/s) to convey 70 percent of the design 100-year flood flow (3 m^3/s). Below Culvert 4, Stonework Creek flows would be routed under Highway 1 through an existing 1200 mm diameter culvert. At the outlet of Culvert 8, creek flows would discharge under Highway 1 through a 900 mm diameter concrete culvert. According to BGC's observations, these works were severely impacted and damaged during the 2013 flood. The 1200 mm diameter culverts under Palliser Trail and Highway 1 became blocked, resulting in the creek flowing parallel to Palliser Trail to the northwest.

Based on an analysis of past events, BGC suggests that the June 2013 event was the largest debris flood on record for Stoneworks Creek, dating back to 1940s. However, no frequency for the 2013 event was provided. Nevertheless, it appears that the 2013 peak flow in Stoneworks Creek was much greater than the previous culvert design 100-year flow of 3 m^3/s.

A return period of about 100 years is considered an appropriate estimate of the 2013 flood at Stoneworks Creek. This corresponds to an approximate 2013 peak flow of about 15 m^3/s for a drainage area of 6.17 km^2, based on the flood frequency estimates provided in Table 2.9.

Exshaw Creek at Exshaw

A report prepared by ARA Engineering Ltd. (ARA) for Alberta Transportation in 2013 (ARA, 2013) provides a peak flow estimate of 42 m^3/s in Jura Creek during the June 2013 flood. Jura Creek is adjacent to Exshaw Creek, and has a drainage area of 15 km^2 at the Highway 1A crossing. The June 2013 flood peak estimate computed by ARA was based on the Basin Runoff Potential Method with a precipitation amount of about 200 mm during the flood event, and was checked by comparing the calculated flow depth with photos of high water marks upstream of the crossing. Using the flood-area relationships provided in Figure 2.3, the 100-year and 200-year flood estimates for a basin with a drainage area of 15 km^2 are 31 and 45 m^3/s, respectively. ARA's peak flow estimate of 42 m^3/s in Jura Creek during the June 2013 flood appears to be closer to the 200-year event based on the regional flood frequency estimates.

Exshaw Creek has a drainage area of about 32.3 km^2 near Exshaw. Assuming that 150-year is an appropriate estimate of the return period of the 2013 flood in Exshaw Creek, a peak flow of about 70 m^3/s is considered a reasonable preliminary 2013 peak flow estimate, based on the flood frequency estimates provided in Table 2.9.

Forty Mile Creek

Forty Mile Creek is currently ungauged, and various methods used to estimate both the 2013 peak and flood frequency statistics provide a wide range of results. Table 2.9 presents recommended values, including a preliminary 2013 peak flow of about 75 m^3/s that corresponds to about a 200-year flood, obtained following the approach described below.

WSC reports a preliminary estimate of a peak flow of 450 m^3/s for the Bow River at Banff (WSC Station 05BB001), and Table 2.9 shows that this flow has a return period of about 150 years.

Northwest Hydraulics Consultants (nhc) completed a flood hazard study for the Bow River and Forty Mile and Echo Creeks at Banff for ESRD prior to the June 2013 flood (nhc, 2013). The study computed 100-year and 1,000-year flood estimates for the Bow River at Banff as 378 and 448 m^3/s, respectively, but the frequency analysis was completed prior to the June 2013 flood. This frequency analysis suggests that the June 2013 peak flow had a return period close to 1,000 years. However, this return period is not consistent with those computed for other locations in the upper reaches of the Bow River, and does not include the flood in its analysis.

The nhc study also references an earlier Banff floodplain study done by AENV that included a 100-year flood estimate of 407 m^3/s (AENV, 1980). This is closer to the 100-year flood estimate of 432 m^3/s for Bow River at Banff (WSC Station 05BB001) provided in Table 2.9.

The nhc report provides a 100-year flood estimate of 43.7 m^3/s for Forty Mile Creek at Banff, as noted in Table 2.10. This estimate is based on the results of a regional flood frequency analysis of relatively short peak flow records (most between the 1970s and 1990s) on similarly sized basins close to the Forty Mile Creek basin.

Golder prepared flood frequency estimates for Forty Mile Creek as noted in Table 2.10 using the regional flood frequency relationships shown in Figure 2.3, that were also used for Cougar, Stoneworks and Exshaw Creeks. This analysis suggests that a 100-year peak flow for Forty Mile Creek at Banff is about 185 m^3/s. The analysis included the preliminary estimates of the 2013 flood at a number of locations in the Bow River, Elbow River and Highwood River basins, i.e., over a much wider region than that in the nhc (2013) study.

Golder believes that the 100-year peak flow estimate for Forty Mile Creek by nhc (2013) is an underestimate because it does not include the 2013 event, and that the estimate based on the standard regional analysis used for the other creeks is an overestimate because it is almost half of the flow recorded for the Bow River at Banff.

The differences in flood frequency estimates for Forty Mile Creek were then addressed to some extent by analyzing the annual peak flows recorded at WSC Station 05BB005, Redearth Creek near the Mouth. Redearth Creek is located on the south side of Bow River and approximately across from Forty Mile Creek. Its drainage area at WSC Station 05BB005 is 147 km^2, which is almost the same as that of Forty Mile Creek upstream of Bow River (148 km^2). It is considered an appropriate surrogate basin for analysis and its flow records between 1974 and 1996 were used in the regional flood analysis undertaken by nhc (2013).

The flow records at WSC Station 05BB005, however, only extend from 1974 to 1996. The peak annual flows for this station were correlated with those at WSC Station 05BB001 (Bow River at Banff) for the concurrent period. The resulting regression relationship was used to generate peak flow estimates at WSC Station 05BB005 from 1909 to 2013, corresponding to the available records at WSC Station 05BB001. Based on this regression relationship, the 2013 peak flow on Redearth Creek is estimated as 76 m^3/s using the peak flow estimate of 450 m^3/s at WSC Station 05BB001, Bow River at Banff. A frequency analysis was conducted on the extended Redearth Creek near the Mouth annual peak flow series, as presented in Table 2.10. Given the lack of records and the range of possible frequencies associated with different analysis techniques, the flood frequency estimates for Redearth Creek as derived above are considered to be appropriate for transfer to Forty Mile Creek at this time.

The estimated 2013 peak flow for Redearth Creek was about 76 m^3/s, which corresponds to a return period of about 200 years. These are considered as the most reasonable estimate for the peak 2013 flow and corresponding return period for Forty Mile Creek upstream of Bow River as presented in Table 2.9 as both basins have almost the same drainage area. No high water marks for the 2013 flood event on Forty Mile Creek near the Fenlands Recreation Center in Banff were available for this study to assess the peak flow. However, a review of the flood maps developed by nhc (2013) along Forty Mile Creek, the topography near the recreation center, and the water levels associated with the return period floods used in the nhc study suggests that a peak flow of 76 m^3/s at this location is not unreasonable.

Table 2.10: Instantaneous Flood Flows (m^3/s) on Forty Mile Creek and Redearth Creek

Return Period (Years)	Forty Mile Creek at Banff (Source: nhc, 2013, which does not include 2013 flood flow)	Forty Mile Creek upstream of Bow River Derived from Regional Relationships in Figure 2.3	Redearth Creek Derived from Recorded and Filled-in Annual Peak Flows at 05BB005	Forty Mile Creek upstream of Bow River Recommended
Drainage Area (km^2)	**139**	**148**	**147**	**148**
2	19.1	12.9	25.1	26
5	26.4	31.1	33.2	34
10	31.0	51.1	39.7	40
20	35.1	76.6	46.8	47
50	40.1	130	57.2	58
100	43.7	185	65.9	66
200	47.2	258	75.5	76
500	51.7	394	90.1	91
1,000	55.0	531	102	102

Summary

The results from the various studies conducted post-June 2013 flood suggest that using a flood return period of between 100 and 200 years for the June 2013 flood event in the upper tributaries of the Bow River is a reasonable approach to estimate the June 2013 peak flows on nearby streams.

2.9.5 Return Period of June 2013 Flood Peak

The June 2013 peak flow estimates were compared to the flood frequency estimates developed at the respective locations to estimate the return period of the June 2013 flood at each location of interest. Table 2.9 shows that the flood event experienced on several tributaries of the upper Bow River in June 2013 had a return period of between 100 and 200 years. Closer to Calgary, the flood event on the Bow River had a return period of about 100 years. In contrast, the upper Elbow River watershed likely experienced a 200-year to 400-year flood event primarily because the severe June 2013 storm event was centred around the upper portions of the Elbow and Highwood Rivers. Downstream of Calgary and the Highwood River, the flood event appears to have a return period of between 100 and 200 years depending on the location. This is likely due to the extreme flood event that was also experienced in the Highwood River, which contributed significantly to the flows in the Bow River in addition to the inflows from the upper Bow River watershed.

3.0 COMMENTS ON EFFECTS OF CLIMATE CHANGE ON FLOOD ESTIMATES

Recent studies on the effect of climate change (e.g., Martz et al., 2007; Valeo et al., 2007) indicate that climate change could result in increased temperature, more frequent drought and water shortages, increased precipitation in some areas and increased flooding. As a result of climate change and variability, many regions of Canada, including the Prairies could experience warmer air temperatures and changes in stream flow magnitude and timing (e.g., higher winter stream flows and lower summer stream flows).

Depending on the climate model used for prediction of future scenarios, precipitation is projected to increase in Alberta, with less precipitation falling as snow and more rainfall-on-snow precipitation events (Valeo et al., 2007). Hence, it is anticipated that such changes in precipitation patterns could increase the frequency and intensity of extreme events (flood, drought, hail and windstorms). For the Bow River watershed, it is predicted that if rain-on-snow events occur more frequently and the snowpack begins to melt earlier, then flood events could occur earlier in the spring.

Using the predictions from the Canadian Regional Climate Model, Valeo et al. (2007) showed that May precipitation could increase by more than 35 percent under a 2xCO_2 scenario. As a result, expected increases in precipitation during the month of May could nearly double spring flood peak flows.

The flood peaks in 2013 in the Bow River and Elbow River basins are the most significant large floods since 1932, as shown on the plots of annual maximum instantaneous flows in Figure 3.1. Based on recorded data over the past 103 years (1911 to 2013), the observed annual peaks in recent years do not appear to be increasing with time in either the Bow River or Elbow River. The trend in the Bow River in fact appears to be a decreasing one, likely due to flow regulation at TransAlta's hydropower reservoirs on the Bow River and its tributaries. There does not seem to be a trend in the Elbow River. In both cases, any apparent trend is not statistically significant.

About 80 percent of the recorded annual peaks in the Bow River and the Elbow River occurred at the end of May and in the month of June as shown in Table 3.1 and Figure 3.2. The frequency of peaks occurring outside this period (earlier or later) also does not appear to be changing with time. The recent patterns in the timing of these floods are similar to what were observed at the beginning the century. There is no clear evidence that the patterns in magnitude or timing of annual peaks have changed significantly over the past hundred years.

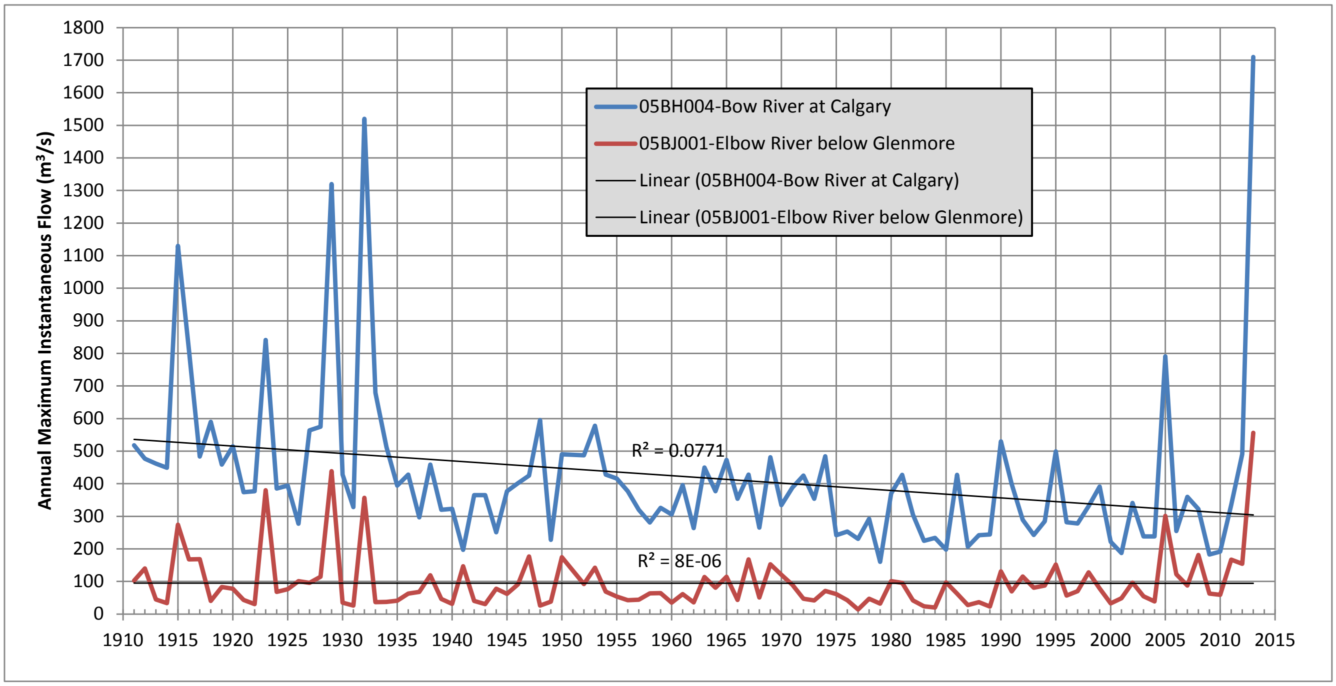
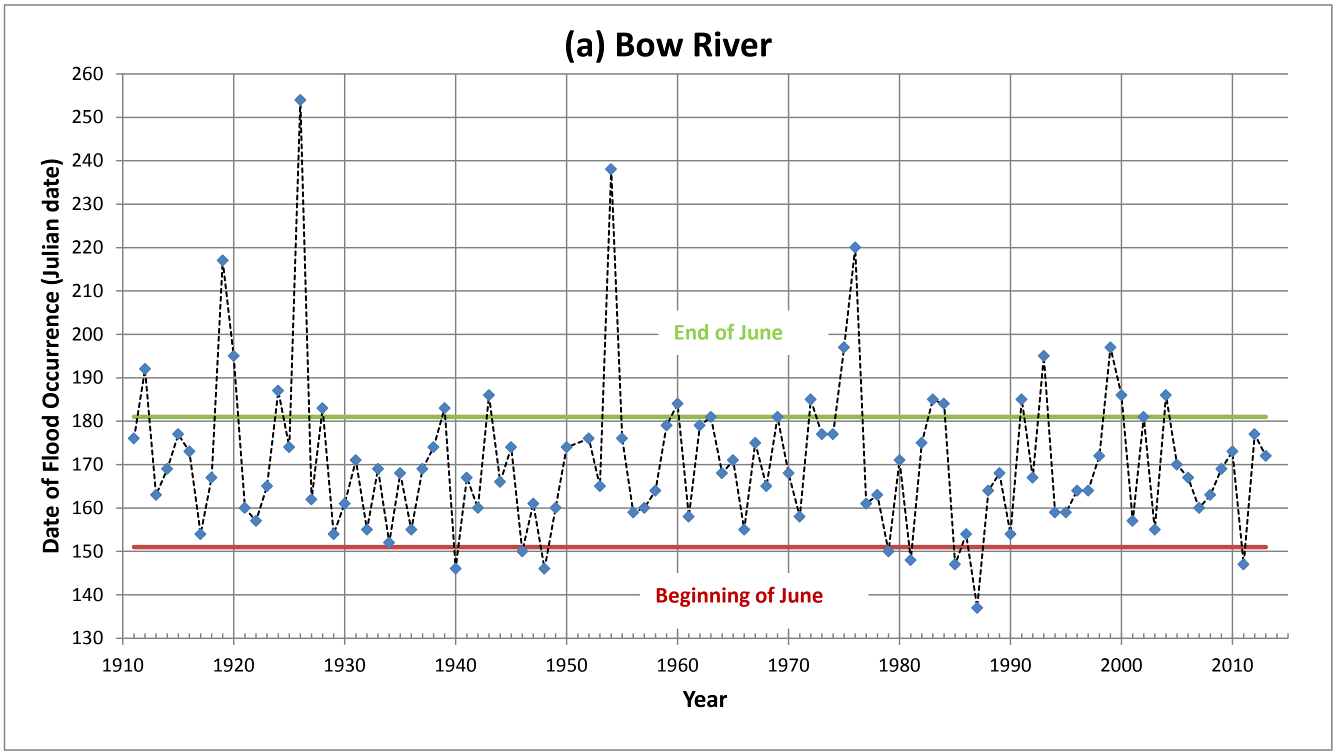


