Memo

March 30, 2017

Re: Flood Mitigation Measures Assessment

The Flood Mitigation Options Assessment (“the Report”) was prepared for The City of Calgary (“The City”) by IBI Group Professional Services (Canada) Inc. (“The Consultant”), in accordance with the contract awarded under RFP#15-1617. The Report is copyright ©2017, The City of Calgary. The report describes the development and use of the Updated Rapid Flood Damage Model (“the Model”), which was created for The City by The Consultant based on the previous model developed for the Government of Alberta[1].

Conditions described in the Report, which apply to the development of the Model, are based on information obtained during the assessment conducted and on the state of development and the rivers’ condition at the time of the assessment. The Report and Model were prepared, based in part, on information provided by The City of Calgary. The information, data, recommendations and conclusions contained in the report are subject to the limitations described in the report, and were limited to the scope and schedule of the project. They represent the Consultant’s professional judgement in light of the limitations, current regulatory context, and industry standards.

For those interested in this work, pertinent points may include, but are not limited to:

- The flood damage model was updated with The City’s most up to date (2015) hydraulic modelling at the time of the study, as described in the report. Flood frequencies and associated depths reflect the results of this hydraulic model.
- Groundwater inundation modelling was based on limited subsurface data, a simplified modelling methodology, and was adjusted using professional expertise.
- Neither groundwater inundation nor flood damage estimates were fully validated or calibrated to historic events, due to a lack of data to complete such analyses.
- The monetized costs and benefits captured in the damage model included those impacts that were judged by The Consultant to be applicable and quantifiable, but did not represent an exhaustive list of all financial, social and environmental impacts (positive and negative) related to flooding and mitigation measures. Further details on parameters that were and were not included in the model are described in the Phase 1 section of the report.
- Given the point above, the benefit-cost results should be taken into consideration alongside the Triple Bottom Line (TBL, also called the “sustainability analysis”) results, which provide a more fulsome analysis of mitigation measures based on expanded social, environmental and implementation feasibility criteria.

The findings and conclusions documented in this report have been prepared for the specific application to this project, and within the specific regulatory context at the time. Regulations are subject to interpretation and change, and should be reviewed over time. If new information is discovered during

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1 IBI Group. *Provincial Flood Damage Assessment Study.* Prepared for Government of Alberta ESRD – Resilience and Mitigation. Feb 2015. Available at: http://aep.alberta.ca/water/programs-and-services/flood-mitigation/flood-mitigation-studies.aspx

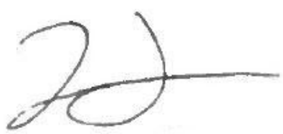
future work, the conclusion of this report, and/or the applicability of The Model, should be re-evaluated prior to any reliance upon the information presented herein.

Any use of this Report is subject to the above qualifications and limitations. The City of Calgary makes no commitment to maintaining, updating or training on the Model. Any damages arising from improper use of the Report or Model shall be borne by the party making such use.

In the interest of ensuring consistent and accurate interpretation of the embedded limitations of the model and information derived from it, The City considers it warranted for parties using or interpreting the Model or related information to advise and confer with the City prior to any public communication or redistribution of same. As the model relies on and contains information prepared within the realm of Professional Engineering practice, relevant Codes of Ethics and standards of practice may apply to the responsible use and distribution of the Model or related/derived information.

This memo outlining qualifications and limitations is attached to and forms part of the Report.

Sincerely,



Frank Frigo, P.Eng.

Project Sponsor, Flood Mitigation Measures Assessment

Leader, Watershed Analysis, Water Resources

City of Calgary

T 403.268.4599 | **Mail code** #433

E Frank.Frigo@calgary.ca

Calgary, Alberta, Canada

Sandra Davis, M.Sc., P.Eng.

Project Manager, Flood Mitigation Measures Assessment

River Engineering, Water Resources

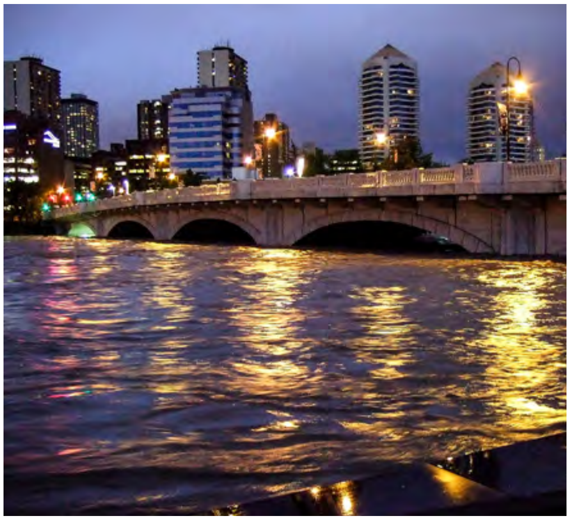
City of Calgary

T 403.268.4432 | **Mail code** #433

E Sandra.Davis@calgary.ca

Calgary, Alberta, Canada

Attachments: 1 – IBI Group Professional Services (Canada) Inc. *Flood Mitigation Options Study.* Prepared for The City of Calgary. Feb 2017.



REPORT

Flood Mitigation Options Assessment

Prepared for the City of Calgary
by IBI Group and Golder Associates Ltd.
#38737 | February 2017

IBI GROUP
500 – Meredith Block, 611 Meredith Road NE
Calgary AB T2E 2W5 Canada
tel 403 270 5600 fax 403 270 5610
ibigroup.com

February 2, 2017

Ms. Sandra Davis, M.Sc., P.Eng.
The City of Calgary
River Engineering Group
Watershed Planning, Water Resources
Water Centre - 625 - 25 Avenue S.E.
P.O. Box 2100, Station M, Mail Code: #433
Calgary, AB T2P 2M5

Dear Ms. Davis:

FLOOD MITIGATION OPTIONS ASSESSMENT - FINAL REPORT

Please find enclosed the final report for the Flood Mitigation Options Assessment. The document is prefaced with an Executive Summary; contains the Phase 1 and Phase 2 components; and is supported by several technical appendices.

At this time we would like to thank the Technical Steering Committee for their input and assistance throughout the process. We appreciate the opportunity to have been of service on this noteworthy endeavour and trust it provides the required information to move forward with a permanent solution to the identified flood issue.

Yours truly,

IBI GROUP	**IBI GROUP**	**GOLDER ASSOCIATES LTD.**
Stephen Shawcross	David Sol	Dejiang Long, Principal
Director	Senior Planner	Senior Water Resources Engineer

SS/mp

Encl.

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Study Team Members

IBI Group

Stephen Shawcross
Augusto Ribeiro
David Sol
Melinda Tracey
Aysia Stante
Michele Penn
Garrett Newman
Carla Pereira
Michael Valenzuela
Jonathan Darton
June Park
Dan Sandink (Institute for Catastrophic Loss Reduction)

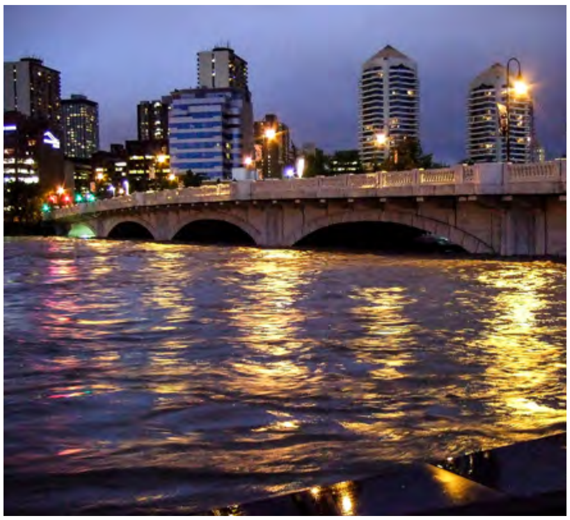
Golder Associates Ltd.