Figure 3.1: Annual Peak Series for the Bow River (WSC Station 05BH004) and the Elbow River (WSC Station 05BJ004)

Table 3.1: Time of Occurrences of Annual Maximum Daily Flood Events in the Bow and Elbow Rivers

Month	Bow River - Occurrences of Annual Maximum Daily Events since 1911		Elbow River - Occurrences of Annual Maximum Daily Events since 1911	
	Number	%	Number	%
April	-	-	4	4
May	8	8	24	23
June	74	73	58	55
July	16	16	7	7
August	3	3	8	8
September	1	1	4	4



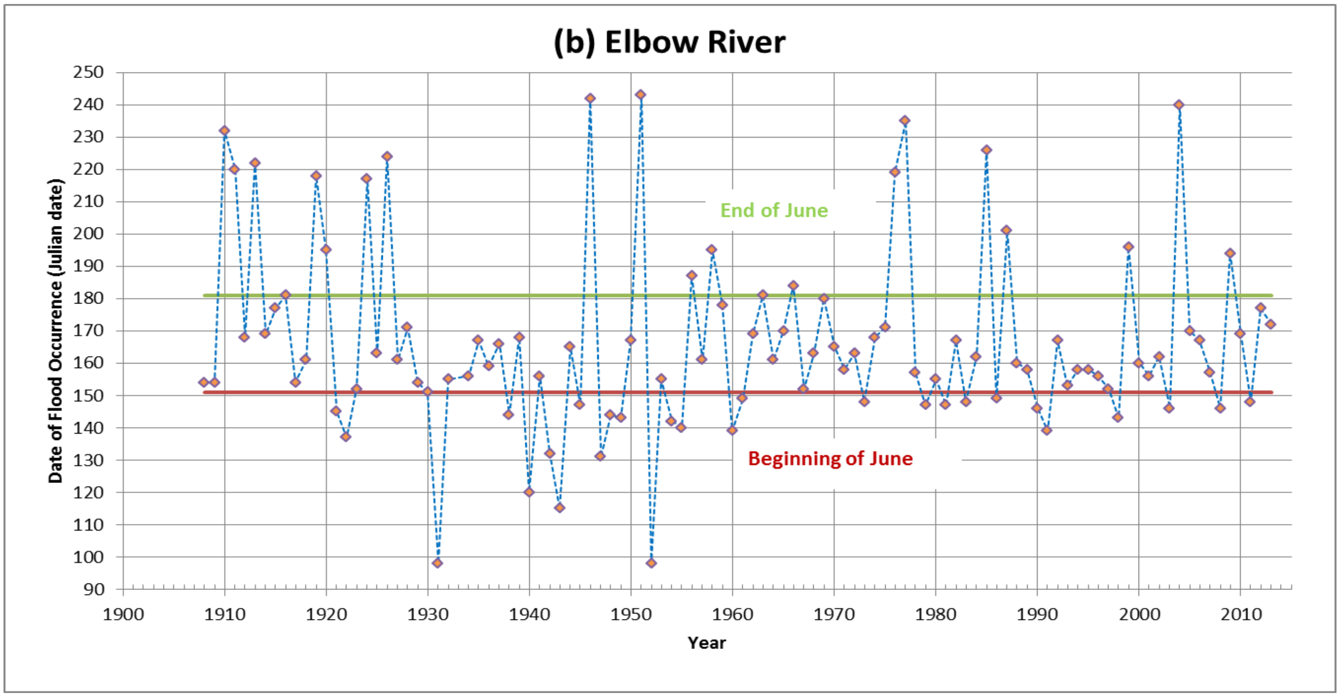


Figure 3.2: Time of Occurrences of Past Annual Floods in the Bow and Elbow River

4.0 COMMENTS ON SEASONALITY OF FLOOD PEAKS

The naturalized flow series for the Bow River below Bearspaw Dam and the Elbow River below Glenmore Dam were analyzed to identify whether one mechanism (snow melt or rainfall) dominates annual high flow generation. Based on recorded data over the past 100 years, about 80% of peak flows for the Bow River and the Elbow River occurred at the end of May and in the month of June as shown in Table 3.1, Section 3. This suggests that typical annual peaks generated from snowmelt/rain-on-snow dominate in the Bow River and Elbow River watersheds. However, major floods, including that of 2013 are clearly driven primarily by extreme rain events, with snowmelt not contributing significantly.

Frequency analyses were conducted as part of the 2010 study on the seasonal peak flow series that were generated from the naturalized (1930-2008) and recorded flows (1911 to 1930) to compare the flood estimates with those derived based on annual flow series. The spring flow series for each year were defined to occur from April to mid-June while the summer flow series were defined to occur from mid-June to September. The analyses were re-conducted with data up to 2013. Table 4.1 provides a comparison of the flood magnitudes generated for various return periods for the Bow River below Bearspaw Dam and the Elbow River below Glenmore Dam.

Table 4.1: Flood Magnitudes Derived using Seasonal Flood Series

Return Period (Years)	Bow River					Elbow River				
	Based on Spring Floods	Based on Summer Floods	Based on Annual Floods	Percentage compared to Annual Floods		Based on Spring Floods	Based on Summer Floods	Based on Annual Floods	Percentage compared to Annual Floods	
				Spring	Summer				Spring	Summer
2	342	325	374	-9%	-13%	48	38	57	-15%	-32%
5	474	450	520	-9%	-13%	90	72	104	-14%	-31%
10	568	547	640	-11%	-15%	130	105	151	-14%	-31%
20	664	650	777	-15%	-16%	181	148	213	-15%	-31%
50	796	802	991	-20%	-19%	274	229	327	-16%	-30%
100	902	932	1,184	-24%	-21%	371	315	448	-17%	-30%
200	1,015	1,075	1,411	-28%	-24%	497	431	611	-19%	-29%
500	1,173	1,291	1,772	-34%	-27%	728	650	915	-20%	-29%
1,000	1,300	1,475	2,100	-38%	-30%	968	883	1,239	-22%	-29%

For the Bow River, the flood peaks derived using spring flow series are less than the flood magnitudes derived using annual flow series by about 9 to 15 percent for return periods between 2 and 20 years, and by about 20 to 40 percent for higher return periods. The flood peaks derived using summer flow series are also significantly smaller than those derived using annual flow series. For the Elbow River, the flood peaks derived using spring flow series are less than the flood magnitudes derived using annual flow series by about 15 to 20 percent. The flood peaks derived using summer flow series are significantly smaller (by more than 30 percent) than those derived using the annual flow series. Therefore, the flood peak discharges for various return periods should be estimated based on the annual peak flow series.

4.1 Contribution of Storm Runoff to Flood Peak Flows

Within the City of Calgary, the Bow River and its tributaries (Elbow River, Nose Creek, Fish Creek and Pine Creek) receive significant stormwater runoff from urban and developed areas. Stormwater runoff contributing to the flood flows of the Bow River above its confluence with Elbow and to the tributary streams such as Elbow River, Nose Creek, Fish Creek and Pine Creek has already been accounted for in the recorded flow values. The analysis of the effect of the stormwater runoff was limited in the 2010 study to areas that are directly contributing runoff to the Bow River and were not included in the recorded data, such as the tributary sub-catchment contributing runoff in the reach of Bow River between its confluence with the Elbow River and Fish Creek.

As part of a Bow River loading study, a stormwater runoff simulation was completed for the entire City of Calgary using the QHM continuous simulation model (Golder, 2007). The simulation period for that study included the stormwater runoff during the June 2005 rainfall. The resulting simulated daily average peak storm runoff discharge from tributary sub-catchments contributing runoff to the Bow River between its confluence with the Elbow River and Fish Creek was estimated to be about 20.5 m^3/s and the peak runoff occurred on June 17, 2005. The instantaneous peak discharge (average runoff over a period of 1 hour) was about 50 m^3/s, and occurred at 23:00 hrs on June 17.

The instantaneous stormwater runoff from the tributary sub-catchments was about 6.4 percent of the peak discharge recorded on the Bow River on June 18, 2005. The lag-time between the flood runoff from the tributary sub-catchment and the peak flood on the main stem of the Bow River was about 19 hrs. The peak stormwater runoff occurred during the rising limb of the Bow River flood hydrograph and therefore the actual contribution of the storm runoff during the peak flow in the Bow River was less than 6.4 percent. The contribution of the receding stormwater runoff to the Bow River peak flow was estimated to be about 20.5 m^3/s, which was about 2.6 percent of the peak flood recorded on the Bow River in June 2005.

The analysis of the 2005 flood event showed that the contribution of the storm-runoff from the sub-catchment between the confluence of the Bow River and the Elbow River and Fish Creek to the peak flood flows in the Bow River was small. A similar conclusion is expected with reference to the storm runoff contribution to the June 2013 flood in the Bow River reach within the City of Calgary.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The 2014 hydrology assessment for the Elbow River and Bow River and its tributaries through The City was required to determine the flood magnitudes that would be used to prepared flood inundation mapping with the updated HEC-RAS hydraulic model of the Bow and Elbow River system through Calgary. As part of the 2014 hydrology assessment, naturalized flow series were generated at the major storage facilities on the Bow River and its tributaries upstream of Bearspaw Dam and on the Elbow River through Glenmore Reservoir.

A key consideration in the 2014 hydrology assessment was the effect of the extreme flood event that occurred in June 2013 in the Bow River, Elbow River, Highwood River and other river basins along the eastern slopes in southern Alberta. The peak flood flows documented or estimated in this study indicate floods of given return periods on the Bow River through Calgary are somewhat larger than those obtained during the 2010 study, however, flood flows near the mouth of Elbow River are significantly larger than those obtained during the 2010 study. For example, the estimated 100-year flood flows on the Bow River above and below the confluence with the Elbow River following the 2013 flood event are 2,020 and 2,820 m^3/s, respectively, compared to 1,710 and 2,450 m^3/s in the 2010 study and 1,970 and 2,670 m^3/s reported in the 1983 study. The differences between the flood estimates reported in the 2010 and current 2014 study are mainly due to inclusion of the significant flood that occurred in June 2013.

A comparison of the June 2013 peak flow estimates to the flood frequency estimates developed at the respective locations suggest that the flood event experienced on several tributaries of the upper Bow River in June 2013 had a return period of between 100-year and 200-year. Closer to Calgary, the flood event on the Bow River had a return period of about 100 years. In contrast, the upper Elbow River watershed likely experienced a 200-year to 400-year event primarily because the severe June 2013 storm event was centred around the upper portions of the Elbow River and Highwood River. Downstream of Calgary and the Highwood River, the flood event appears to have a return period of between 100-year and 200-year depending on the location. This is likely due to the extreme flood event that was also experienced in the Highwood River, which contributed significantly to the flows in the Bow River in addition to the inflows from the upper Bow River watershed.

5.2 Recommendations

Table 5.1 summarizes computed, naturalized instantaneous flood flows for the Bow River and its tributaries, including the Elbow River, for various return periods.

Table 5.1: Recommended Naturalized Instantaneous Flood Flows (m^3/s) for the Bow River and its Tributaries, Including the Elbow River, for Various Return Periods

Return Period (Years)	Bow River above Elbow River	Elbow River above Glenmore Dam	Elbow River below Glenmore Dam	Bow River below Elbow River	Nose Creek at Bow River	Bow River below Nose Creek	Fish Creek at Bow River	Bow River below Fish Creek	Pine Creek at Bow River	Bow River below Pine Creek	Highwood River at Bow River	Bow River below Highwood River
2	369	84.6	63.9	433	6.15	439	39.0	478	3.9	482	205	687
5	659	194	143	802	14.2	816	85.7	902	12.9	915	473	1,390
10	927	307	234	1,160	23.0	1,180	134	1,320	19.8	1,340	742	2,080
20	1,230	454	275	1,500	35.3	1,540	198	1,740	27.3	1,770	1,210	2,980
50	1,660	708	494	2,150	60.2	2,210	317	2,530	38.1	2,570	1,660	4,230
100	2,020	954	803	2,820	88.8	2,910	444	3,360	47.0	3,400	2,210	5,610
200	2,390	1,250	1,130	3,520	130	3,650	618	4,270	56.7	4,320	2,870	7,200
500	2,920	1,770	1,690	4,610	214	4,820	946	5,770	70.8	5,840	3,980	9,820
1,000	3,340	2,220	2,270	5,610	310	5,920	1,300	7,220	82.4	7,300	4,940	12,240

Report Signature Page

This report presents the methodology and results of the 2013 Bow River and Elbow River hydrology assessment and flood documentation study. Please direct any questions or clarification regarding the contents of this report to the following study team members who prepared this report.

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APPENDIX A

Naturalized Daily Flows and Flood Routing at Key Locations

A1 AVAILABILITY OF INPUT DATA

The process of developing natural flow estimates requires the use of historic records of reservoir levels and outflows from the date each structure started its operation. This appendix describes the methodology for calculating natural flows as well as how this methodology was implemented at each location of interest given the available data. It should be noted that the primary purpose of developing natural flows was to properly assess incoming annual peak flows into all major structures, and for as many years as possible. Naturalized annual peak flows constitute a principal input into the hydrologic frequency analyses, which is a key step in the development of design flood hydrographs with target return periods in the upper Bow River and its tributaries. Therefore, where seasonal flow data were available (i.e. data from April to October), they could still be used to help assess the annual maximum flows. Annual peak flows were assessed for as many years as possible, as further explained in subsequent sections that provide more information about each storage site where natural flow series were developed.

A2 PROJECT DEPLETION METHOD

Alberta Environment uses the Project Depletion Method to calculate natural flows on all major rivers in Alberta. The same methodology is employed by the Prairie Provinces Water Board (PPWB). The PPWB consists of representatives from Environment Canada (representing the Federal Government) and the representatives of the three Prairie Provinces. The short summary that explains the project depletion method in this section follows closely the documentation of the Natural Flow Computation Program (NFCP) program used in this study. Technical specifications for NFCP were approved by the PPWB in November of 2008.

Natural flows are river flows that would have been observed at selected locations in a river basin assuming there had been no human intervention by operation of large storage reservoirs or withdrawals. The most common approach to estimate natural flows is the Project Depletion Method, which is essentially aimed at “undoing” the impacts of human intervention in a systematic way, reach by reach, in a downstream progression.

The calculation procedure is explained below for a small example shown in Figure A1 that contains all elements found in complex river basins. There are two river reaches with a reservoir R_1 at their confluence. In this example, natural flow is calculated at the reservoir site. There is one diversion into the reservoir (D_1) and one return flow (RT_1) into the reservoir, one diversion channel out of the reservoir (D_2), and regulated outflow from the reservoir into natural channel reach C_3. The general approach to calculate natural flows at any location is to estimate local runoff which originates between the given location and the closest upstream locations at which natural flows had already been evaluated. Denote the natural flow at reservoir as Q_{R1} and the local runoff between natural flows Q_1, Q_2 and the reservoir as LR. The natural flow at the reservoir site can then be calculated as:

$$Q_{R1} = Q_1 + Q_2 + LR \qquad (1)$$

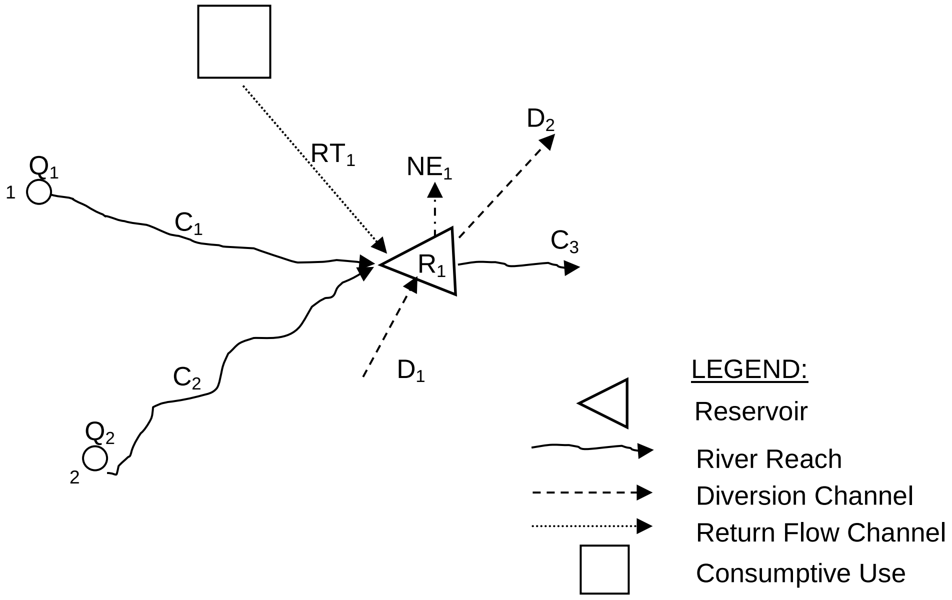


Figure A1: Sample Schematic for Calculation of Natural Flows

Consequently, the principal component of estimating natural flows is determination of the local runoff LR. Assuming Qr1 and Qr2 are the recorded flows at locations 1 and 2, LR for the reservoir in Figure A1 can be calculated using the following equation assuming average flow over time step t:

$$LR = Q_{C3} + Q_{D2} - Q_{RT1} - Q_{D1} + \Delta V/t - Q_{r1} - Q_{r2} \tag{2}$$

where:

Q_{C3}	the recorded flow in channel C_3
Q_{D1}	flow in diversion channel D_1
Q_{D2}	flow in diversion channel D_2
Q_{RT1}	flow in return flow channel RT_1
$\Delta V/t$	reservoir storage change over time step t

Reservoir storage change is further evaluated using the starting and ending storage (Vs and Ve) for a time step, along with adjustments for net evaporation (evaporation minus precipitation) for a given time interval *t*. Note that the sign for net evaporation is reversed since the consideration is to remove the effect of net evaporation (i.e. put the evaporation loss back in the river since this loss would not have happened if the reservoir had not been built):

$$\frac{\Delta V}{t} = \frac{Ve - Vs}{t} + \frac{(E - P)[A(Ve) + A(Vs)]}{2t} \tag{3}$$

where:

V_e	volume at the end of time step *t* (m^3)
V_s	volume at the start of time step *t* (m^3)
P	total precipitation over time step *t* (m)
E	total evaporation from the reservoir surface over time step *t* (m)
$A(V_e)$	surface area (m^2) corresponding to the ending volume *Ve*
$A(V_s)$	surface area (m^2) corresponding to the starting volume *Vs*

To summarize, local runoff LR can in general be assessed by conducting a water balance calculation for a sub-catchment which is delineated by the downstream point for which LR is evaluated and the upstream control points where recorded flow series are available. The general expression is:

$$LR = \sum_{i=1}^{m} Q_i - \sum_{j=1}^{n} Q_j + \sum_{k=1}^{l} \frac{\Delta V_k}{t} \tag{4}$$

where:

Q_i	average outflows (i=1,m) from a sub catchment within time step *t*
Q_j	average inflows (i=1,m) into a sub catchment within time step *t*

while the storage change term ΔV/t is summed up over all storage reservoirs in the sub-catchment area under consideration. Inflows and outflows into a sub-catchment include all diversions and return flows into it, as well as diversions out of it. Normally, natural flows should be calculated at all on-stream reservoir locations, especially when reservoirs have sizeable live storage.