Dejiang Long
Wolf Ploeger
Peter Thiede
Slobodan Simonovic (Slobodan P. SIMONOVIC Consulting, Ltd.)
Donald Haley

City of Calgary

Sandra Davis
Tanya Laing
Frank Frigo
Andrew Forsyth
Darren Todd
Darrell Sargent
Pamela Reid
Sarah Hbeichi
Carolyn Bowen

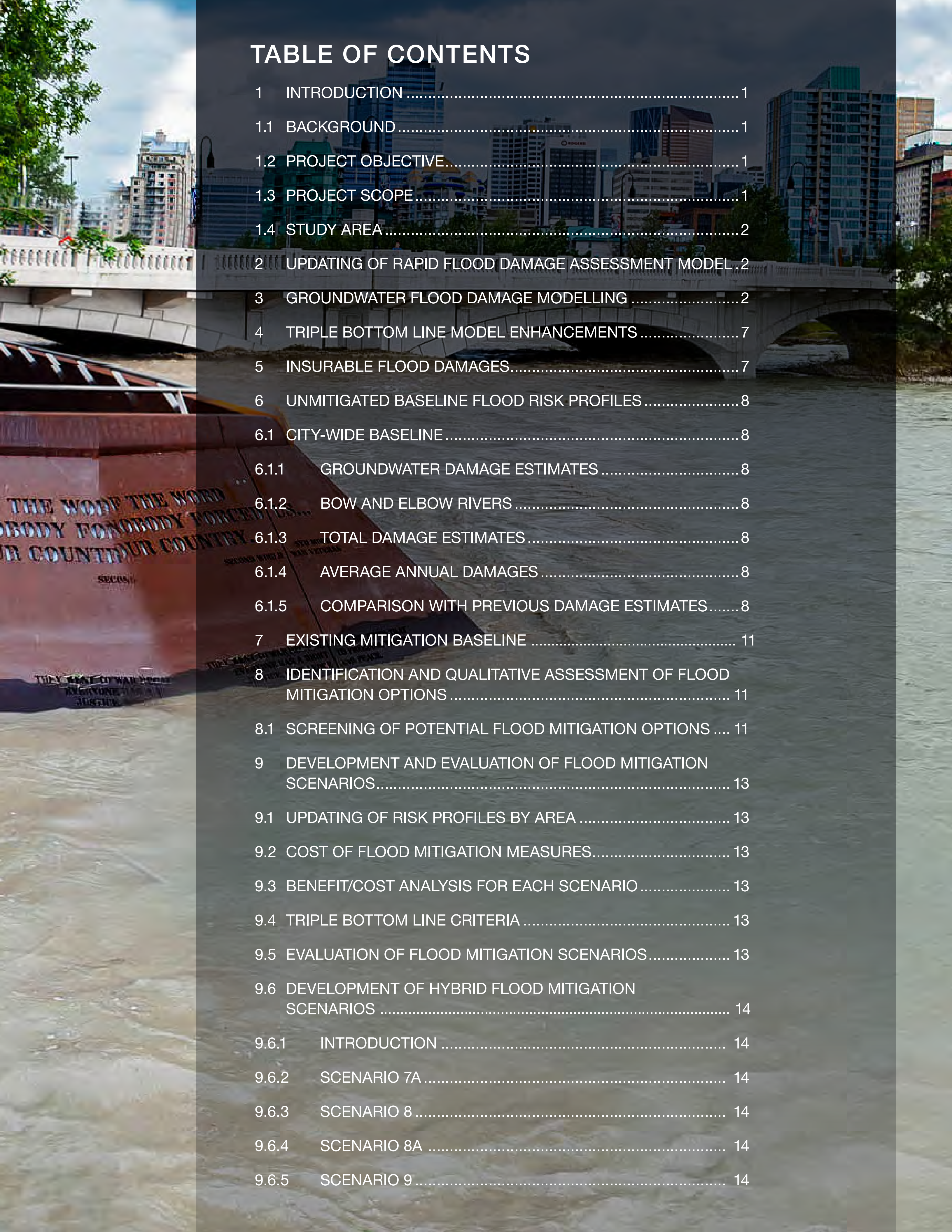
Executive Summary



Flood Mitigation Options Assessment - Executive Summary

Prepared for the City of Calgary
by IBI Group and Golder Associates Ltd.
38737 | February 2017

CALGARY FLOOD, 2013



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1 Introduction

1.1 Background

The flood of June 2013 was the largest flood in Calgary since 1932, causing estimated damage of $409 million to City of Calgary infrastructure as well as extensive damage to private property in the city. This event also caused a significant amount of social, environmental and economic damage and disruption and put the safety of Calgarians at risk. Global climate change models predict that extreme rain events are likely to become more frequent and severe in the future, potentially leading to higher flood risks; therefore it is imperative that there be proactive approaches to increasing flood resiliency.

Since the 2013 flood, The City of Calgary (The City) and The Government of Alberta (The Province) have been evaluating and reviewing several flood mitigation options. The City has been implementing flood mitigation measures and evaluating potential flood mitigation options within the city limits, including the following:

1. Bank stabilization and erosion protection works at various locations throughout the city;
2. The Glenmore Reservoir diversion tunnel;
3. The identification and design of addition permanent flood barriers throughout the city;
4. Replacing gates ~~on~~ at the Glenmore Dam to increase its storage capacity;
5. Evaluating how changes in land use policy could limit the damage during a flood event; and
6. Updating the flood emergency response plan including design of temporary barriers.

The Glenmore diversion tunnel was analyzed in considerable detail; however, is no longer under consideration as a more economically-efficient alternative is being developed for the Elbow River (the Springbank Off-Stream Reservoir). Several new barriers have been designed and constructed within the City limits in addition to the installation of outfall gates on the Bow and Elbow Rivers to prevent backup into communities. In a number of areas river channel constrictions (debris and select gravel bars) have been removed and improvements to storm and sanitary lift stations implemented.

In light of the changing dynamics of the floodplain and The City's desire to better understand flood risks, as well as costs and benefits a range of structural and non-structural flood mitigation options, IBI Group and Golder Associates were retained by The City in July of 2015 to undertake the Flood Mitigation Options Assessment Study (The Study).

1.2 Study Objectives

The analysis conducted in the Study is critical to support informed decision-making for prioritizing and implementing flood risk reduction strategies and flood mitigation measures. This will include determining which structural options are the most appropriate and providing direction for land use policy changes or other non-structural mitigation approaches in flood prone areas. The main objectives of the Study are to:

1. Develop and apply a reliable, transparent and repeatable calculation process to understand and quantify flood risks across Calgary including aspects related to public safety, community planning and function, damage to buildings and infrastructure, service disruption, direct and indirect economic impacts, and the environment.
2. Provide guidance on what levels of protection are appropriate (i.e., what return period to protect to) for various flood affected communities in consideration of the costs and benefits of various flood mitigation options.
3. Analyze and compare which individual or combined flood mitigation options (i.e. flood mitigation scenarios) are the most cost beneficial at specified levels of service (e.g., 1:50, 1:100, 1:200 or 1:350 year flood protection level).
4. Provide a Triple Bottom Line evaluation of the various flood mitigation scenarios to support prioritization of key structural and non-structural investments and actions to increase flood resiliency.
5. Provide guidance in prioritizing structural and non-structural flood mitigation measures.

1.3 Study Scope

The Study has been conducted in two phases:

1. Phase 1 involves an update of the flood damage model created by IBI Group for the Province, including groundwater modelling and use of the updated hydrologic and hydraulic information already generated by Golder for The City and the Province, and groundwater modelling.
2. Phase 2 involves application of the updated flood damage model and an assessment of various flood mitigation scenarios, including a triple bottom line analysis that includes community consultation considerations and the creation of a prioritized list of investments and actions.

Both phases of the Study have been performed in the context of current flood resiliency conditions, such as the existing flood protection provided by the Glenmore Dam, permanent flood barriers in the city and the 2014 changes to the Municipal Development Plan and the City of Calgary Land Use Bylaw 1P2007.