Equation (1) suggests that natural flows be first determined at upstream locations (e.g. locations 1 and 2 in the example in Figure A1). The calculation then proceeds in the above manner for all requested locations in the river basin in a downstream progression. It should be noted that for short (e.g. daily) time steps, the length of river reaches along channels C_1 and C_2 may require the use of channel routing, such that the routed outflow from these channels takes part in the mass balance calculation at the reservoir node, both for calculating local runoff LR, which would require the routing of recorded flows along these channels, and for calculating the natural flow, which would require routing of the natural flow estimates previously made at nodes 1 and 2. Alberta Environment uses the Wilson's routing equation which was built into the SSARR model. A brief description of Wilson's equation is provided below.

As with the other river routing methods, the governing equation is related to channel storage change over a time step, which is a function of average inflow and outflow:

$$\frac{I_{t-1}+I_t}{2}-\frac{O_{t-1}+O_t}{2}=\frac{\Delta S}{t} \qquad (5)$$

By subtracting both sides of the above equation with O_{t-1} , multiplying by $t/(O_t-O_{t-1})$ and by letting $\Delta S/(O_t-O_{t-1}) = TS$, the above equation becomes:

$$Ot=\frac{\left[\frac{I_{t-1}+I_t}{2}-O_{t-1}\right]\cdot t}{TS+\frac{t}{2}}+O_{t-1} \qquad (6)$$

where the term *TS* represents the average travel time along a river reach for given flow conditions, evaluated either by reading from the *TS* vs *Q* table or by using a functional form of the travel time vs flow curve as:

$$TS=\frac{Kts}{\left(\frac{O_{t-1}+O_t}{2}\right)^n} \qquad (7)$$

The routing coefficients *Kts* and *n* must previously be determined by finding the best fit curve for a given set of the available *(Ts,Q)* coordinates. Usually, *Ts* can be determined for any given flow rate by linear interpolation from a table of *(Ts,Q)* points (these tables were provided by Alberta Environment and used in this project). In the above definition of *Ts*, the base of the denominator shown below represents the average channel flow over a time step as the arithmetic average of the outflows at the beginning and the end of the time step:

$$\frac{O_{t-1}+O_t}{2}$$

Various implementations of the SSARR method may rely on different estimates of the average channel flow during a given time step (which may also include inflows into the channel in some form). The method relies on the established empirical relationship between the travel time and flow for a given channel. Once this relationship is available, the calibration consists of deciding how many sequential phases a given river reach should be divided into, which is conducted using repeated simulation trials until the observed downstream hydrograph closely matches the simulated channel outflow. All work on calibration of the SSARR method in the South Saskatchewan River basin had already been done by Alberta Environment. The upper Bow River Basin schematic that was obtained from Alberta Environment already has the channels broken into lengths that work as single phase channels (i.e. no further subdivision is required).

The use of the SSARR channel routing method is optional (i.e., natural flows can be calculated with or without channel routing), since calculating natural flows using sufficiently long (monthly, seasonal or annual) time steps does not require channel routing. In this study, the time step was daily, while the travel time between the most upstream point of interest (Banff) and the most downstream point at Bearspaw Reservoir is well above one day, indicating that channel routing is required. The use of the SSARR routing method in the calculation of natural flows does not change the methodology. Instead, it merely introduces a more realistic account of flow changes in large river systems where the total travel time is greater than the calculation time step. It should also be noted that the SSARR river routing is as accurate as the available input data. As any other differential equation, a coarse time step and a large variation between the flows in two subsequent time steps may jeopardize the accuracy of the results.

It should be noted that the Wilson's equation deals with the transformation of surface water movement aimed to account for the channel storage change from day to day. However, large channel storage changes may happen in the Bow River during the formation of ice cover in November, and its subsequent melting in April. These transformations of water into ice and back into liquid can also be understood movements of flow into and out of storage, but such channel storage changes are not modelled by the Wilson's equation.

A3 GENERATION OF DAILY NATURAL FLOWS AT SPRAY LAKE

Figure A2 shows the Spray Lake and diversion to the three downstream power plants that eventually discharge into the Bow River at Canmore. The Spray River drains in the northerly direction and joins the Bow River at Banff. Flow monitoring station 05BC001 is located just upstream of the confluence. The Spray Lake is a naturally occurring lake, which was dyked off to divert water through three hydro power plants over a shorter distance and a large drop in elevation. The diversion route is indicated in orange color in Figure A2. The total catchment area of Spray Lake at the mouth is approximately 751 km^2, of which about 520 km^2 drain into Spray Lake. Although the remaining catchment area downstream of the Lake is roughly one third of the total, the upstream runoff into Spray Lake is considerably higher due to higher specific yield, such that roughly 85% of the total annual natural flow of Spray Lake at the mouth (station 05BC001) originates upstream of the dam.

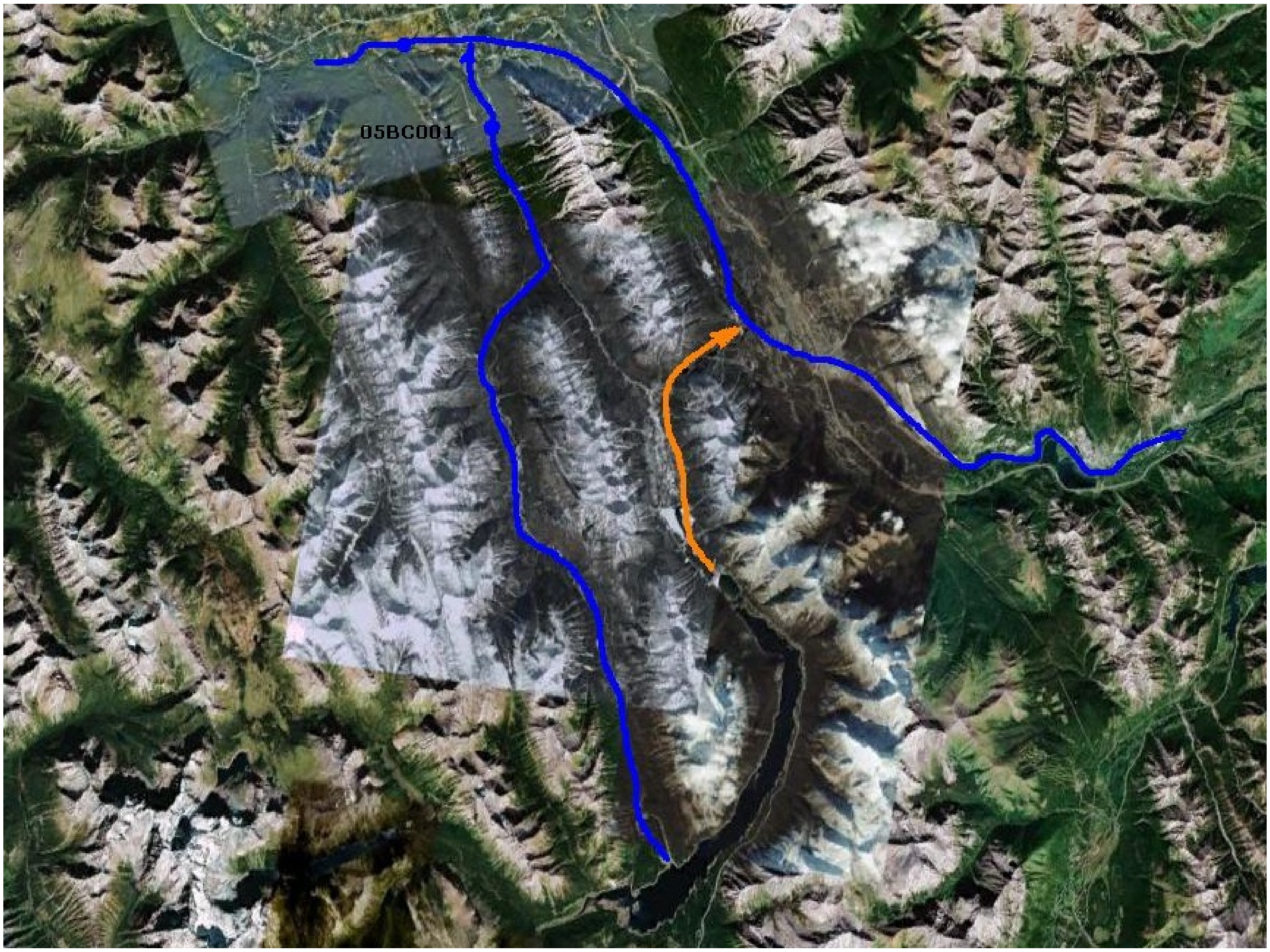


Figure A2: Spray Lake and Hydro Power Diversion

Proper calculation of natural flows at Spray Lake requires the historic daily lake levels as well as all daily outflows from the lake. The old Spray river channel still collects the runoff downstream of the lake, but after construction of the dam in 1949 it also serves as a potential spillway conduit to evacuate large floods that exceed the capacity of the diversion route. The spillway into the Spray River has historically been used only once in 1974. There are several issues associated with assessing daily natural flows at the dam site:

- Daily diversion flows for power generation from Spray Lake were only available after 1975, which makes it impossible to properly assess natural flows at the dam site between 1949 and 1975;
- Between 1918 and 1939 peak flows at the dam site were based on recorded flows at station 05BC002. This station is now submerged by the lake. Its original drainage area was 360 km^2, which was increased by a factor of 1.3 to account for additional catchment area into the lake that was created by the dam (520 km^2) less the adjustment for the considerable increase in the lake surface area which is handled by net evaporation directly in the water balance equation. Regression equation Y=0.77X+10.543, assessed on the basis of the available data for both series, has a good fit (R^2 = 0.86);

- For periods from 1912 to 1917 and 1940 to 1948, peak flows were generated based on the relationship established between the natural Spray River flows at the mouth 05BC001 (drainage area 750.6 km^2) and the peak flows at the dam site from 1918 to 1939 from records available at station 05BC002, which is expressed by the regression equation mentioned under b) above; and
- For the 1949 to 1975 period, both peak flows and continuous daily flows were estimated based on inferential relationship developed between the recorded flows of Spray River at the mouth and the calculated natural flows at the dam after 1975. Different models were used for assessing annual peak flows and continuous time series, due to the difficulties of relating the reduced flows at the mouth to the flows at the dam for the available period after 1975. These models are further discussed below.

Infill of daily continuous natural flow estimates for Spray Lake at the mouth is required to enable proper flood routing from Banff all the way to Ghost Reservoir, as well as to allow more accurate calculation of natural flows at Ghost reservoir. The model used for the development of continuous daily natural flows at the mouth for the 1949 – 1975 period was calibrated to meet the two following objectives:

a) Fit the regression between the recorded Spray River at the mouth after 1975 (with reduced catchment area) and the sum of natural flows at the dam and flows at the mouth for the same period ($R^2 = 0.923$) ; and

b) Make sure that the resulting flow estimates also follow the same statistical distribution and have similar mean and standard deviation as the available estimates of natural flow at 05BC001 for the periods with available data.

The above two objectives were met. However, the resulting annual peak flows from this model were not distributed according to the same frequency that was found in the years of available data. It was felt that if the peak flows from this series were used as input into the frequency analyses, they may reduce the anticipated design peak flows at the dam, which would unnecessarily bias the estimates towards lower values. This concern was also driven by comparison of the flows at 05BC001 for the 1949 – 1975 period with the flows at the same site for 1975 – 2008 period. Recorded peak flows at 05BC001 between 1949 and 1975 are higher on average than the flows encountered in the post 1975 period, as shown in Table A1. Also, daily flows at the mouth and at the dam may differ in the range of 2 to 10 times with a high variance. Although the in-filling of daily flow series at 05BC001 was completed for the 1949 – 1975 period, it is suggested that future updates to the database of natural flows provided in this study include retrieval of the recorded outflows from the dam from TransAlta, in order to allow proper evaluation of daily natural inflows into the Spray Lake.

Annual peak flow estimates at the Spray Lake were based on the regression established for the post-1975 period between the recorded flows at the mouth (station 05BC001) and the sum of these flows with the naturalized flows at the dam site, which represent the equivalent of the natural flows at the mouth. This regression equation is $Y = 2.942X + 26.415$, however, the regression fit is not as consistent ($R^2 = 0.59$), and the regression line slope is subject to significant changes if selected outliers are removed. Table A1 provides a listing of all peak flows for the three distinct periods (prior to 1949, 1949 – 1975, and post 1975).

Station 05BC001 shows the Spray River flows that were measured after the dam was constructed. As mentioned earlier, the peak flows at this station were considerably higher in the 1949 to 1975 period than in the post 1975 period. This justifies higher annual peak flows at the dam estimated for the same period. It should also be noted that Mud Lake diversion, which transfers some of the runoff that would naturally occur into the Lower Kananaskis Lake, was included in the estimates of natural flows at the dam since it is functions as a permanent modification to the watershed. The Mud Lake diversion would continue to operate during floods.