1.4 Study Area

The study area encompasses all flood prone communities and undeveloped land along the Elbow and Bow Rivers through the city limits as defined by the most recent flood inundation map prepared by Golder for The City and the Province. This includes the areas impacted by various flood events up to the 1,000-year flood event, as illustrated in **Exhibits 2.9 and 2.10.**

2 Updating of Rapid Flood Damage Assessment Model

The Rapid Flood Damage Assessment Model (RFDAM), employed to determine flood damages as part of the City of Calgary Flood Damage Estimate Study of 2014, was updated in this Study to include the updated hydrologic and hydraulics information for the Bow and Elbow Rivers; a re-allocation of spill areas for damage estimation purposes; additions to the building inventory as a result of the expanded flood hazard area; recalculation of flood elevations for individual structures based on the latest 3D modelling; a re-computation of basement damages based on groundwater modelling; and finally, the addition of a module for evaluating social and environmental aspects of flood damage.

The modifications and enhancements as described above make the RFDAM the most sophisticated and site-specific, object-based tool available for computing flood damages within Alberta.

3 Groundwater Flood Damage Modelling

Areas outside the surface flood inundation extents can be subjected to basement flooding due to sewer backup or groundwater seepage through basement cracks. Sewer backup can be caused by higher groundwater pressures in hydraulic connection with the fluid in the sanitary system (e.g., through leaks in sewer fittings or connectors) or the sewer may be hydraulically connected with surface water. Therefore, potential groundwater flood damage can be influenced by both surface and groundwater flood levels.

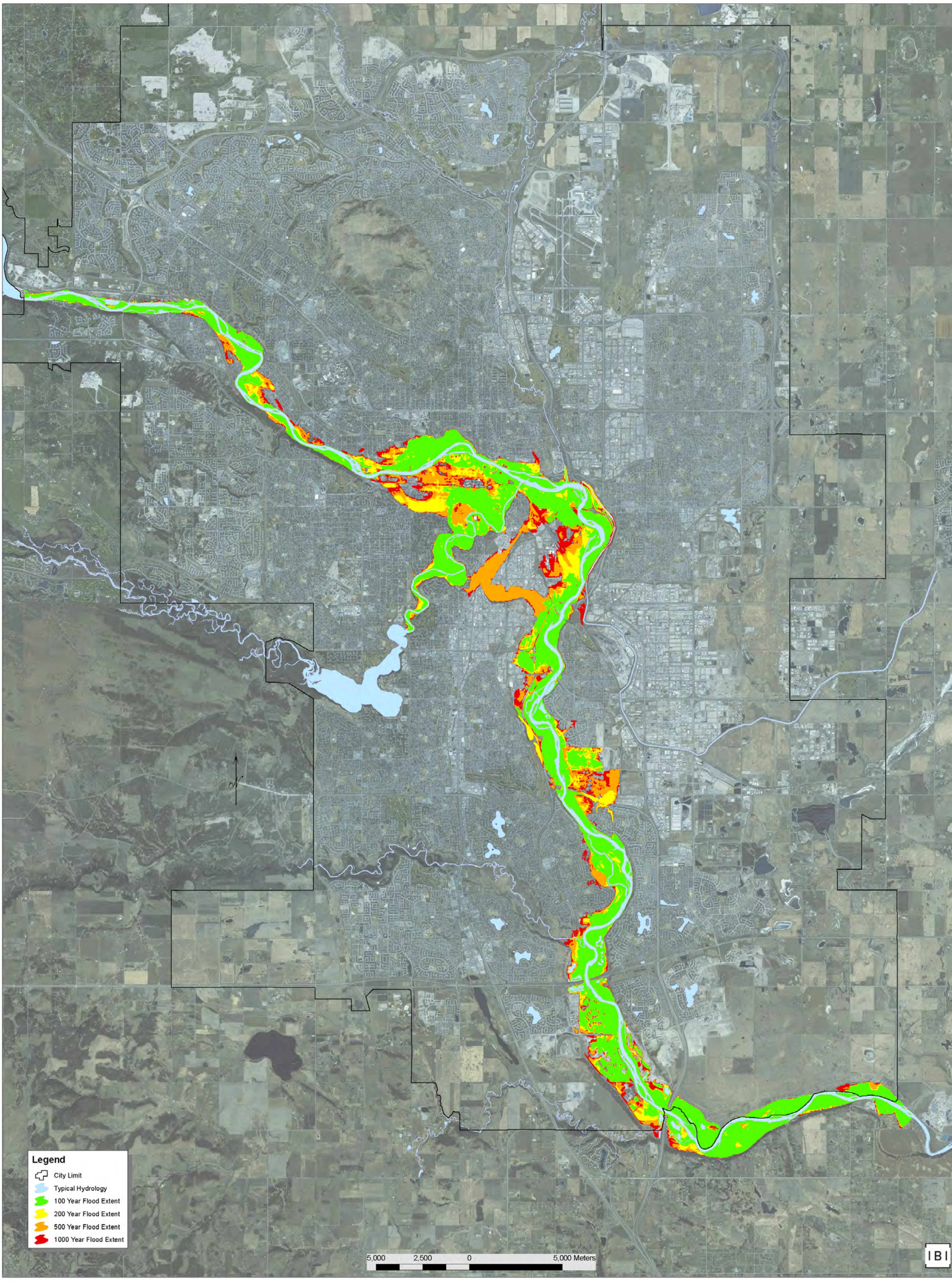
The Bow and Elbow River channels in Calgary are underlain by a permeable alluvial aquifer. The groundwater levels in the alluvial aquifer may rise as the river water levels rise during river floods. Modelling of groundwater flood levels is conducted in this Study to generate the following information to support groundwater flood damage modelling:

- Definition of the maximum extents of the alluvial aquifer where potential groundwater flooding might occur as a result of rising river flood levels; and
- Estimation of maximum groundwater levels in the alluvial aquifer, which are caused by rising river flood levels.

In consideration of the overall characteristics of the alluvial aquifer, a simplified relationship of maximum groundwater level versus distance from the edge of surface inundation, was developed based on groundwater modelling at selected cross sections and river water level hydrographs. This simplified relationship was then applied throughout the city to estimate or approximate the maximum groundwater levels within the alluvial aquifer for the various return periods of floods. These model groundwater surfaces were used to estimate basement damages from groundwater flooding beyond the area of surface inundation.