Table A1: Summary of Daily Naturalized Peak Flow Estimates for Spray River at Dam and at the Mouth (05BC001)

Year	Peak Flow at the Dam (m^3/s)	Year	Peak Flow at the Dam (m^3/s)	Peak Flows at 05BC001	Year	Peak Flow at the Dam (m^3/s)	Peak Flows at 05BC001
1912	65.7	1949	144	39.9	1976	62.3	9.17
1913	75.1	1950	85.0	19.9	1977	47.6	8.50
1914	76.9	1951	191	55.8	1978	72.1	11.2
1915	60.7	1952	68.5	14.3	1979	43.3	8.09
1916	108	1953	88.2	21.0	1980	59.4	11.4
1917	62.7	1954	83.8	19.5	1981	83.0	15.7
1918	96.9	1955	73.5	16.0	1982	70.5	11.0
1919	74.7	1956	70.0	14.8	1983	58.2	7.03
1920	76.9	1957	52.2	8.75	1984	65.8	9.01
1921	63.1	1958	49.8	7.96	1985	150	8.72
1922	57.7	1959	56.7	10.3	1986	102	17.4
1923	112	1960	56.1	10.1	1987	43.5	7.64
1924	52.8	1961	89.4	21.4	1988	63.6	10.3
1925	65.1	1962	48.3	7.45	1989	64.8	7.79
1926	43.7	1963	49.8	7.96	1990	75.2	17.5
1927	78.6	1964	85.3	20.0	1991	71.8	12.3
1928	73.8	1965	83.5	19.4	1992	52.4	10.1
1929	64.3	1966	76.4	17.0	1993	52.9	9.09
1930	57.2	1967	72.9	15.8	1994	44.8	6.40
1931	52.7	1968	48.7	7.56	1995	109	18.8
1932	121	1969	65.2	13.2	1996	84.0	14.9
1933	131	1970	70.2	14.9	1997	72.5	9.35
1934	73.2	1971	68.2	14.2	1998	58.8	9.99
1935	57.9	1972	156	43.9	1999	71.9	10.4
1936	62.7	1973	67.0	13.8	2000	47.2	6.95
1937	48.9	1974	115	30.0	2001	39.8	8.36
1938	70.4	1975	48.8	7.62	2002	93.8	19.4
1939	51.4				2003	53.1	12.1
1940	48.1				2004	57.6	10.3
1941	45.2				2005	70.3	23.5
1942	56.8				2006	73.1	11.5
1943	61.8				2007	95.2	17.7
1944	35.2				2008	58.1	11.6
1945	55.9				2009	50.1	10.5
1946	71.0				2010	49.8	9.1
1947	53.8				2011	67.9	42.0
1948	101				2012	96.8	21.2
					2013	238.9	42.9

A4 GENERATION OF DAILY NATURAL FLOWS AT LAKE MINNEWANKA

Lake Minnewanka is a naturally occurring lake that was raised to increase its storage. In addition to this, about 15% of the total runoff into Lake Minnewanka comes from the Ghost river catchment via the Ghost River diversion. This diversion was built in 1941 and a flow monitoring station has operated until 1994. Although the station has been discontinued, this diversion continues to operate, and it would also operate during floods. Consequently, in this study Ghost diversion was considered as integral part of runoff into Lake Minnewanka for calculation of natural flows into the lake.

Natural flows into Lake Minnewanka were estimated based on its recorded outflows available from Water Survey of Canada stations 05BD002 until 1941 and from station 05BD004 from 1942. The Lake elevations (WSC station 05BD003) are available from 1917. There are many days with missing data prior to 1943, when the continuous daily records began. However, the records between 1917 and 1943 are usually available at least once or twice a week, which allowed the use of linear interpolation as the first approximation for infilling the missing data, particularly since this lake is large and the levels do not vary substantially from day to day. Until 1941, the dam was operated in the range between 1450 and 1455 m, with flow regulation having a relatively small impact on the downstream Bow River flows at Ghost and Bearspaw Dams The mean annual flow of Cascade River at the mouth is 8.4 m^3/s, compared to about 90 m^3/s for the Bow River at Bearspaw dam. Effects of flow regulation are more pronounced after 1942, when the lake levels were raised to operate in the range between 1465 and 1475 m and the Ghost diversion started to operate. Table A2 shows a comparison of daily peak natural flows at Lake Minnewanka for three periods (prior to 1943, 1943 – 1975, and after 1975).

Table A2 shows that expected peak natural flows were higher during the 1943-1975 period than during the post-1975 period. There is presently no plausible explanation for this statistical discrepancy, but it can be noted that the diversions from the Ghost River were higher in the period prior to 1980s, and that the more recent modification of the diversion weir restricts the diverted flows to a maximum of 400 cfs (11.33 m^3/s), which did not exist in the earlier period between 1943 and 1975.

Table A2: Summary of Daily Naturalized Peak Flow Estimates for Cascade River at Lake Minnewanka

Year	Peak Flow at the Dam (m^3/s)	Year	Peak Flow at the Dam (m^3/s)	Year	Peak Flow at the Dam (m^3/s)
1917	89.0	1943	53.1	1976	40.6
1918	72.6	1944	37.9	1977	38.1
1919	155	1945	51.0	1978	51.2
1920	106	1946	47.8	1979	29.8
1921	53.6	1947	47.4	1980	58.8
1922	39.7	1948	130	1981	89.0
1923	124	1949	29.2	1982	48.1
1924	53.6	1950	87.1	1983	38.1
1925	36.6	1951	78.0	1984	36.9
1926	39.0	1952	71.5	1985	29.6
1927	50.0	1953	130	1986	75.5
1928	65.2	1954	72.1	1987	27.8
1929	69.1	1955	59.4	1988	48.4
1930	60.1	1956	63.8	1989	38.3
1931	34.4	1957	46.5	1990	94.4
1932	116	1958	44.4	1991	61.3
1933	84.9	1959	47.8	1992	40.9
1934	39.7	1960	40.9	1993	38.6
1935	50.1	1961	61.5	1994	32.5
1936	38.1	1962	51.5	1995	102
1937	30.6	1963	52.9	1996	60.3
1938	47.3	1964	70.6	1997	43.6
1939	46.8	1965	122	1998	49.6
1940	30.6	1966	62.5	1999	45.0
1941	18.1	1967	73.5	2000	24.4
1942	53.3	1968	38.0	2001	41.3
		1969	83.0	2002	58.8
		1970	88.8	2003	49.2
		1971	77.4	2004	53.8
		1972	77.4	2005	80.1
		1973	87.9	2006	32.8
		1974	105	2007	85.2
		1975	36.7	2008	43.6
				2009	27.1
				2010	32.5
				2011	57.1
				2012	111
				2013	307

A5 GENERATION OF DAILY NATURAL FLOWS AT THE UPPER AND LOWER KANANASKIS LAKES

Upper and Lower Kananaskis Lakes are also naturally occurring lakes that were raised to higher elevations to provide more balancing storage and head for hydro power generation. The upper Kananaskis Lake receives runoff from the catchment area of about 150 km^2 and it drains into the lower Kananaskis Lake, which, in addition to receiving outflow from the Upper Kananaskis Lake, also receives inflow from a local catchment area of roughly the same size (151 km^2), although some of the runoff originating from this area is diverted into the Spray Lake via the Mud Lake diversion. The Lower Kananaskis Lake eventually drains into the Barrier Lake, located some 50 km downstream of it.

The Upper Kananaskis Dam had its normal full supply level raised in 1942 by about 14 m. The Lower Kananaskis Dam was built in 1955 with an increase in full supply elevation by 11 m and allowed annual fluctuation of water levels by 14 m. Prior to 1942, both lakes have been operated as natural water bodies. The hydro power plants associated with these lakes are known as Interlakes and Pocaterra. The following procedure is needed to calculate natural inflows into both lakes:

a) Use the Upper Kananaskis storage levels and outflow records to remove the effect the storage and calculate natural flows at the Upper Kananaskis Lake; and

b) Use the Lower Kananaskis storage levels, outflows and the outflow from the Upper Kananaskis as a part of the total inflow to assess the net runoff from the local contributing catchment into the Lower Kananaskis Lake.

The data available for full implementation of the above procedure are only available for the 1985 to 2013 for both reservoirs. Water levels at both lakes and the outflows from the Lower Kananaskis Lake are also available for 1975-1985 period, but the turbine flows out of the Upper Kananaskis Lake are missing. It was decided to naturalize flows from 1975 to 1985 for the combined Upper and Lower Kananaskis sub-catchments by using the storage change at both reservoirs and outflows from the Lower Kananaskis Lake. Daily peak flows for the years with missing data were developed based on the regression established between total natural flow for both catchments and each individual catchment for the 1985 – 2007 data. This approach provided 10 more years of data (1975-1984) that can provide input into statistical frequency analyses. The resulting regression fit and equations are shown in Figure A3 and A4. Table A3 shows the annual maximum daily natural flow estimates for the Upper and Lower Kananaskis Lakes (indicated as Interlakes and Pocaterra in Figures A3 and A4).

Flows from Interlakes to Pocaterra are readily available from TransAlta in electronic format only for the 1985 – 2013 period, while data for years prior to 1985 are only available on microfiche.

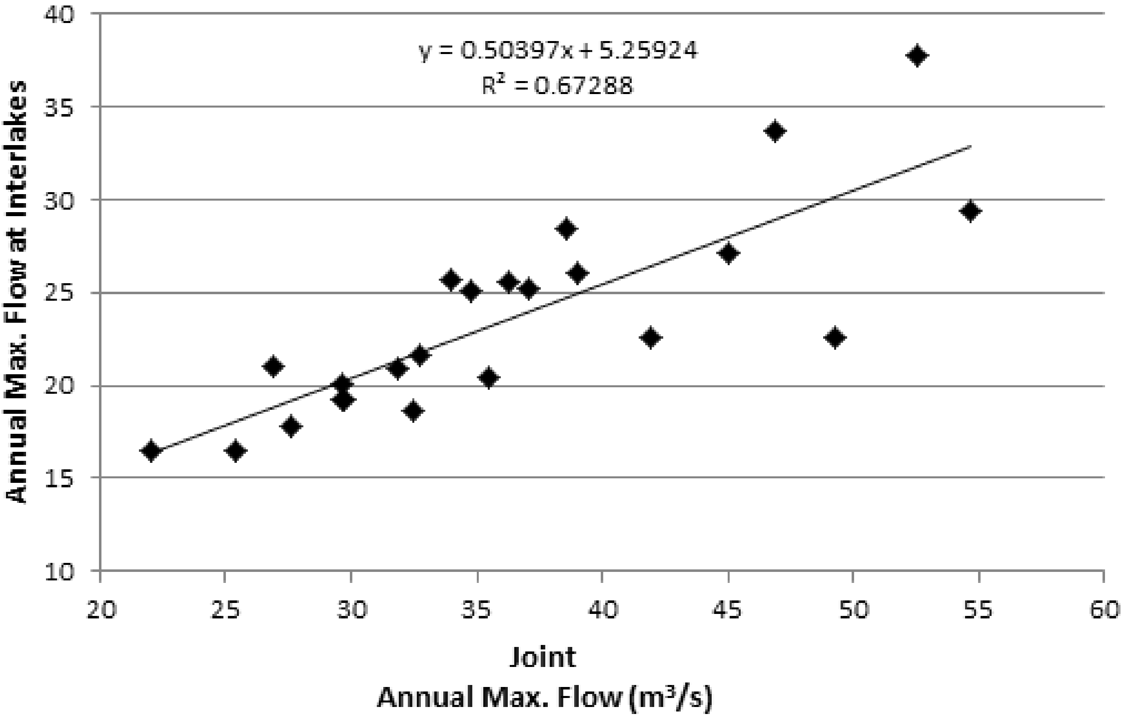


Figure A3: Interlakes Peak Flow vs Total (Interlakes and Pocaterra) Peak Flow

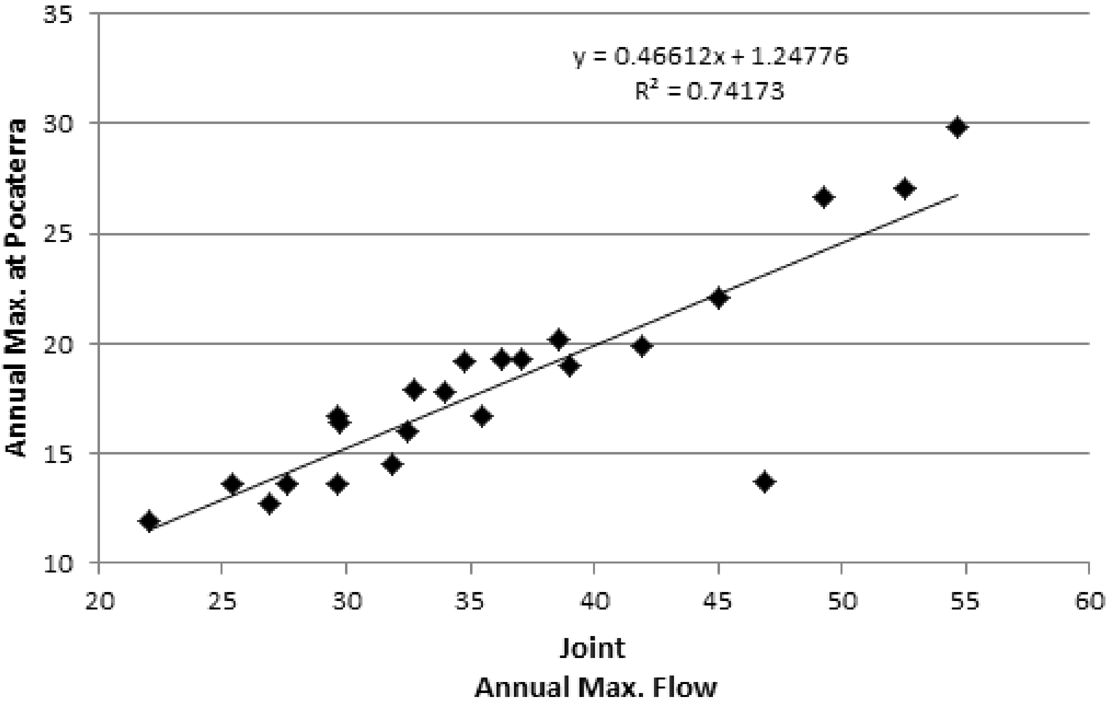


Figure A4: Pocaterra Local Inflow vs Total (Interlakes and Pocaterra) Natural Flow

Table A3: Summary of Daily Naturalized Peak Flow Estimates for Kananaskis River at Interlakes and Pocaterra

Year	Joint Annual Maximum Flow below Pocaterra (includes total catchment)	Estimated Annual Maximum Flow above Interlakes	Estimated Annual Maximum Local Inflow into Pocaterra
1975	35.5	23.2	17.8
1976	26.7	18.7	13.7
1977	30.3	20.5	15.4
1978	37.6	24.2	18.8
1979	38.9	24.8	19.4
1980	34.4	22.6	17.3
1981	41.3	26.1	20.5
1982	37.9	24.4	18.9
1983	31.5	21.1	15.9
1984	33.3	22.0	16.8
1985	27.6	17.8	13.6
1986	52.6	37.8	27.0
1987	46.9	33.6	13.7
1988	37.1	25.2	19.3
1989	31.9	20.9	14.5
1990	39.0	26.1	19.0
1991	38.6	28.5	20.2
1992	34.0	25.7	17.8
1993	29.8	19.2	16.4
1994	26.9	21.0	12.7
1995	49.3	22.6	26.6
1996	45.0	27.2	22.0
1997	35.5	20.5	16.7
1998	34.8	25.0	19.2
1999	32.8	21.6	17.9
2000	25.4	16.5	13.6
2001	22.0	16.5	11.9
2002	54.7	29.4	29.8
2003	29.7	20.1	13.6
2004	29.6	19.2	16.7
2005	32.5	18.6	16.0
2006	36.3	25.6	19.3
2007	41.9	22.6	19.9
2008	14.6	–	14.6
2009		16.4	10.3
2010		14.7	10.4
2011		22.1	23.8
2012		26.5	32.0
2013		64.7	24.0

A6 GENERATION OF DAILY NATURAL FLOWS AT BARRIER LAKE

Proper evaluation of daily natural flows at the Barrier Dam requires the following information:

a) Estimated daily natural flows at both the Upper and Lower Kananaskis Lake. This was only available for the 1985 – 2013 period.

b) Continuous daily recorded outflows from the Lower Kananaskis Lake (Pocaterra). Some data are available prior to 1955 but mainly as seasonal records, and there is a large section of data completely missing from 1955 to 1975, when the continuous records begin.

c) Calibrated travel time vs flow relationship for the 50 km Kananaskis River reach between Pocaterra and Barrier to allow proper channel routing. This information is not currently available. Calculation of actual flows conducted by Alberta Environment's model does not use any channel routing on this reach.

d) Historic daily elevations of Barrier Reservoir. These have been made available by Alberta Environment from 1948 to 1988, and they are also available from Water Survey of Canada as a continuous record from 1970 to 2013 (station 05BF024). These two datasets do not always agree well in the overlapping period from 1970 to 1988.

Historic daily outflows from the Barrier Reservoir

For periods prior to 1985, there were two Water Survey of Canada stations in operation. Station 05BF025 is located immediately downstream of the dam, with a total catchment area of 899 km^2 and a continuous flow record from 1975 to 2008 (which eliminates the need to use TransAlta's data), while station 05BF001 is located further downstream and includes a slightly larger catchment of 933 km^2 due to a small tributary upstream of it. The data record at this station is available from 1911 to 1962, but there were many missing data gaps that required in-filling, including the complete blackout period from 1963 to 1974 inclusive. Alberta Environment maintains a weekly natural flow database, which contains mean weekly outflows from the Barrier dam from 1948 to 2001. The mean weekly recorded flow data were used as a basis for infilling the missing Barrier outflows, using the linear interpolation model the middle of one week to the middle of the subsequent week, as shown in Figure A5.