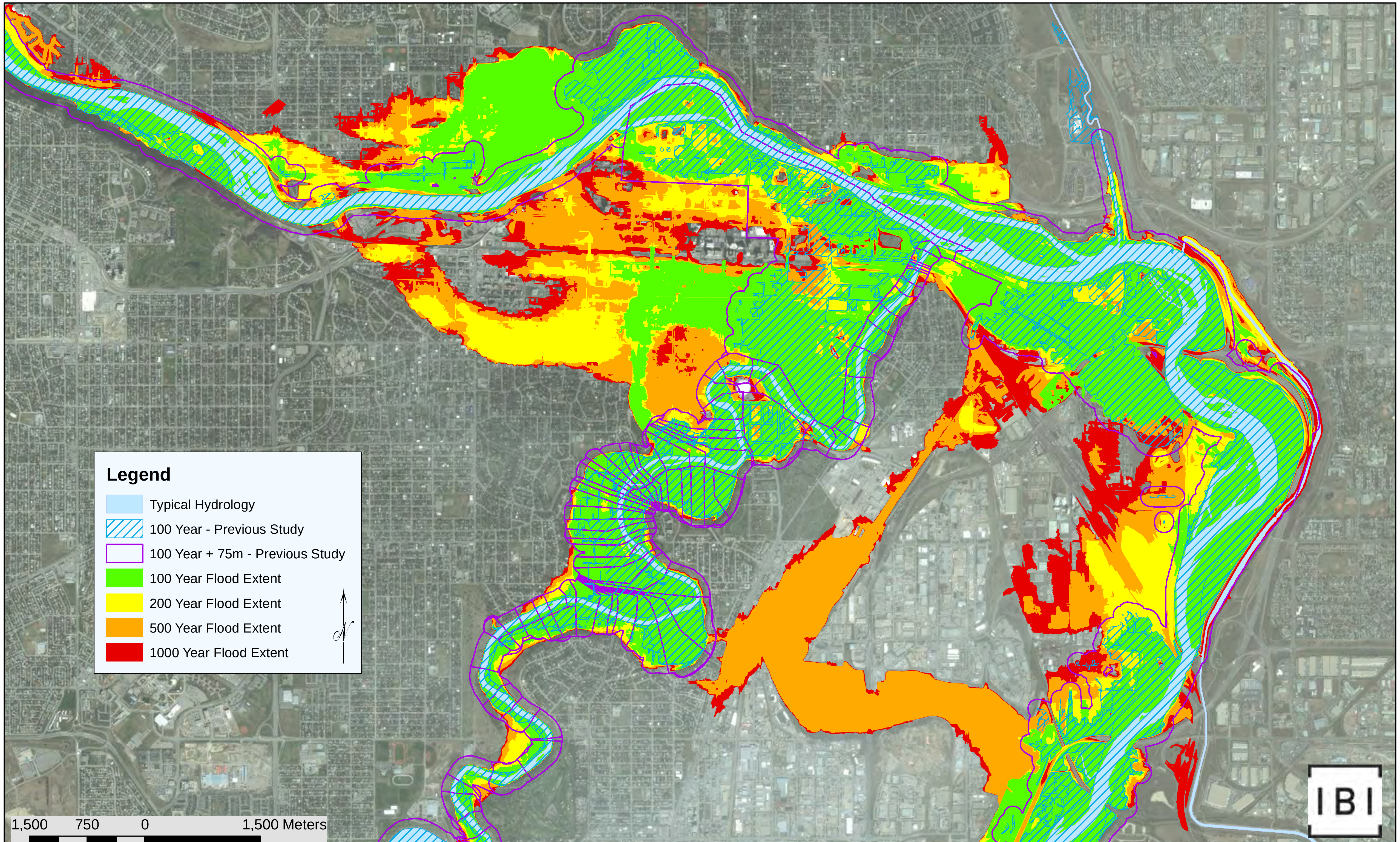
In addition, groundwater modelling was conducted to account for the effects of permanent barriers on groundwater levels behind the barriers and their potential effects on basement damage due to groundwater flooding. These effects are reflected by the modified and simplified relationship of maximum groundwater levels versus distance, where permanent barriers are located.

Calgary Flood Extents



Source: Golder Associates Ltd., September 2014, Bow River and Elbow River Basins – Hydrology of 2013 Flood Event, Prepared for The City of Calgary.

Flood Extents Used for Previous and Current Study



Source: Golder Associates Ltd., September 2014, Bow River and Elbow River Basins – Hydrology of 2013 Flood Event, Prepared for The City of Calgary.

IBI Golder Associates Calgary

Flood Mitigation Options Assessment
February 2017

Exhibit 2.10

4 Triple Bottom Line Model Enhancements

The City has adopted a Triple Bottom Line (TBL) policy framework as a means of incorporating economic, social, and environmental considerations into all of The City's decisions and actions. To meet the TBL objectives a more explicit assessment of these considerations was undertaken resulting in an enhanced estimation methodology for the following damage components:

- Intangible Damages (Health and Environment)
- Business Disruption
- Residential Displacement
- Traffic Disruption
- Waste Disposal
- Flood Fighting and Emergency Response and Recovery
- Infrastructure Damages

The aforementioned aspects were monetized and included as a separate line item in the total damage estimations.

5 Insurable Flood Damages

One of the Study objectives was to provide an overview of flood insurance coverage for Alberta and Calgary and to determine if a calibration of depth-damage curves to account for insurable losses was feasible.

Flood coverage is one of the most complicated aspects of home insurance in Canada. Thus, it is generally not possible to provide an objective, reliable assessment of the proportion of flood-related losses that would be insured following any type of flooding event for any specific location in Canada. The analysis conducted in this Study concluded that available flood insurance data does not lend itself to any type of uniform recalibration of depth-damage curves or flood damage modelling for a variety of reasons including the following:

- Payment information is not depth specific.
- It does not separate content and structural damage.
- Indirect damages and direct damages are blended.
- Coverage is extremely variable by insurance company and options selected by individual homeowners.
- Most homeowners are unlikely to be covered for overland flooding at present.

Moreover, insurers and the industry in general is not supportive of developing in high flood risk areas, regardless of flood protection measures that may be put in place to protect properties. Insurers recognize the probability of failure of structural flood defences and factor structural failure into pricing and other considerations related to flood insurance.

Notwithstanding the aforementioned, flood insurance premiums were calculated as part of the evaluation of mitigation alternatives.

6 Unmitigated Baseline Flood Risk Profiles

6.1 City-Wide Baseline

The preliminary estimates reflect total potential damages as they do not consider any existing mitigations. This is equivalent to failure of existing structures and lack of any non-structural measures. The preliminary baseline allows for the evaluation, including benefit-cost analyses, of both current and proposed mitigation options. The accompanying exhibit (**Exhibit 2.3**) highlights the total damage estimates for the flood study area.

6.1.1 Groundwater Damage Estimates

Groundwater accounts for a significant portion of flood damages in Calgary, particularly for higher frequency events where there is limited overland inundation. Total direct groundwater damage peaks at $334 million for the 50-year flood event and ranges from 72% of direct damages for the 10-year flood event down to 4% at the 1000-year flood event.

6.1.2 Bow and Elbow Rivers

The areas along the Bow River constitutes a majority of the direct damages ranging from 74% to 51% of the total and generally decreasing with probability. In addition, the areas along the Bow River experience much greater non-residential damages than those along the Elbow River.

6.1.3 Total Damage Estimates

Total damage estimates by return period are illustrated in **Exhibit 2.3.**

As detailed, damages are estimated at $3.26 billion for the 1:100 year flood event, increasing to $9.74 billion for the 1:500 year flood event and $12.8 billion for the 1:1,000 year flood event.

6.1.4 Average Annual Damages

Average Annual Damages (AAD) are the cumulative damages occurring from various flood events over an extended period of time, averaged for the same timeframe. The average annual damages are obtained by integrating the area under the damage-probability curve, which depicts total damage versus probability of occurrence and is illustrated for the entire study area in **Exhibit 2.6**.

6.1.5 Comparison with Previous Damage Estimates

A variety of factors have contributed to an increase in the estimated flood damages for the city from the 2014 study. These are summarized as follows:

- Increase in flood peak discharge estimates.
- Expanded flood hazard areas.
- Reallocation of flood inundation areas for damage estimation.
- Residential displacement and commercial disruption.
- Monetization of intangibles.
- Groundwater damage estimates.

The effects of these factors resulted in an essential doubling of the average annual damage from $84 million in the 2014 analysis to $168 million, in this Study, with the largest change (62% increase) attributable to increase in flood peak discharge estimates.