The model shown in Figure A5 is considered acceptable for providing continuous estimates of daily flows from the Kananaskis River in the 1963 – 1974 period, and for in-filling occasional missing data prior to 1963, since the continuous stream records are required for estimation of natural inflow hydrographs at Ghost and Bearspaw reservoirs. Although daily flow estimates obtained in this way were used to remove the effect of the Barrier Reservoir storage, the resulting flows were not considered appropriate for estimation of peak daily flows at the Barrier Reservoir site, because this model obviously underestimates annual daily peak flows which are never higher than the annual weekly peak flows. Therefore, the 1963 – 1974 (inclusive) period was not used in the assessment of peak annual flows.

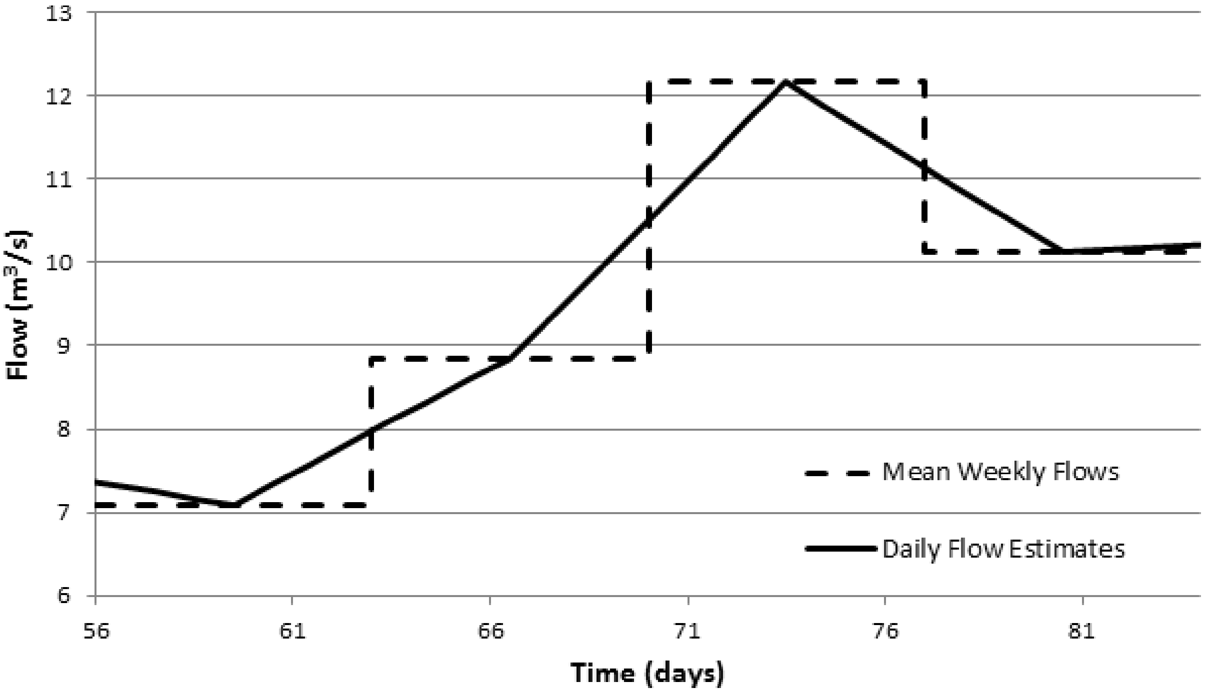


Figure A5: Approximate Conversion of Mean Weekly Flows to Mean Daily Flows

The Barrier Dam was built in 1948, before raising the Pocaterra levels in 1955. Prior to 1948, the additional raising of the Upper Kananaskis Lake level starting in August of 1942. Hence, there was a reason to suspect that the annual peak flows at the Barrier dam site exhibited statistical difference before and after 1943, and especially after 1955 due to additional inclusion of the balancing effect of the Lower Kananaskis Lake. To investigate this assumption, the annul peak flows at the Barrier Reservoir site were separated into two series (pre and post 1943) and plotted using the probability plot with the standard Weibull plotting position formula [r/(n+1), where r is the sequential number of data point in the sorted order, while n is the total number of data points]. The resulting plot is in Figure A6.

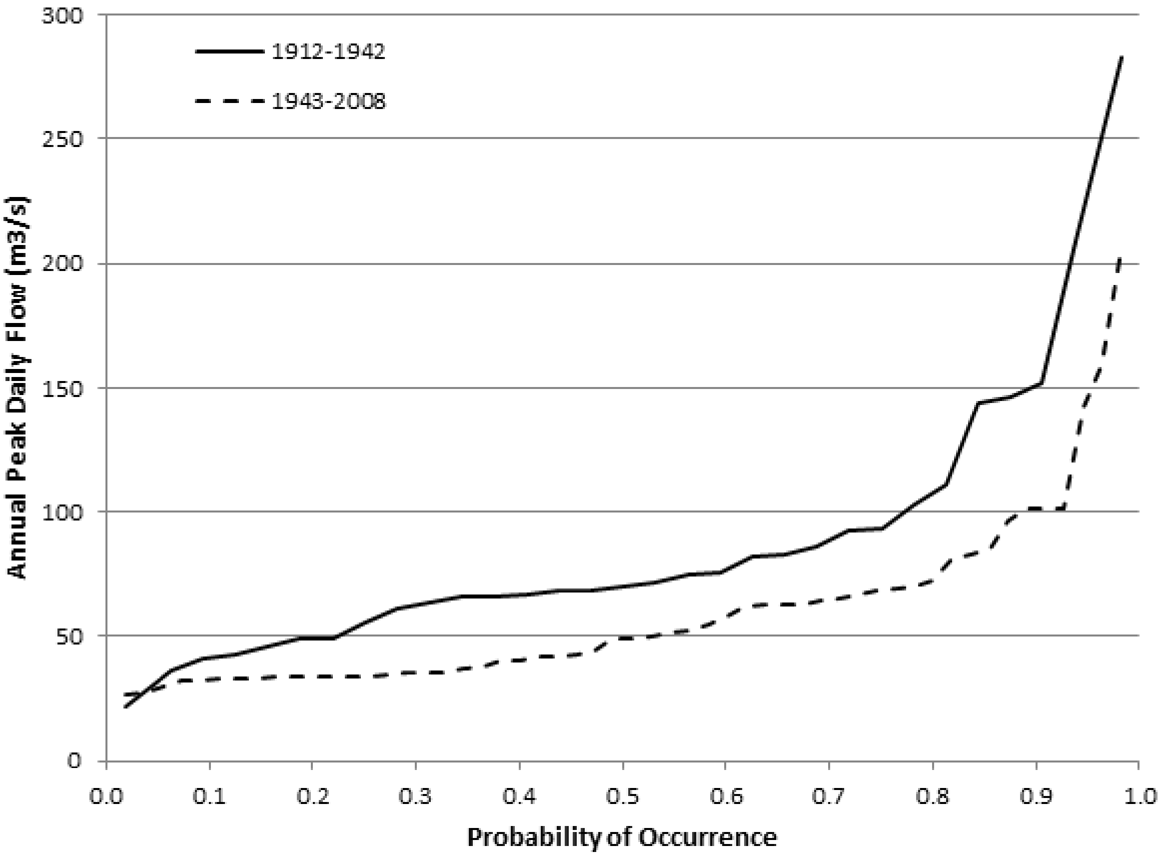


Figure A6: Annual Peak Flows at Barrier Lake Pre- and Post-1943

It is obvious that the peak flows encountered after 1942 are smaller. For example, the median peak flow in the post 1943 period of 50 m^3/s corresponds to the median peak flow of about 70 m^3/s in the pre-1943 period. This model was further refined by using the moving average for both of the above plots, which were then fitted with higher order polynomials to define a functional relationship for each curve. The post 1943 natural peak flows obtained by removing the effect of the Barrier Lake were then adjusted to include increases that correspond to the difference between the two probability curves shown above. The actual differences that were added were depended on the magnitude of the post 1943 flood. For very small peak flows, the added adjustments were also small and in a few cases of very small peak flows they were left unchanged. Table A4 shows the resulting annual peak flow estimates for pre and post 1943 period, excluding the 1963-1974 period for reasons outlined above.

Table A4: Summary of Daily Naturalized Peak Flow Estimates for Barrier Lake

Year	Peak Flow at the Dam - Natural Conditions (m^3/s)	Year	Initial Estimates of Peak Flows at the Dam (m^3/s)	Adjusted Estimates of Peak Flows at the Dam (m^3/s)
1912	92.3	1943	49.3	71.4
1913	60.9	1944	26.6	32.7
1914	67.1	1945	62.9	85.4
1915	152	1946	66.5	93.3
1916	209	1947	50.1	70.6
1917	85.8	1948	148	229
1918	93.4	1949	104	182
1919	75.0	1950	95.5	159
1920	71.4	1951	97.8	167
1921	68.0	1952	57.2	77.4
1922	65.7	1953	106.2	188
1923	144	1954	90.9	144
1924	75.9	1955	61.7	82.8
1925	68.0	1956	44.6	71.3
1926	48.7	1957	32.1	52.3
1927	103	1958	44.7	71.2
1928	82.1	1959	46.1	71.5
1929	146	1960	47.8	71.7
1930	69.7	1961	65.4	89.8
1931	45.9	1962	103	177
1932	283	1975	44.6	71.4
1933	111	1976	35.8	60.8
1934	55.8	1977	31.4	46.8
1935	49.3	1978	38.0	64.4
1936	63.4	1979	31.8	50.5
1937	43.0	1980	50.0	71.2
1938	82.7	1981	76.0	118
1939	41.3	1982	37.12	62.9
1940	36.5	1983	30.2	43.9
1941	21.7	1984	24.9	28.7
1942	66.3	1985	31.6	48.7
		1986	68.9	98.7
		1987	28.0	38.1
		1988	32.9	56.9
		1989	91.6	150
		1990	72.0	110
		1991	45.9	72.0
		1992	40.4	67.2
		1993	38.6	65.2
		1994	24.0	25.3
		1995	106	187
		1996	46.3	70.9
		1997	32.3	53.9
		1998	52.8	72.9
		1999	26.9	35.0
		2000	17.9	17.9
		2001	21.0	21.0
		2002	69.3	102.7
		2003	32.6	55.4
		2004	29.5	41.4
		2005	88.1	135
		2006	48.4	71.3
		2007	54.2	74.0
		2008	56.0	75.8
		2009		27.3
		2010		33.8
		2011		47.2
		2012		71.6
		2013		301

A7 GENERATION OF DAILY NATURAL FLOWS AT GHOST RESERVOIR

The impoundment of Ghost Reservoir started in August of 1929. Prior to 1929, the only possible change to natural flows upstream of Ghost Reservoir would be due to the operation of Lake Minnewanka on Cascade River, which at that time was operating in the lower range between 1450 and 1455 m. Although the Cascade River flows have been adjusted for the effects of Lake Minnewanka storage, the missing link required for estimating natural flows at the Ghost Reservoir site prior to 1929 are the recorded flows in the vicinity of the Ghost reservoir site.

Station 05BE006 (Bow River below Ghost dam) started operation in 1933. The upstream flow monitoring station at Seebe (05BE004) started operation in 1923. The Ghost River tributary (station 05BG001) that also contributes significant flows to the Ghost Reservoir storage has missing data between November 1920 and December 1928. The recorded flow data series that represents recorded outflows (or inflows) into the Ghost Reservoir do not exist prior to 1930.

Hence, it was only possible to assess natural flows into Ghost reservoir between 1930 and 2008, following required in-filling of the missing data. When the outflows were missing, the storage change and both inflows (Station 05BE004 at Seebe and the Ghost River tributary station 05BG001) were used to generate the outflow estimates. When the storage levels were missing and both outflows and inflows were available, storage levels were estimated by balancing inflows and outflows and by solving for the end of day storage as the only unknown. A regression was also developed between the Bow River below Ghost Reservoir (05BE006) and the Bow River at Calgary (05BH04), and it was used occasionally for in-filing the missing data when there was no other option.

The following information was necessary to estimate daily natural flows at the Ghost Reservoir for the 1930 – 2008 period:

a) Recorded and natural flows of the Bow River downstream of confluence with the Spray River;

b) Recorded and natural flows of the Cascade River at Lake Minnewanka;

c) Recorded and natural flows of the Kananaskis River at Barrier Reservoir;

d) Time of travel vs flow for all routing reaches of the Bow river between Banff and the Ghost Reservoir as well as on the Kananaskis river below the Barrier dam;

e) End of day Ghost Reservoir elevations;

f) Recorded Ghost Reservoir outflows; and
g) Precipitation and evaporation on Ghost reservoir.

The NFCP model was run on a daily basis from 1930 to 2008 to obtain estimates of natural flows at the Ghost Reservoir. The model schematic is shown in Figure A7. The calculation procedure starts at the most upstream nodes, and evaluates natural flows at each node in a downstream progression. This procedure requires separate routing of recorded flows from the three upstream control points, which are the confluence of the Bow and Spray Rivers, Lake Minnewanka and the Barrier Reservoir downstream to the Ghost reservoir. These routed flows were used to calculate the local inflow into the Ghost Reservoir by subtracting them from the Ghost Reservoir outflow adjusted for storage change. Once the local inflow is calculated in this manner, it is added to the sum of routed natural flows starting from the same three control points and ending at the Ghost Reservoir. This is a complex procedure that is significantly aided by the existing computer model designed for this purpose.

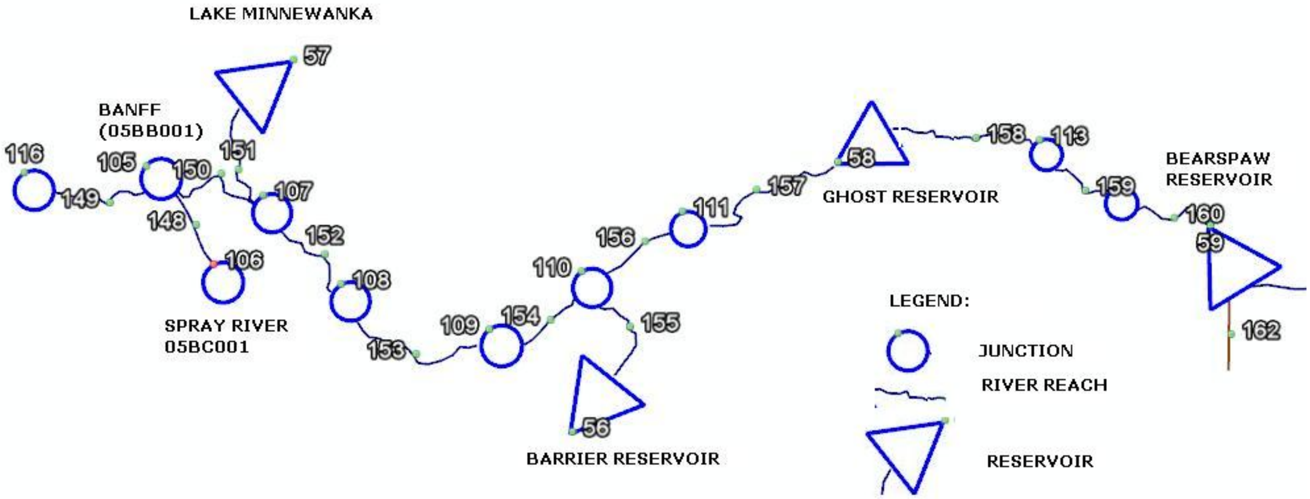


Figure A7: NFCP Modelling Schematic

Denote with R recorded flows, N natural flows, F( ) the channel routing function, LI local inflow, $\Delta V / \Delta t$ storage change and NE net evaporation on the Ghost Reservoir. The calculation of local inflow into the Ghost Reservoir process can then be mathematically expressed as:

$$LI_{58} = \Delta V / \Delta t + NE + R_{158} - F(R_{150} + R_{151} + R_{155})$$

It should be understood that the actual routing of flows happens channel by channel, and that two channels that meet at a node provide the sum of routed flows at their downstream ends which is further routed through the downstream channel. In that sense, the term $F(R_{150} + R_{151} + R_{155})$ schematically represents the result of combined routing of all three control flows through all sequential channels in the schematic, resulting with the routed outflow from channel 157. The natural flow is then the sum off the three upstream natural flows routed to the Ghost Reservoir site, and adjusted by the evaluated amount of local inflow LI_{58}, hence:

$$N_{58} = LI_{58} + F(N_{150} + N_{151} + N_{155})$$

The same considerations are valid regarding the routing of natural flows as for the routing of recorded flows (i.e. channel routing must follow the sequence of channels shown in the schematic). There are inaccuracies in this procedure that can be related to many missing values that had to be filled using various regression models, as well as ice formation which resulted in erroneous flow or elevation measurements. In some days in the winter the calculated natural flows have negative values, which implies that more work is required to modify the data and rectify these situations. However, the high flow events show reasonable hydrographs which provide insight into the duration and timing of flood events, in addition to the peak flows. Table A5 shows the resulting summary of peak flows obtained from the daily 1930 – 2008 series. It is noted that the first half of the natural flow series (1930 – 1969) has the three benchmark statistics (25 percentile, median and 75 percentile) of flows which are on average 50m^3/s higher than the peak flows in the second half of the series from 1970 to 2008.