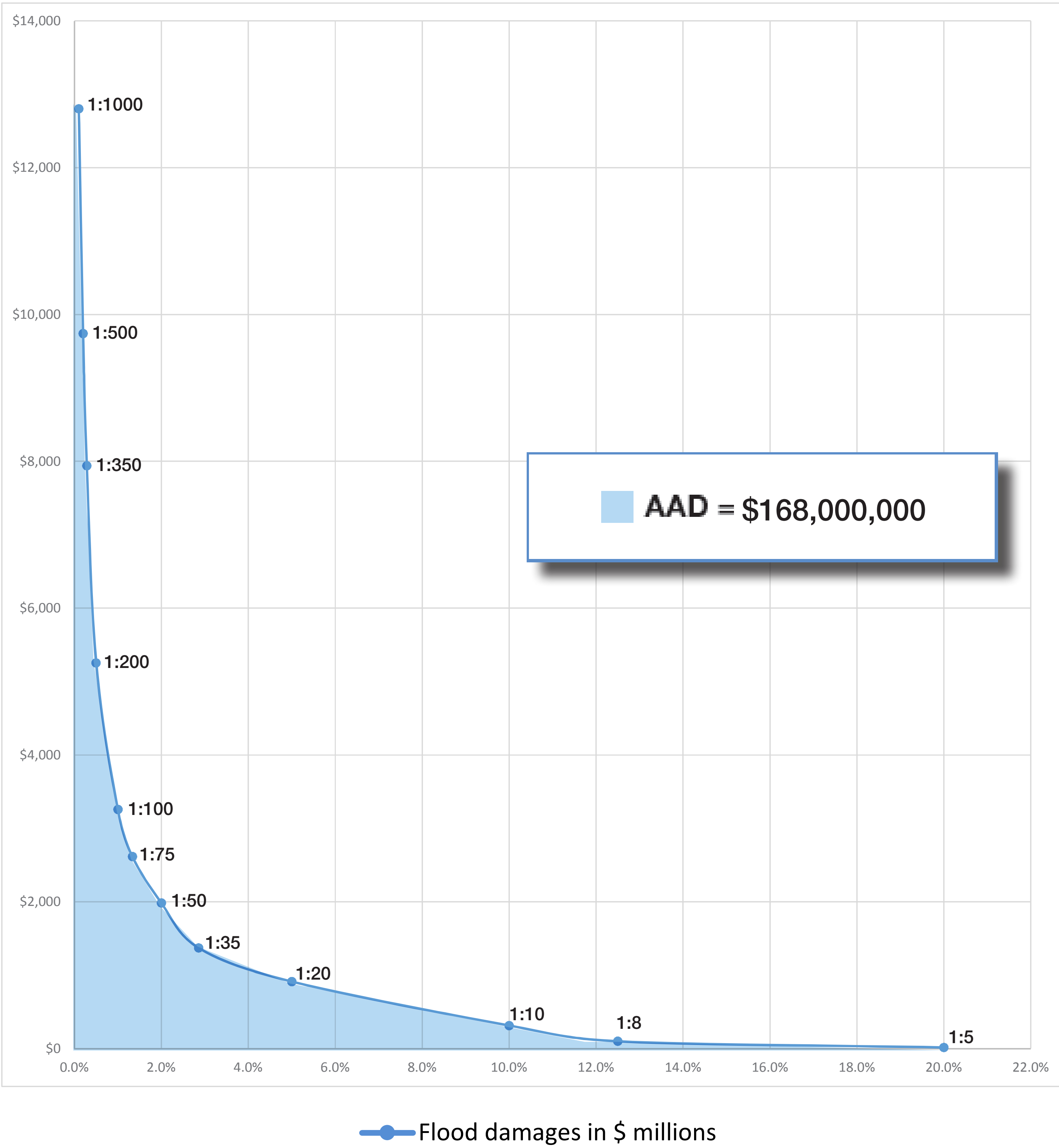
Flood Study Area Total Damages

Damage Category		Return Period 5	8	10	20	35	50
Residential	Direct	$7,126,000	$42,535,000	$121,203,000	$359,928,000	$523,486,000	$704,926,000
	Displacement	$294,000	$2,631,000	$6,781,000	$21,113,000	$31,308,000	$41,075,000
	Subtotal	$7,420,000	$45,166,000	$127,984,000	$381,041,000	$554,794,000	$746,001,000
Commercial	Direct	$2,869,000	$10,803,000	$29,968,000	$71,417,000	$122,418,000	$218,168,000
	Disruption	$2,216,000	$8,407,000	$38,198,000	$91,097,000	$167,741,000	$361,219,000
	Subtotal	$5,085,000	$19,210,000	$36,415,000	$116,002,000	$232,484,000	$386,955,000
Infrastructure		$0	$13,800,000	$63,870,000	$213,580,000	$314,696,000	$391,614,000
Traffic Disruption		$0	$652,000	$1,029,000	$3,259,000	$7,468,000	$13,691,000
Habitat Restoration		$0	$4,047,000	$4,514,000	$5,837,000	$7,237,000	$8,366,000
Emergency Response		$0	$3,400,000	$10,887,000	$36,406,000	$53,641,000	$66,752,000
Waste Disposal		$168,000	$894,000	$2,347,000	$6,957,000	$10,488,000	$14,341,000
Tangibles	Direct	$9,995,000	$67,139,000	$215,041,000	$644,925,000	$960,600,000	$1,314,707,000
	Indirect	$2,677,000	$20,030,000	$63,756,000	$164,668,000	$277,884,000	$505,444,000
	Subtotal	$12,672,000	$87,169,000	$278,797,000	$809,593,000	$1,238,483,000	$1,820,152,000
Intangibles		$2,345,000	$12,613,000	$35,361,000	$102,881,000	$133,214,000	$164,206,000
Grand Total		**$15,017,000**	**$99,782,000**	**$314,158,000**	**$912,474,000**	**$1,371,698,000**	**$1,984,357,000**

Damage Category		Return Period 75	100	200	350	500	1000
Residential	Direct	$934,557,000	$1,109,205,000	$1,615,144,000	$1,929,321,000	$2,153,960,000	$2,554,062,000
	Displacement	$54,703,000	$68,387,000	$113,922,000	$153,039,000	$181,498,000	$225,110,000
	Subtotal	$989,261,000	$1,177,591,000	$1,729,066,000	$2,082,360,000	$2,335,458,000	$2,779,172,000
Commercial	Direct	$295,762,000	$398,755,000	$732,732,000	$1,320,176,000	$1,676,316,000	$2,127,897,000
	Disruption	$517,934,000	$739,583,000	$1,535,202,000	$2,985,234,000	$3,987,784,000	$5,879,685,000
	Subtotal	$583,672,000	$824,154,000	$1,848,870,000	$3,810,152,000	$4,903,251,000	$7,125,350,000
Infrastructure		$486,377,000	$548,842,000	$705,730,000	$866,399,000	$934,836,000	$1,074,926,000
Traffic Disruption		$26,228,000	$53,284,000	$71,195,000	$88,993,000	$131,919,000	$153,906,000
Habitat Restoration		$10,000,000	$10,973,000	$13,696,000	$16,187,000	$17,938,000	$21,829,000
Emergency Response		$82,905,000	$93,553,000	$120,295,000	$147,682,000	$159,347,000	$183,226,000
Waste Disposal		$19,270,000	$23,429,000	$36,891,000	$51,556,000	$59,729,000	$73,291,000
Tangibles	Direct	$1,716,697,000	$2,056,801,000	$3,053,605,000	$4,115,896,000	$4,765,112,000	$5,756,885,000
	Indirect	$711,041,000	$989,208,000	$1,891,201,000	$3,442,690,000	$4,538,215,000	$6,537,047,000
	Subtotal	$2,427,737,000	$3,046,009,000	$4,944,806,000	$7,558,586,000	$9,303,327,000	$12,293,932,000
Intangibles		$187,123,000	$211,108,000	$310,334,000	$382,559,000	$436,802,000	$508,616,000
Grand Total		**$2,614,861,000**	**$3,257,117,000**	**$5,255,140,000**	**$7,941,145,000**	**$9,740,129,000**	**$12,802,548,000**

Average Annual Damages (AAD)	**$168,000,000**

Flood Damages Probability Distribution Bow and Elbow Rivers



7 Existing Mitigation Baseline

Many parts of the city are currently protected to various levels by existing permanent barriers. The City is currently constructing several new permanent barriers and drainage improvements. To conduct benefit/cost analyses of the various flood mitigation scenarios, only the additional benefits beyond the existing mitigation measures should be considered for these scenarios.

Therefore, a second flood damage baseline (i.e., 'Scenario 0'), was calculated. This scenario represents the damages that would be incurred at the current level of protection. The difference in the AAD of the unmitigated and existing mitigation baseline is the benefit of existing measures. The benefit of potential mitigation scenarios is the additional amount they reduce from the existing mitigation baseline.

The average annual damage for the study area is estimated at $116.6 million for existing mitigation baseline. Existing mitigation measures provide considerable benefit. The difference in AAD between the unmitigated and existing mitigation baselines amounts to an annual benefit of over $50 million.

The majority of existing mitigations are effective for floods of higher frequency (below 1:100 year flood event). Therefore, the damage estimates differ greater for these flood events and are essentially equal above the 1:200 year flood event. The existing baseline damages are detailed in **Exhibit 2.8.**

For the purposes of this Study, the benefits provided by all of the potential scenarios have been derived from the existing mitigation baseline scenario, referred to as Scenario 0 or simply "the baseline". The benefits have been calculated as the reduction in AAD from the $116.6 million baseline.

8 Identification and Qualitative Assessment of Flood Mitigation Options

There are two basic approaches to reducing flood damages. The first approach of structural measures consists of methods to control the extent of flooding by construction of dams, reservoirs, dykes or other protective works. The second approach which limits the susceptibility of the developments to flood damages, is effected through a variety of non-structural measures, especially land use controls. **Exhibit 3.1** details the various types of flood damage reduction measures and alternatives.

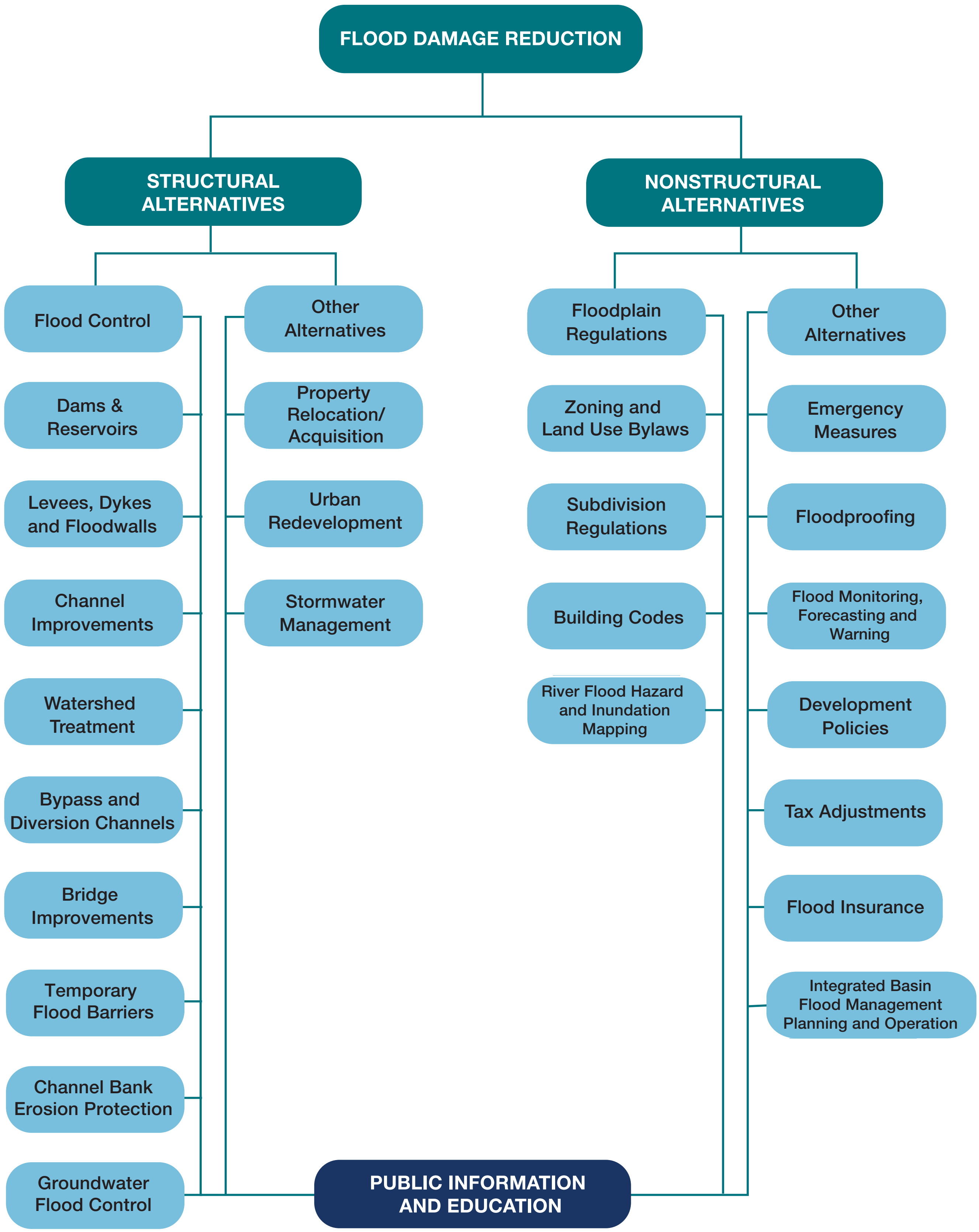
Studies conducted by the Province and The City involved identification and evaluation of a variety of structural and non-structural measures including dams and storage sites, river diversion, barriers, erosion protection, improvements to the stormwater system, select groundwater control measures along with improvements to flood warning, flood management plans and flood mapping.

8.1 Screening of Potential Flood Mitigation Options

Various structural and non-structural flood mitigation options were screened in this Study using a qualitative option evaluation method based on high-level and broad-based criteria. The result of this high-level evaluation was a prioritized list of potential options to be included in the development of flood mitigation scenarios for the city. These options included the following:

- new flood storage facilities along with updated operating rules to the existing hydro facilities and reservoirs in the Bow River Basin;
- permanent barriers along the Bow River;
- permanent barriers along the Elbow River;
- stormwater and drainage improvements;
- groundwater flood control measures at select locations;
- temporary flood barriers at various locations as part of The City's Emergency Response Plan;
- selective buy-out of flood-affected houses;
- flood insurance; and
- a variety of contingency measures along with modifications to the floodplain regulations and grant programs related to the installation of sump pumps and backflow preventers.

Flood Damage Reduction Alternatives



9 Development and Evaluation of Flood Mitigation Scenarios

A total of 13 flood mitigation scenarios were developed and evaluated. Each of these scenarios has multiple individual flood mitigation components, some common to several scenarios. The scenarios evaluated are highlighted in **Exhibit 3.16**.

9.1 Updating of Risk Profiles by Area

For the areas protected by the various potential flood mitigation measures, new overland and groundwater inundation surfaces were produced, and the associated damages recalculated. They include direct, indirect and intangible damages.

9.2 Cost of Flood Mitigation Measures

The costs for the various flood mitigation measures included in the scenario analysis were obtained from The City. Only a high level review of the cost information was conducted in this Study. The available cost information was generated by the various sources (e.g. The City, the Province, and consultants engaged by The City or the Province). The available cost information was based on various levels of design ranging from conceptual to detailed engineering.

9.3 Benefit/Cost Analysis for Each Scenario

The benefit/cost (B/C) ratio of a project is the ratio of net present value of the benefits (or average annual flood damage reductions) over the net present value of the costs including capital, operation, maintenance and repair costs. This value is an indicator of financial efficiency.

If benefits exceed costs, the ratio is greater than 1.0. If, benefits are less than costs, the ratio is less than 1.0. A financially-efficient project would have a B/C ratio greater than 1.0. At a B/C ratio of 1.0, the project is at a breakeven point financially.

9.4 Triple Bottom Line Criteria

For the purposes of this study, the criteria, objectives and weightings were selected by assessing priorities identified by community engagement, Community Advisory Group, City subject matter expertise, the IBI Group draft evaluation criteria and the City's sustainability appraisal tool.

Criteria were subdivided into three basic categories as follows:

1. Social Criteria: Community Well-Being
2. Environmental Criteria
3. Scenario Implementation
4. Economic Criteria

The following exhibit (**Exhibit 4.2**) details the criteria and objectives along with the rating and weighting scheme employed in the evaluation of the various mitigation scenarios.

9.5 Evaluation of Flood Mitigation Scenarios

The following exhibits provide a summary of the results of the flood mitigation scenario evaluation using the above-mentioned Triple Bottom Line approach.

Exhibit 4.3 details the results of the benefit/cost analysis, illustrating the benefit/cost ratio, damages averted, residual damages and present value of total costs for the 11 new scenarios. All scenarios render positive benefit/cost ratios with Scenario 1 achieving the highest ratio at 3.22 followed by Scenarios 4 and 4a at 2.53 and 2.09, respectively. Scenario 4a provides the greatest benefits at $87.8 million of average annual damages averted. This is followed by Scenario 7 at $85.1 million of average annual damages averted.