Table A5: Summary of Daily Natural Peak Flow Estimates for Ghost Reservoir

Year	Peak Flow at the Dam - Natural Conditions (m^3/s)	Year	Peak Flow at the Dam - Natural Conditions (m^3/s)
1930	454	1970	342
1931	313	1971	382
1932	816	1972	445
1933	575	1973	328
1934	430	1974	518
1935	408	1975	246
1936	432	1976	268
1937	282	1977	227
1938	402	1978	298
1939	294	1979	205
1940	302	1980	326
1941	179	1981	475
1942	314	1982	298
1943	346	1983	241
1944	234	1984	270
1945	319	1985	228
1946	385	1986	390
1947	375	1987	222
1948	676	1988	308
1949	204	1989	312
1950	461	1990	528
1951	432	1991	425
1952	378	1992	279
1953	537	1993	243
1954	408	1994	239
1955	386	1995	594
1956	399	1996	382
1957	281	1997	334
1958	282	1998	318
1959	314	1999	346
1960	255	2000	214
1961	400	2001	222
1962	270	2002	400
1963	346	2003	261
1964	403	2004	281
1965	582	2005	562
1966	370	2006	307
1967	454	2007	509
1968	261	2008	382
1969	356	2009	287
		2010	308
		2011	453
		2012	607
		2013	1539

A8 GENERATION OF DAILY NATURAL FLOWS AT BEARSPAW RESERVOIR

Natural flows at Bearspaw Reservoir were also generated as part of the NFCP run, as shown in Figure A8 which also includes the Bearspaw Reservoir. Daily reservoir elevations were received from Alberta Environment, and they were also available from TransAlta from 1985 to 2007. There are occasionally large differences between the reservoir levels available from those two sources, requiring judgement in the final data selection. Outflows from the Bearspaw Reservoir are available from TransAlta only after 1985.

There are two Water Survey of Canada stations on the Bow River below the Bearspaw dam. Station 06BH008 is close to the dam, but its record begins in 1983 and it is incomplete. The only other long term flow monitoring station in the relative vicinity of the Bearspaw dam is the Bow River at Calgary (05BH004). This station also needed some in-filling of missing data between 1930 and 2008, which was accomplished by developing a relationship with the Bow River below Ghost Dam (05BE006). The use of the Bow River at Calgary data is not a perfect solution, since there is a time lag of 6 to 8 hours between the Bearspaw dam and the flow monitoring station, but it was the only choice at this point. Bearspaw Reservoir outflows should be obtained from Transalta for the period since the dam started operation. Water Survey of Canada does not monitor Bearspaw reservoir levels.

Time series of the Bearspaw Reservoir levels provided by Alberta Environment begins in 1955, but this series does not contain the data related to the initial impoundment. Hence, for the period prior to 1955, the levels were kept constant with the evaporation and precipitation set to zero. Calculation of natural flows at Bearspaw reservoir was conducted within the NFCP using the following steps:

a) Calculate local inflow between the Ghost and Bearspaw reservoirs as:

$$LI_{59} = \Delta V / \Delta t + NE_{59} + R_{162} + D_{163} - F(R_{158})$$

where R162 is the outflow from the Bearspaw dam into the Bow River, D163 is the diversion by the City of Calgary, and F (R_{158}) is the routed recorded outflow from the Ghost Dam.

b) Calculate the natural flows by adding the local inflow LI59 to the routed natural flow at Ghost Reservoir:

$$N_{58} = LI_{59} + F(N_{58})$$

The resulting natural flows show that the local runoff that originates between the Ghost and Bearspaw reservoirs does not significantly increase the natural flows at the Ghost dam. In fact, during large floods, the peak flows are often lower at Bearspaw than at the Ghost dam, since the channel attenuation overcomes the additional flow increases due to local runoff. This is likely caused by the lower channel slope and larger width compared to the river sections upstream of the Ghost dam. Table A6 provides the annual flood inflow series to Bearspaw Reservoir.

Table A6: Summary of Daily Naturalized Peak Flow Estimates for Bearspaw Reservoir

Year	Peak Flow at the Dam Natural Conditions (m^3/s)	Year	Peak Flow at the Dam Natural Conditions (m^3/s)
1930	425	1970	414
1931	311	1971	419
1932	1223	1972	448
1933	619	1973	347
1934	454	1974	527
1935	405	1975	249
1936	420	1976	282
1937	273	1977	245
1938	404	1978	304
1939	301	1979	198
1940	280	1980	321
1941	185	1981	498
1942	336	1982	308
1943	359	1983	246
1944	238	1984	271
1945	348	1985	215
1946	403	1986	486
1947	414	1987	212
1948	688	1988	318
1949	208	1989	302
1950	488	1990	539
1951	432	1991	408
1952	447	1992	332
1953	599	1993	251
1954	447	1994	290
1955	398	1995	563
1956	398	1996	357
1957	299	1997	329
1958	312	1998	318
1959	327	1999	375
1960	312	2000	211
1961	428	2001	205
1962	287	2002	372
1963	350	2003	265
1964	404	2004	269
1965	521	2005	676
1966	372	2006	315
1967	424	2007	486
1968	281	2008	355
1969	439	2009	219
		2010	228
		2011	403
		2012	507
		2013	1712

A9 GENERATION OF DAILY NATURAL FLOWS AT GLENMORE RESERVOIR

Glenmore reservoir level data are available form Water Survey of Canada (station 05BJ008), with data records from 1976 to 2008. Additional water level data were obtained from 1933 to 1988 from Alberta Environment. There are two Water Survey of Canada stations downstream of the dam (05BJ005 and 05BJ001). Together, they provide continuous data coverage for the 1912 – 2008 period. There is also one more flow monitoring station upstream of the dam (05BJ010), with data available after 1979.

The reservoir level data begin with the reservoir being close to full in 1933, so the actual impoundment of the dam could not be included in the calculation of natural flows. Consequently, the reservoir was modelled with fixed elevation (i.e., zero storage change) and zero net evaporation for all years prior to 1933, implying that the recorded flows downstream of the dam was equal to natural. Natural flows after 1933 were assessed by using the outflows from the dam adjusted for Glenmore reservoir storage change. The results of the updated bathymetric survey were used in this study to incorporate the latest estimate of the storage capacity curves. Table A7 provides the resulting summary of flood series derived from the daily flow series.

Table A7: Summary of Daily Naturalized* Peak Flow Estimates for Glenmore Reservoir

Year	Peak Flow at the Dam Site (m^3/s)	Year	Peak Flow at the Dam (m^3/s)	Year	Peak Flow at the Dam (m^3/s)
1908	159	1933	55.3	1971	83.2
1909	94.0	1934	23.5	1972	42.0
1910	18.6	1935	29.2	1973	44.0
1911	89.5	1936	30.0	1974	62.3
1912	122	1937	53.6	1975	45.6
1913	38.8	1938	60.0	1976	38.1
1914	28.9	1939	91.4	1977	15.8
1915	239	1940	36.5	1978	45.6
1916	146	1941	34.3	1979	33.5
1917	147	1942	123	1980	52.8
1918	35.4	1943	30.9	1981	87.3
1919	72.5	1944	24.3	1982	36.1
1920	67.7	1945	73.8	1983	30.8
1921	37.4	1946	50.6	1984	21.0
1922	26.5	1947	69.1	1985	54.8
1923	331	1948	128	1986	53.2
1924	59.5	1949	37.0	1987	29.1
1925	66.5	1950	34.9	1988	32.9
1926	88.1	1951	136	1989	21.5
1927	83.3	1952	81.9	1990	121.8
1928	100	1953	129	1991	49.4
1929	382	1954	45.6	1992	108
1930	30.6	1955	45.9	1993	81.5
1931	22.9	1956	37.2	1994	60.4
1932	311	1957	30.6	1995	218
		1958	55.2	1996	41.8
		1959	47.7	1997	51.9
		1960	30.0	1998	96.0
		1961	50.4	1999	53.4
		1962	30.2	2000	18.1
		1963	122	2001	42.6
		1964	64.0	2002	79.4
		1965	103	2003	31.2
		1966	37.0	2004	36.2
		1967	192	2005	374
		1968	50.5	2006	110
		1969	128	2007	78.1
		1970	94.7	2008	173
				2009	46.9
				2010	60.9
				2011	180
				2012	146
				2013	484

** Naturalized daily peak flow estimates may be slight different from published values of daily peak flows*

Floods recorded prior to 1933 have greater median and 75 percentile values, than the other two periods that were compared (1933 – 1969) and (1970 – 2008) are statistically similar.

A10 ROUTING OF DESIGN HYDROGRAPHS

Following development of inflow hydrographs for the various return periods, the next step was to route the hydrographs through the storage structures to account for the effects of storage and evaporation on the flood flows. Routing was conducted using the existing guidelines for operating these structures during floods. In some cases there is allowance for variability to provide flexibility to the operation such as “keep the outflow between 100 and 160 m^3/s if inflow is above 100 m^3/s”. Setting up a computer model to mimic the behaviour of an operator may therefore involve strengthening of the rules by the modeller, in order to ensure repeatability of simulation runs. The new version of the WRMM model from Alberta Environment was used in this study. This model includes both channel routing using the SSARR routing method, as well as reservoir routing. The routing equations are formulated as constraints to a linear program. The benefit of this model is that it has flexibility to represent various reservoir operating policies, including a mix of rule curves and multiple water use zones and priority factors that drive the simulation as cost parameters in the objective function.

A11 FLOOD ROUTING AT GLENMORE RESERVOIR

Glenmore reservoir was built in 1933 on the Elbow River to provide water supply for the City. Its original design did not include an allowance for flood storage. However, flood operational guidelines exist, and they provide instructions on the reservoir drawdown and release policies for the bottom outlet and spillway. Considerable judgement is required on the part of the operators in terms of the draw down of the reservoir during a flood event, ranging from 2 m to 4 m.

Low level outlet releases are linked to the incoming flows and the achieved drawdown. The maximum low level outlet flows is 165 m^3/s. This limit is achieved during the condition where it is necessary to evacuate the incoming flood and simultaneously lower the reservoir level to a desired target drawdown. Once the target drawdown is reached, the outflows will be equal to inflows, and if inflows exceed 165 m^3/s the reservoir will begin to fill since the outflow remains set at 165 m^3/s. Once the reservoir levels has reached the invert of the spillway, the flood will be evacuated through both the low level outlet and the spillway for the first 1.0 m of flow depth over the dam crest and with a gradual shut down of the bottom outlet. At a water level of 1.0 m above the dam crest, the low level outlet is closed and the spillway continues to discharge the flood as it has reached sufficient head to provide adequate outflow capacity.

As part of the model setup, the results of the most recent bathymetric surveys from the City of Calgary were used in this study. Table A8 provides a summary of the initial assumptions, along with the key elevations and outflows obtained from applying the existing rules for routing design hydrographs through the Glenmore Reservoir.

Table A8: Summary of Flood Routing Results for the Glenmore Reservoir

Return Period (years)	Initial Conditions		Reservoir Elevation (m)		Flows (m^3/s)		Spillway Required
	Starting Reservoir Elevation (m)	Starting Outflow (m^3/s)	Minimum	Maximum	Maximum Inflow	Maximum Outflow	
2	1,074.83	100	1,072.33	1,074.83	56	100	NO
5	1,074.83	100	1,072.33	1,074.83	107	100	NO
10	1,074.83	150	1,072.33	1,074.83	154	165	NO
20	1,074.33	165	1,072.33	1,074.33	211	165	NO
50	1,074.33	165	1,071.33	1,076.58	302	245	YES
100	1,074.33	165	1,071.33	1,076.83	385	366	YES
200	1,074.33	165	1,071.33	1,077.08	481	477	YES
500	1,073.66	165	1,071.33	1,077.36	632	624	YES
1,000	1,073.66	165	1,071.33	1,077.61	766	757	YES

Table A8 shows that the low level outlet has sufficient capacity for floods that have magnitude which is less or equal to the 50 year return period, assuming the current operating rules are implemented in a timely manner. The analysis also shows that the use of the spillway will be required for floods with return flow period above 50 years.

A12 FLOOD ROUTING THROUGH THE UPPER BOW SYSTEM

Synthetic inflow hydrographs for the selected return flow periods were developed for all key storage structures in the Upper Bow River basin. Their routing through the storage structures and interconnecting river reaches was conducted based on the existing flood operating guidelines obtained from TransAlta Utilities. In their definition of the operating rules, TransAlta distinguishes the Key Elevations for each reservoir as a guideline for triggering the use of the spillway. When the storage is below the Key Elevations, incoming flows are only released through the turbines, subject to the maximum capacity of each plant. Most hydro power plants in the system are designed to operate turbines during flows up to flows above the long term historic averages, and most are designed to also operate during floods together with spillway structures, thus allowing hydro power plants to act as low level outlets and add to the total outflow capacity, while simultaneously generating power. Table A9 provides a listing of maximum flow capacity for each hydro power plant in the Upper Bow River Basin.

Table A9: Maximum Flows through Hydro Power Plants

Name of Hydro Power Plant	Maximum Outflow (m^3/s)
Three Sisters	24.6
Spray	45.3
Rundle	62.3
Interlakes	19.8
Pocatera	31.2
Barrier	36.8
Cascade	39.6
Kananaskis	120.7
Horseshoe	104.8
Ghost	243.5
Bearspaw	155.7

The Key Elevations at which the spillway operation begins have been established as part of earlier PMF studies, and they are adhered to every year to meet the existing safety requirements. These elevations typically involve a mandatory drawdown of reservoir levels in May of each year, with a gradual return to the full supply levels in June and early July. In addition to the Key Elevations, Transalta has also established target elevations for each storage reservoir as a function of time, as part of earlier operational studies. These target elevations were based on the overall integrated system modelling, with the existing downstream maintenance flow requirements in the Bow River. It was decided that the second week of June (Julian day 161) is the most likely timing for floods of high magnitude. Consequently, the target elevations provided a reasonable estimate of the starting reservoir levels for this week. These levels are somewhat below the Key elevations, but they are normally very close to them (usually lower but within 1 to 2 meters). A typical sketch of the key and target elevations is shown in Figure A8.

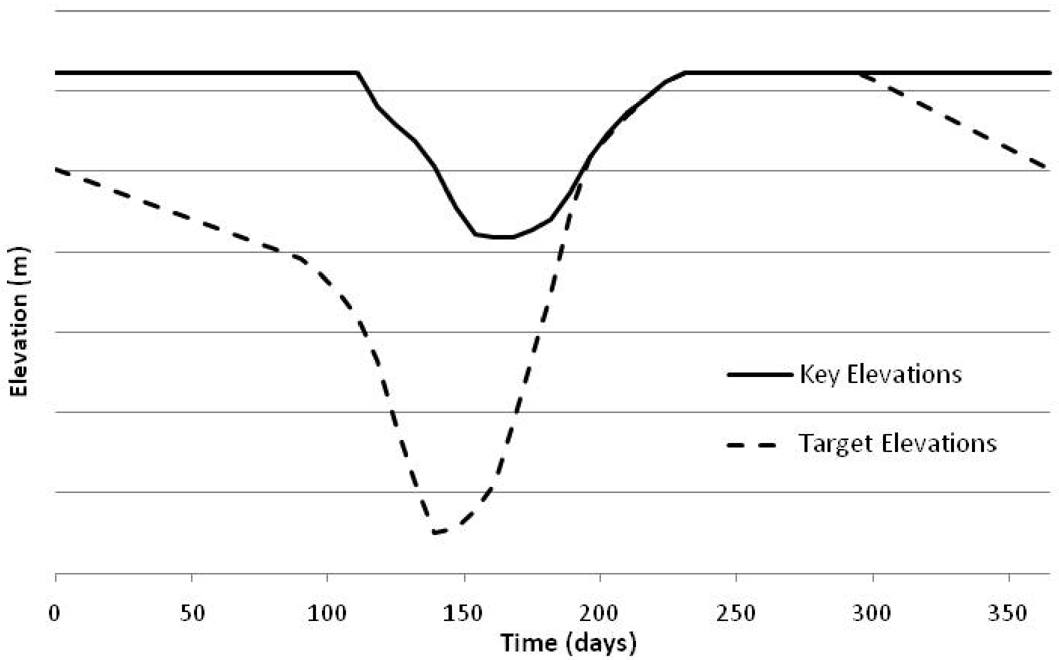


Figure A8: Key and Target Elevations for a Typical Upper Bow Storage Reservoir

TransAlta's flood operating guidelines that were used in this study are summarized as follows:

- Start from the target elevation for the starting date of the flood, and attempt to bring the reservoir to the target elevation at the end of the current time step. This may be possible if there is sufficient inflow. If not, set the outflow to zero and attempt to bring the reservoir level as close as possible to the target elevation at the end of the time step.
- If Inflow is above the hydro power plant outflow capacity (as may be anticipated during floods), set the outflow equal to the plant capacity and keep the surplus water in storage, thus ending at a reservoir level higher than the target elevation at the end of a time step.
- Once the reservoir level reaches the Key Elevation, keep the plant operation at full capacity and open the spillways to evacuate the excess water and maintain the key elevations as close as possible.

Some reservoirs have alternate outlet structures with a prescribed sequence of start-up and shut-down (examples are Spray Lake and Lower Kananaskis Lake). These rules were taken into consideration in the model setup.

The highest retention capacity is available at Upper and Lower Kananaskis Lake, Lake Minnewanka and Spray Lake. Except for Spray Lake, these are also the locations that have the lowest peak inflows, such that their attenuation does not add much to the reduction of the incoming floods into the Ghost and Bearspaw reservoirs. The principal control points that determine runoff into Ghost Lake are the Bow River at Banff, Spray River at the mouth, and the Kananaskis River at Barrier Dam. The first two control points function as natural flow gauges, while the Barrier Dam has negligible flood retention capacity. Therefore, all three control points can be assumed to essentially function without any flood retention capability, and subsequent routing of their runoff through Ghost Lake and Bearspaw reservoir also has little capacity to reduce the incoming flood peaks.

The Upper Bow River Basin modelling schematic is illustrated in Figure A9. Included in the model are smaller structures, such as the Kananaskis hydro power plant, in order to include their outflow capacity tables. Channel routing is applied in all channels between Banff and Bearspaw, and on the channel between the Barrier reservoir and the confluence of the Bow and Kananaskis rivers, based on the information provided by Alberta Environment. The model was run using 6-hourly time steps, over an event base of 16 days, which translates to 64 consecutive time steps of 6 hour length. To achieve this, the WRMM was modified to increase its current limit to 52 time steps per year.

Table A10 provides a summary of the routed peak flows for two simulations. The first simulation was based on the synthetic hydrographs which were derived for all key locations in the Upper Bow Basin. The other simulation was based on constructing flood hydrographs with added historic information available from high water marks. This simulation included only Ghost Lake and Bearspaw reservoir, since there was no historic information in the upper parts of the catchment that could be used to extend this analysis further upstream. It should be noted that in the base case simulation (based on the 79 years of daily natural flows estimated for the Upper Bow Basin), the floods with the same return period were assumed to occur simultaneously at all key locations in the basin. This may not be a realistic assumption for more frequent flood events, and as a result the routed peak flows appear to be slightly higher than the ones that would have been obtained by conducting frequency analyses of the recorded flows downstream of Bearspaw reservoir.

Table A10: Peak Flows of Routed Flood Hydrographs

Return Period (Years)	Naturalized Flood Flows of Systematically Recorded Data and Historic Data (m^3/s)	Naturalized Flows of Systematically Recorded Data (m^3/s)
2	378	445
5	536	551
10	682	671
20	863	751
50	1,178	862
100	1,492	950
200	1,893	1,068
500	2,584	1,338
1,000	3,301	1,564

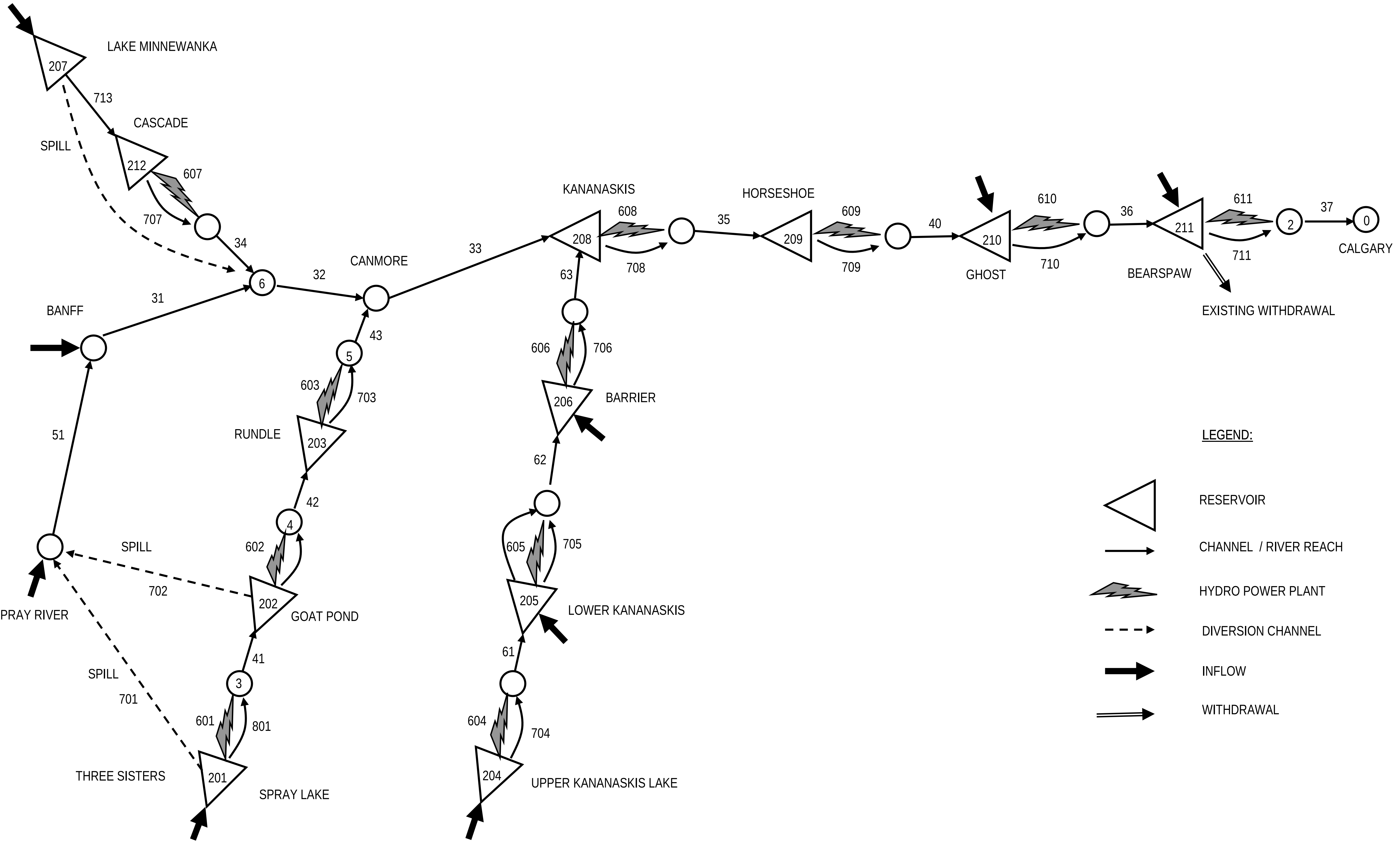
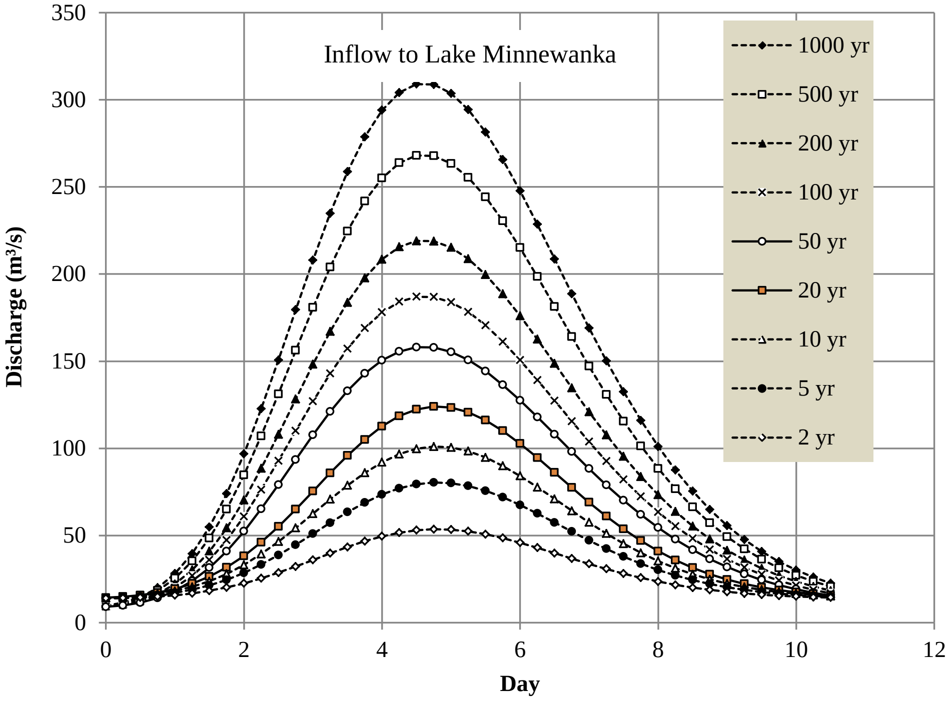
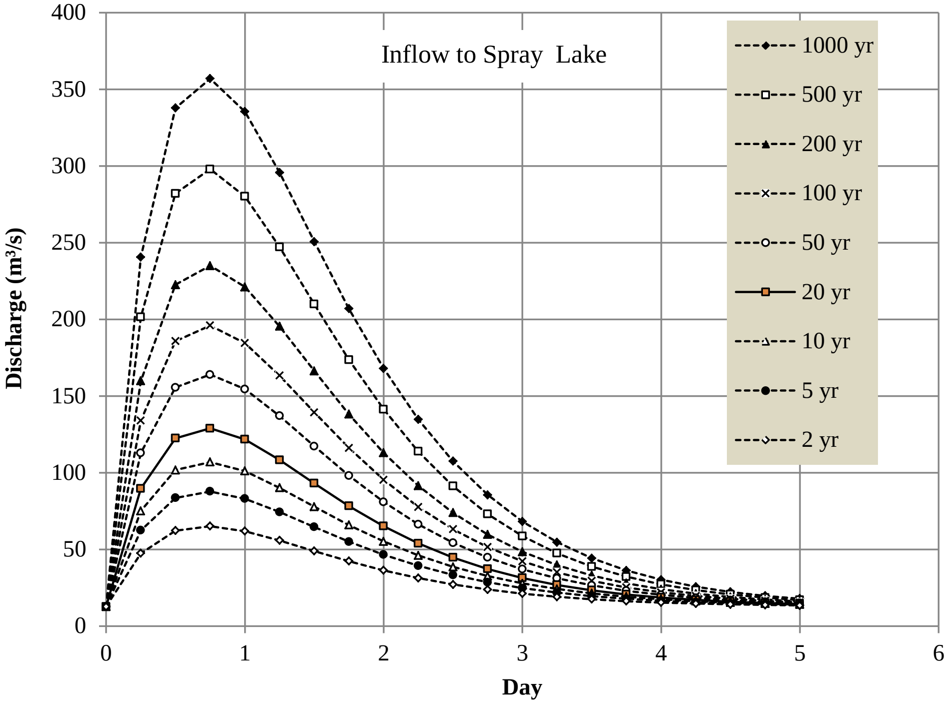


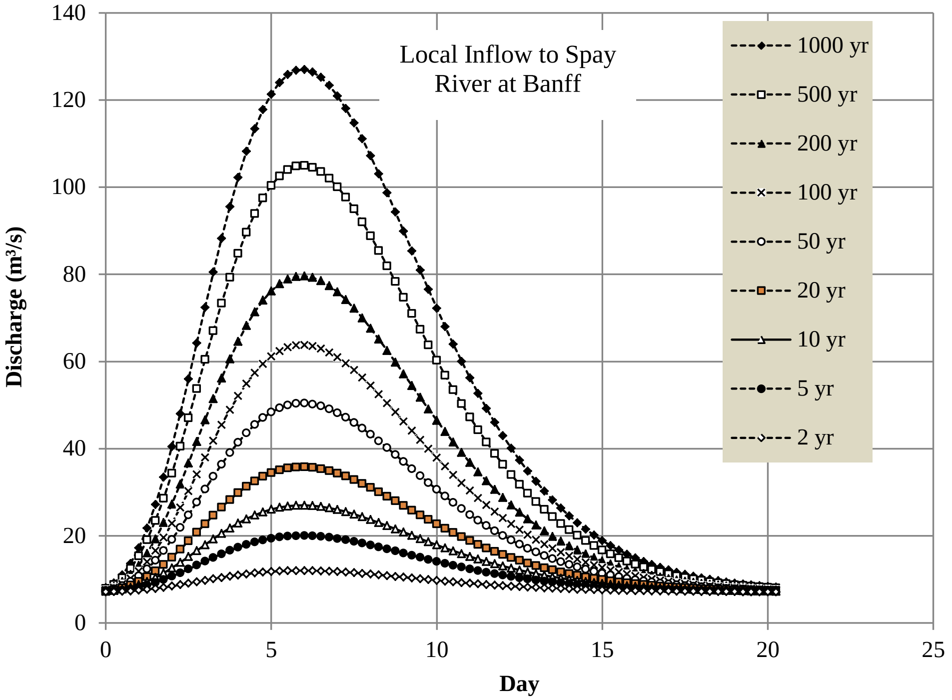
Figure A9: Upper Bow River Basin Modelling Schematic

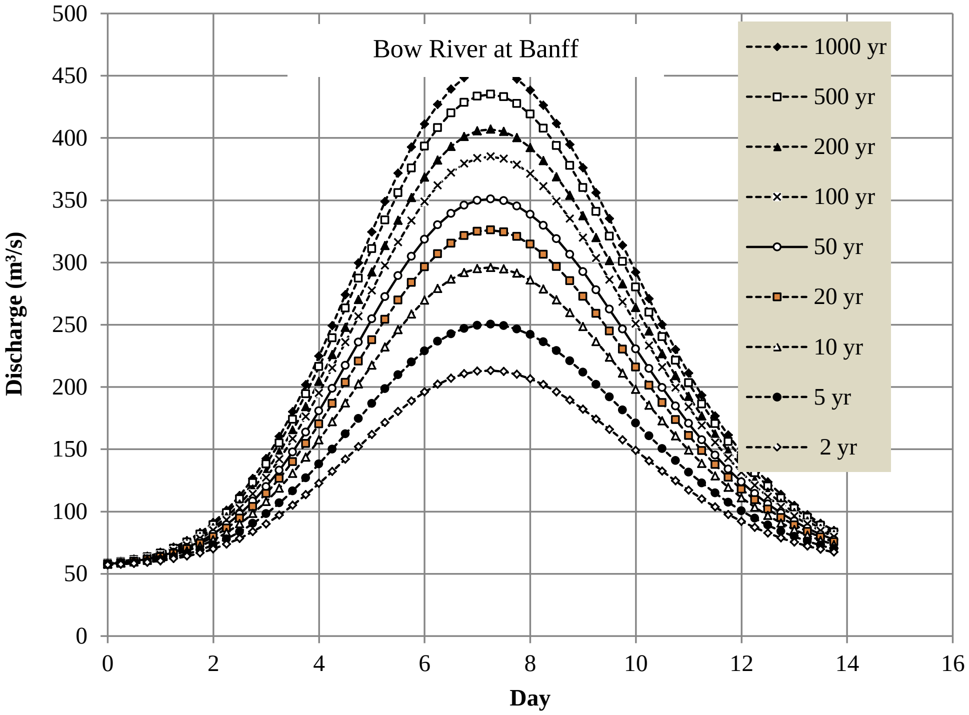
APPENDIX B

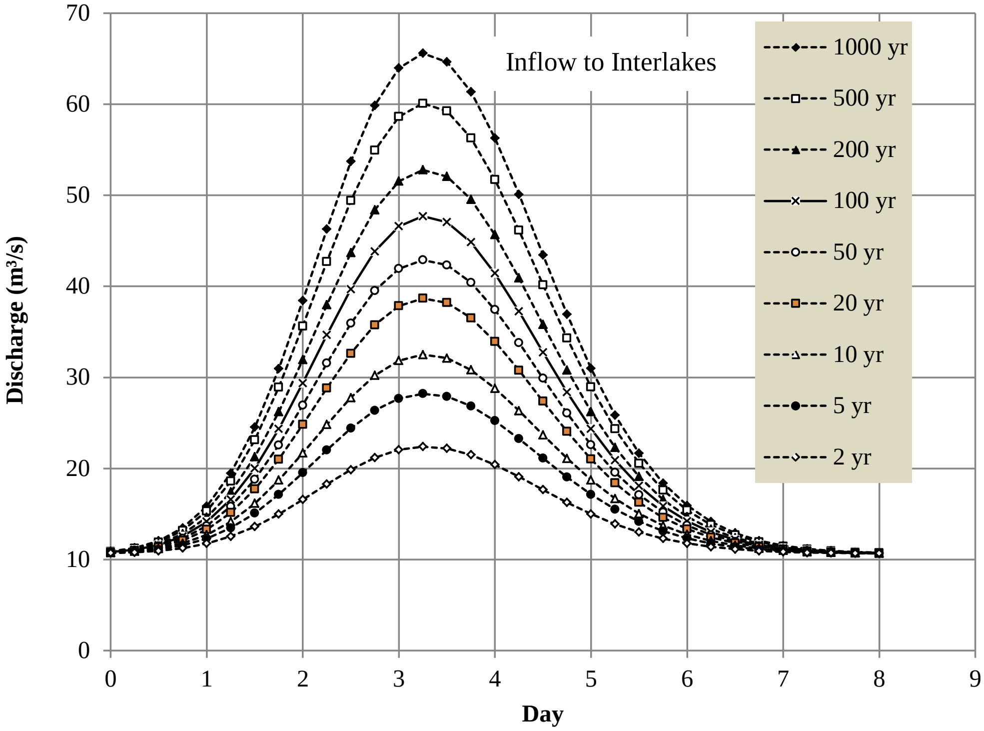
Naturalized Daily Flood “Hydrographs”