Scenarios 3 and 3a have the highest present value costs of $2.14 and $2.3 billion, respectively. Scenario 1 has the lowest present value cost of $0.7 billion.

Exhibit 4.4 illustrates the Triple Bottom Line scoring and ranking for the 12 scenarios. As evidenced, Scenario 7 achieves the highest overall score and therefore is first ranked, followed by Scenarios 2 and 1.

Exhibit 4.5 illustrates how the various scenarios are ranked with respect to the Triple Bottom Line goals. Scenario 7 ranks high with respect to social and environmental criteria but lower on the economic criteria due to the high cost estimate for the Bow River dam.

Scenario 7 maintains the first rank if the percent weight for the social or environmental criteria is doubled. Scenario 7 is ranked close second if the percent weight is doubled for the economic or implementation criteria, while Scenario 1 is ranked first. This shows that Scenario 7 is relatively robust as a favored or preferred scenario.

9.6 Development of Hybrid Flood Mitigation Scenarios

9.6.1 Introduction

Having identified scenario 7 as the preferred flood mitigation scenario by virtue of the highest ranking with respect to the Triple Bottom Line evaluation criteria, further analysis and design modifications were undertaken as a means of enhancing the flood damage reduction attributes. This led to the development of four additional scenarios: 7a, 8, 8a and 9. (See Exhibit 4.6).

9.6.2 Scenario 7a

The flood mitigation measures in Scenario 7a are the same as those in Scenario 7 but without the upstream storage facility on the Bow River. The purpose of this scenario is to illustrate the amount of risk remaining if the barriers along the Bow River have the lower protection levels (i.e. 1:25 years). Essentially, this scenario could be considered as an interim flood mitigation solution in consideration of the time it will take to design, gain approval and construct a new upstream Bow River reservoir.

Comparing Scenario 7a to Scenario 1 reveals that the 1:25 year barriers along the Bow River add $2.2 million in annual benefits. However, it should be noted that Scenario 1 also includes temporary barriers that provide protection in some of the same locations. Therefore, this comparison understates the stand-alone benefit of the barriers.

Without the cost of the upstream Bow reservoir, the B/C ratio is more than double that of scenario 7 at just over 3. However, there is an additional $11.5 million in remaining annual damages.

9.6.3 Scenario 8

The flood mitigation measures in Scenario 8 are the same as scenario 7 but with the addition of higher barriers protecting the downtown areas to the 1:200 year flood level (or 1:1,000 years in combination with an upstream Bow River reservoir) and the inclusion of groundwater protection within the Sunnyside barrier. In addition to the 6 km of barriers included in scenario 7, the raised pathway barrier for downtown is 2.6 km long with an average height of 1.1 m.

With the additional barriers in place to the 1:1,000 year flood protection level for the downtown areas, benefits are not meaningfully increased, because significant flooding of the downtown does not occur until the 1:500 year flood level is exceeded with the upstream reservoir in place. With the addition of groundwater control for the Sunnyside barrier, average annual damages are reduced by $460,000, a significant reduction. With a $2.85 million cost, the benefit/cost ratio is 5:1.

This scenario provides very little benefit gain for the City overall. However, there is a significant benefit to the Sunnyside community.

9.6.4 Scenario 8a

Scenario 8a is essentially an illustration of Scenario 8 without the construction of the upstream reservoir on the Bow River. As with the comparison between scenarios 7 and 8, there is little extra benefit for scenario 8a over scenario 7a. Without the upstream Bow reservoir, the barriers provide protection to the 1:200 year flood level. With SR1 in place, the probability of flood inundation in the downtown areas is not high until the 1:200 year flood occurs in the Bow River.

9.6.5 Scenario 9

Scenario 9 further raises the barrier protection level of Scenario 8 outside of the downtown areas with higher barriers. Bowness and Sunnyside are protected to the 1:100 year flood level with barriers averaging in height between 1.1 and 1.9 m. Inglewood is protected to the 1:200 flood level with an average additional barrier height of 0.7 m.

The additional heights provide $4.4 million greater annual benefits than the barriers in Scenario 7a.

Definition of Flood Mitigation Scenarios to be Modelled

Flood Mitigation Measures			Scenario Number												
			0	0a	1	1a	2	3	3a	4	4a	5	5a	6	7
Category	Type	Brief Description	Baseline	Baseline + Non-structural	SR1	#1 with high downtown barriers	SR1 + new Bow reservoir	Bow reservoir + Elbow barriers	#3 with ground water mitigation	SR1 + Bow bariers	#4 with ground water mitigation	Bow and Elbow barriers	#5 with ground water mitigation	Floodway buyouts	SR1 + Bow reservoir + select Bow barriers
Structural	Flood Storage/ Regulation Reservoir	TransAlta's hydro facilities and reservoirs in the Bow River basin - historical operating rules	✓	✓											
		TransAlta's hydro facilities and reservoirs in the Bow River basin - current TA and GoA agreement			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		One new flood storage facility on the Bow River (likely between Cocrane and Calgary)					✓	✓	✓						✓
		Glenmore reservoir on the Elbow River, including gate improvements	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Springbank off-stream reservoir (SR1) in the Elbow River basin			✓	✓	✓			✓	✓			✓	✓
	Permanent Barriers	Existing barriers (existing conditions without raising dykes)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Discovery Ridge barrier (not in the hydraulic model domain)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Stampede barrier (designed based on 494 m^3/s in Elbow River)	50	50	200	200	200	50	50	200	200	50	50	200	200
		Zoo barrier (designed based on 2820 m^3/s in Bow River)	100	100	200	200	350	200	200	200	200	100	100	200	350
		Eau Claire West barrier (designed based on 2390 m^3/s in Bow River)	200	200	200	200	1000	1000	1000	200	200	200	200	200	1000
		Heritage Dr./Glendeer Circle barrier (designed based on 2820 m^3/s in Bow River)	100	100	200	200	350	200	200	200	200	100	100	200	350
		Centre Street bridge lower deck – gates (designed based on 1660 m^3/s in Bow River)	50	50	75	75	350	350	350	75	75	75	75	75	350
		Bonnybrook improvements (designed based on 2820 m^3/s in Bow River)	100	100	200	200	350	200	200	200	200	100	100	200	350
		Deane House barrier (designed based on 803 m^3/s in Elbow River)	100	100	200	200	200	100	100	200	200	100	100	200	200
		Downtown barriers including those along Elbow & Bow Rivers (designed based on 2627m^3/s in Bow River and 879 m^3/s in Elbow River)				350									
		Bow River barriers (designed based on 2280m^3/s upstream of Elbow confluence and 3506 m^3/s downstream of Elbow confluence)								200	200				
		Bow River barriers (designed based on 2280m^3/s upstream of Elbow confluence and 3520 m^3/s downstream of Elbow confluence)										200	200		
		Elbow River Barriers (designed based on 1130m^3/s in Elbow River)						200	200			200	200		
		Bow River barriers (Bowness North and South, Sunnyside) (designed based on 1300m^3/s in Bow River)													200
		Bow River barriers (Fish Hatchery) (designed based on 1729m^3/s in Bow River)													200
		Bow River barriers (Bowness North and South, Sunnyside) (designed based on 2020m^3/s in Bow River)													
		Bow River barriers (Inglewood, Fish Hatchery) (designed based on 2820m^3/s in Bow River)													
		Bow River barrier for downtown (designed based on 2390m^3/s in Bow River)													
	Stormwater and Drainage Improvements	Existing stormwater outfall gates (e.g. downtown, Mission, Eau Claire, Bowness)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Gates and pump stations at planned permanent barriers	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Sunnyside pump station / Sunnyside stormwater (Community Drainage Improvement CDI additional #2 pumps)			✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
		Quarry Park pump station			✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
	Groundwater Flood Control	Groundwater control as supplemental feature of planned permanent barriers							✓		✓		✓		
	Temporary Barriers	Temporary flood barriers at various locations per the City's flood emergency response plan	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Non-structural	Contingency Measures	Flood warning protocols		✓											
		Education & awareness		✓											
		Emergency measures - protection of highest risk or best B/C areas		✓											
	Flood Plain Regulations	Land use bylaws (no below-grade suites)		✓											
		Develoment policies (basement floodproofing)		✓											
		Homeowner grant program - sump pumps/backflow preventers		✓											
	Buyouts	Select buyouts (200 year floodway)												✓	

Color scheme:
- Going ahead/done (green)
- Planned/will go ahead when funding obtained (yellow)
- No immediate plans to implement, may consider in scenarios (orange)

Note: The values for the permanent barriers under the various scenarios refer to the minimum return periods of floods (in unit of year) which the barriers are designed to protect against (or the minimum flood protection level).