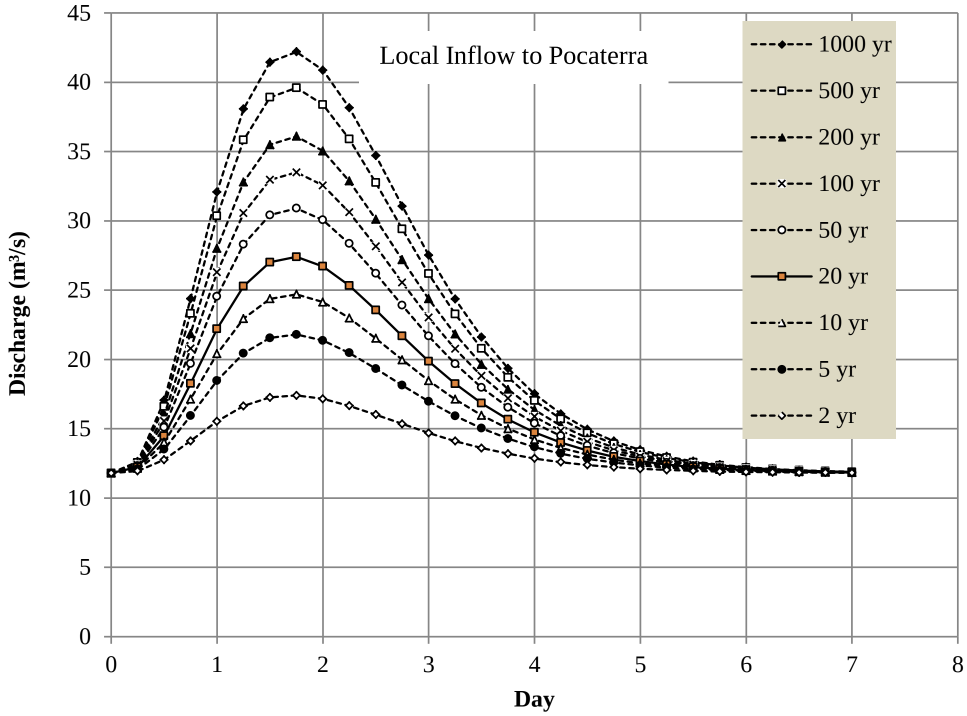

Inflow to Lake Minnewanka
Discharge (m³/s)
Day
0
50
100
150
200
250
300
350
0
2
4
6
8
10
12
1000 yr
500 yr
200 yr
100 yr
50 yr
20 yr
10 yr
5 yr
2 yr

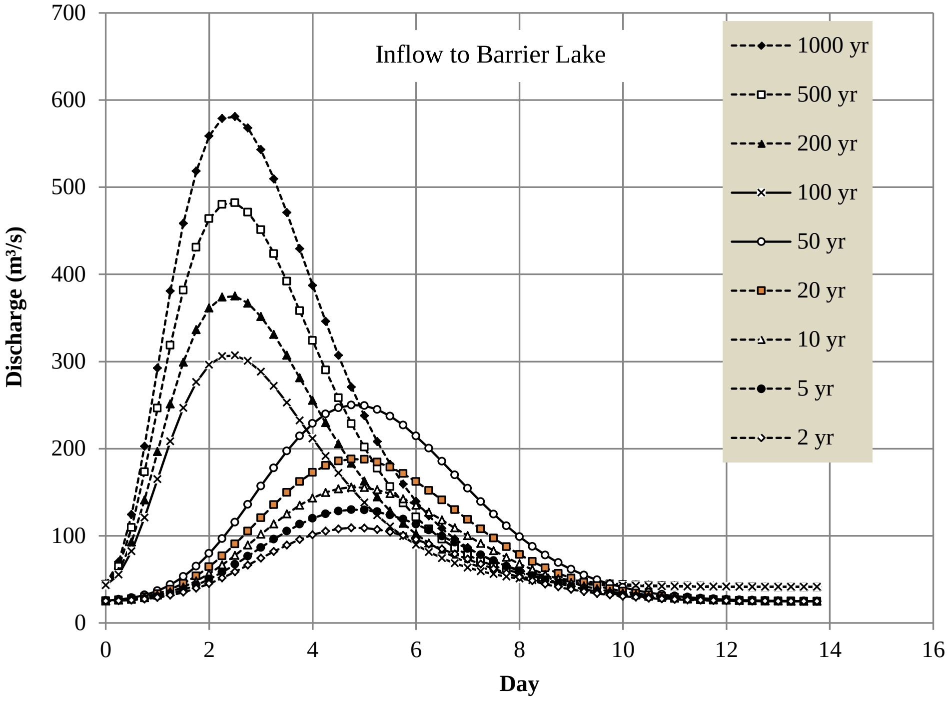

Inflow to Spray Lake
Discharge (m³/s)
Day
0
50
100
150
200
250
300
350
400
0
1
2
3
4
5
6
1000 yr
500 yr
200 yr
100 yr
50 yr
20 yr
10 yr
5 yr
2 yr

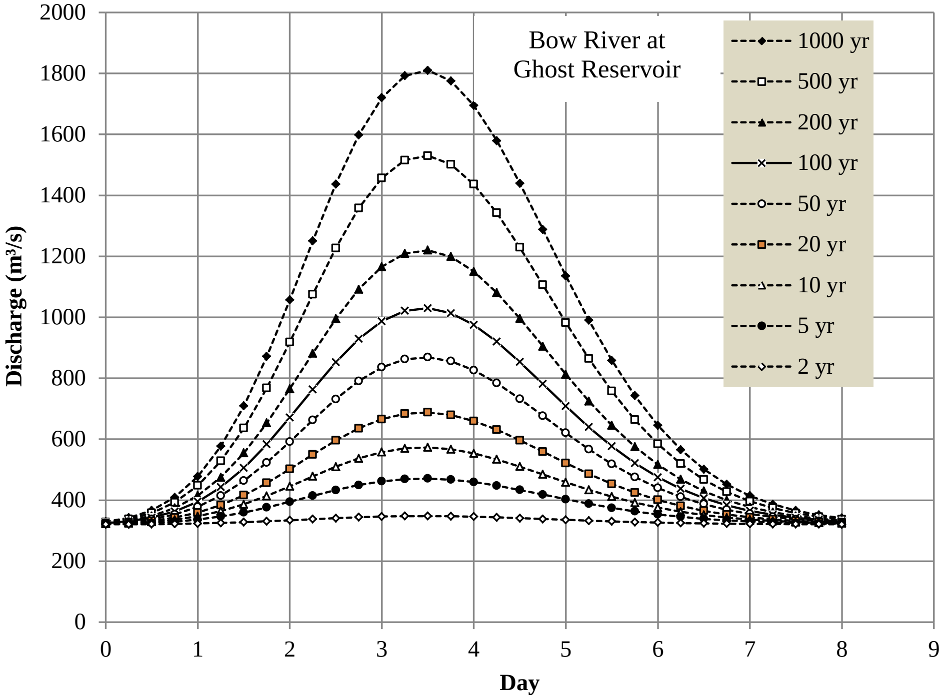

Local Inflow to Spay River at Banff
1000 yr
500 yr
200 yr
100 yr
50 yr
20 yr
10 yr
5 yr
2 yr
Discharge (m³/s)
Day
0
20
40
60
80
100
120
140
0
5
10
15
20
25

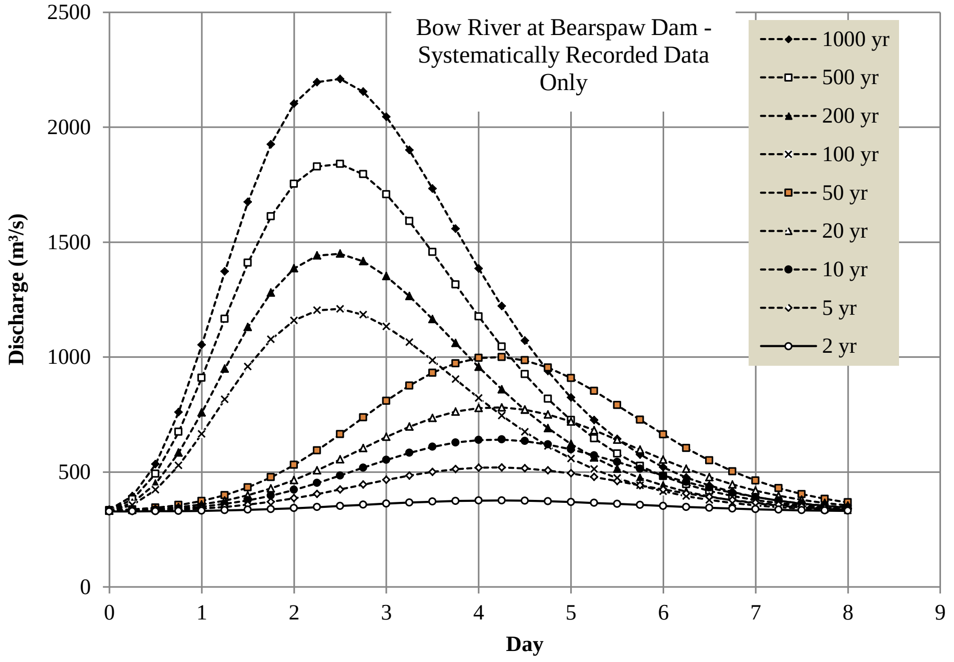

Bow River at Banff
1000 yr
500 yr
200 yr
100 yr
50 yr
20 yr
10 yr
5 yr
2 yr
Discharge (m³/s)
Day
0
50
100
150
200
250
300
350
400
450
500
0
2
4
6
8
10
12
14
16

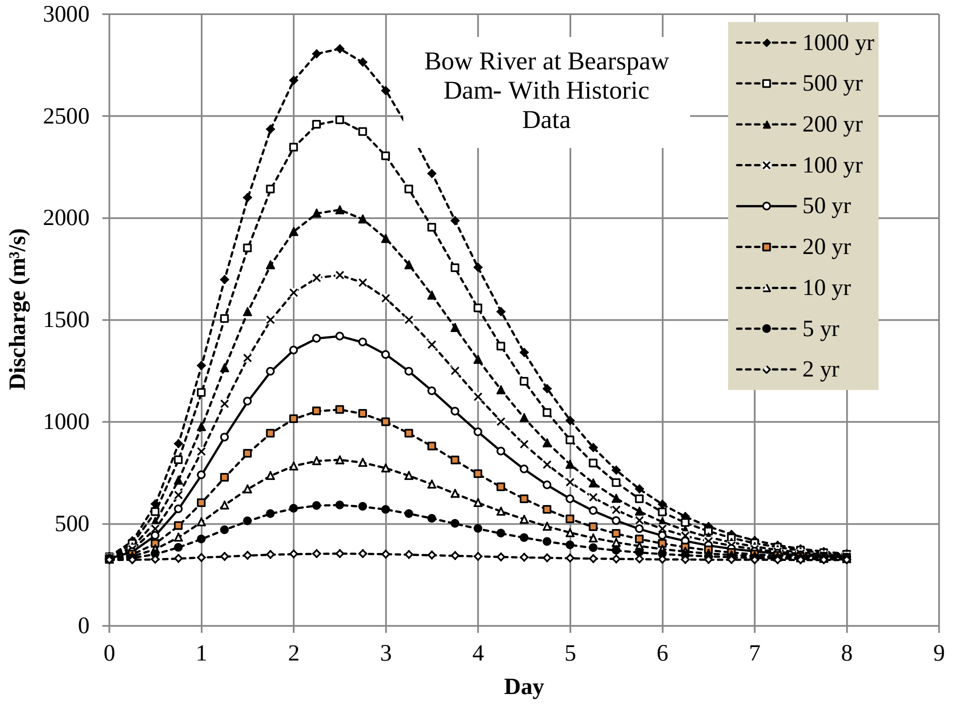

Inflow to Interlakes
Discharge (m³/s)
Day
0
10
20
30
40
50
60
70
0
1
2
3
4
5
6
7
8
9
1000 yr
500 yr
200 yr
100 yr
50 yr
20 yr
10 yr
5 yr
2 yr

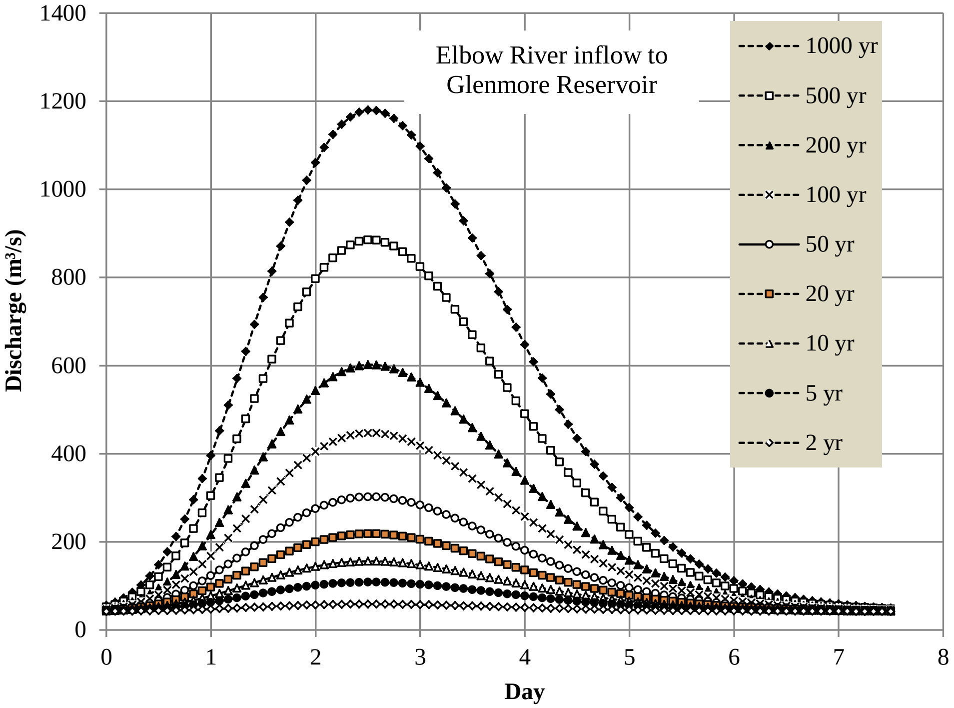

Local Inflow to Pocaterra
Discharge (m³/s)
Day
0
5
10
15
20
25
30
35
40
45
0
1
2
3
4
5
6
7
8
1000 yr
500 yr
200 yr
100 yr
50 yr
20 yr
10 yr
5 yr
2 yr


Inflow to Barrier Lake
Discharge (m³/s)
0
100
200
300
400
500
600
700
Day
0
2
4
6
8
10
12
14
16
1000 yr
500 yr
200 yr
100 yr
50 yr
20 yr
10 yr
5 yr
2 yr


Bow River at
Ghost Reservoir
Discharge (m³/s)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Day
0
1
2
3
4
5
6
7
8
9
1000 yr
500 yr
200 yr
100 yr
50 yr
20 yr
10 yr
5 yr
2 yr


Bow River at Bearspaw Dam - Systematically Recorded Data Only
Discharge (m³/s)
Day
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8
9
1000 yr
500 yr
200 yr
100 yr
50 yr
20 yr
10 yr
5 yr
2 yr


Bow River at Bearspaw Dam- With Historic Data
Discharge (m³/s)
Day
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8
9
1000 yr
500 yr
200 yr
100 yr
50 yr
20 yr
10 yr
5 yr
2 yr


Elbow River inflow to
Glenmore Reservoir
Discharge (m³/s)
Day
0
200
400
600
800
1000
1200
1400
0
1
2
3
4
5
6
7
8
1000 yr
500 yr
200 yr
100 yr
50 yr
20 yr
10 yr
5 yr
2 yr

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