Flood Mitigation Evaluation Criteria

Goal	Criteria	To what extent does the scenario help achive the following objectives, **compared to the baseline existing condition?** (refer to **Exhibit 3.10**)
Social	Complete communities	**Maintains community fabric** *Preserves existing communities, homes and heritage. Maintains opportunities for revitalisation/densification (eg. East Village). Amenities and transportation choices are not negatively impacted.*
	Equitable protection	**Provides equitable protection from flooding** *across communities, the city and does not negatively impact upstream or downstream*
	Vulnerable populations	**Protects vulnerable populations** *Risk-sensitive development, protection of Calgarians who because of age, disability or other circumstances are at greater risk.*
	River aesthetics	**Maintains community and river aesthetics** *River views from private and public property, natural-looking river*
	Recreation access	**Maintains or enhances accessibility and recreation opportunities** *Protects/provides access to the river, riparian areas, natural areas, and parks.*
	Emergency access	**Protects connectivity and ease of access and departure during flooding or other emergencies/disasters** *Does not negatively impact emergency response, reduces residential and non-residential loss of life*
	Risk transparency	**Increased transparency/visibility of risk** *For property owners/prospective buyers regarding flooding risk*
Environmental	Water security	**Protects/provides water supply security** *Promotes efficient, sustainable water management so that the region's water supply meets the current and future needs of a growing city and region of users (municipalities and irrigation districts).*
	Riparian health and ecosystem functions	**Protects riparian health and species habitat and allows natural ecosystem functions** *Protects/enhances riparian areas and health of aquatic and terrestrial species. Lets the floodplan flood, provides room for the river, allows the river to flood*
	Water quality and contamination prevention	**Protects river water quality and prevents contamination of air, land, and water** *Does not have a short or long term detrimental impact on water quality and prevents contamination from spills, stormwater and groundwater flooding, transportation of goods, construction of scenario.*
Implementation	Timeliness of Implementation	**Contributes to orderly implementation of investments.** - *Timeliness and ease of implementation. How quickly can it be implemented and does it complement future measures?*
	Adaptability/Flexibility	**Contributes to flexibility of implementation.** How ***adaptable*** *the solution is - ease of future adaptability and flexibility (can it be raised/improved, can it address climate change issues?)*
	Jurisdictional control	***How easy it is for the City to implement.*** *Jurisdictional ability of The City to implement; financial ability for The City to implement; dependent on other jurisdictions to commit to/implement/fund.*
	Regulatory complexity	**Complexity of regulating land use and development with respect to different structural mitigation measures.** *(City: bylaws; At the Provincial and Federal levels: environmental and land/building regulations, mapping, funding, disaster relief programs)*
Economic	Economic Environment	**Indirect Protection of Calgary's economic engine** *Protects the downtown and business continuity. Protects critical infrastructure and essential services, transportation corridors.*
	Economic Efficiency	*Benefit/Cost Ratio*
	Damages Averted	*Total Benefits*
	Total Cost	*Present Value of deveopment and operating costs*

Net Present Value - Benefit/Cost Summary

Indicator	Scenario										
	1	1a	2	3	3a	4	4a	5	5a	6	7
	SR1	#1 with high downtown barriers	SR1 + new Bow reservoir	Bow reservoir + Elbow barriers	#3 with groundwater mitigation	SR1 + Bow bariers	#4 with groundwater mitigation	Bow and Elbow barriers	#5 with groundwater mitigation	Floodway buyouts	SR1 + Bow reservoir + select 1:25 Bow barriers
Development Cost	$510,000,000	$992,645,885	$1,410,000,000	$1,802,850,000	$1,959,100,000	$903,286,859	$1,134,672,408	$1,323,036,113	$1,725,662,291	$1,818,000,000	$1,447,534,050
O&M*	$5,100,000	$5,100,000	$14,100,000	$9,100,000	$9,100,000	$5,100,000	$5,100,000	$100,000	$100,000	$0	$14,100,000
PV Benefits (average annual damages)	$2,255,422,000	$2,394,764,000	$2,676,498,000	$2,270,535,000	$2,476,359,000	$2,773,550,000	$2,773,550,000	$2,241,871,000	$2,672,673,000	$853,170,000	$2,688,400,000
PV Costs (development & operating total cost)	$701,065,000	$1,183,711,000	$1,988,997,000	$2,143,770,000	$2,300,020,000	$1,094,352,000	$1,325,737,000	$1,326,782,000	$1,729,409,000	$1,818,000,000	$2,026,531,000
Benefit / Cost Ratio	3.22	2.02	1.35	1.06	1.08	2.53	2.09	1.69	1.55	0.47	1.33
Net Present Value	$1,554,357,000	$1,211,053,000	$687,501,000	$126,765,000	$176,339,000	$1,679,198,000	$1,447,813,000	$915,089,000	$943,264,000	-$964,830,000	$661,869,000

TBL Scenario Scoring

Goal	Criteria	Objective To what extent does the scenario help achive the following objectives, **compared to the baseline existing condition?**	Scenario Rating (-6 to +6)												Weight (1-6)	Highest Ranked Scenario by Criteria
			0a	1	1a	2	3	3a	4	4a	5	5a	6	7		
			Non-structural	SR1	SR1 + DT barrier	SR1 + Bow Res	Bow Res + Elbow barriers	3 w/ GW	SR1 + Bow barriers	4 w/ GW	Barriers on Bow+ Elbow	5 w/ GW	Flood-way buyouts	SR1, Bow Res, Select barriers		
Social	Complete communities	**Maintains community fabric** *Preserves existing communities, homes and heritage. Maintains opportunities for revitalisation/densification (eg. East Village). Amenities and transportation choices are not negatively impacted.*	-1	3	4	6	-4	-4	-5	-5	-6	-6	-5	5	2	2
	Equitable protection	**Provides equitable protection from flooding** *across communities, the city and does not negatively impact upstream or downstream*	1	-4	-5	3	-2	-2	2	2	5	5	-3	4	3	5
	Vulnerable populations	**Protects vulnerable populations** *Risk-sensitive development, protection of Calgarians who because of age, disability or other circumstances are at greater risk.*	0	3	4	5	2	2	2	2	1	1	-1	5	1	2
	River aesthetics	**Maintains community and river aesthetics** *River views from private and public property, natural-looking river*	-1	5	1	5	-5	-5	-4	-4	-6	-6	6	4	2	6
	Recreation access	**Maintains or enhances accessibility and recreation opportunities** *Protects/provides access to the river, riparian areas, natural areas, and parks.*	1	5	-1	5	-4	-4	-5	-5	-6	-6	3	4	2	1
	Emergency access	**Protects connectivity and ease of access and departure during flooding or other emergencies/disasters** *Does not negatively impact emergency response, reduces residential and non-residential loss of life*	2	3	2	3	-1	-1	-1	-1	-2	-2	-2	3	1	1
	Risk transparency	**Increased transparency/visibility of risk** *For property owners/prospective buyers regarding flooding risk*	2	1	2	1	3	3	3	3	4	4	1	3	1	5
		TOTAL Community Well-Being score	**5**	**21**	**1**	**50**	**-28**	**-28**	**-18**	**-18**	**-18**	**-18**	**-3**	**49**	12	2
Environmental	Water security	**Protects/provides water supply security** *Promotes efficient, sustainable water management so that the region's water supply meets the current and future needs of a growing city and region of users (municipalities and irrigation districts).*	0	1	1	6	6	6	1	1	0	0	0	6	6	2
	Riparian health and ecosystem functions	**Protects riparian health and species habitat and allows natural ecosystem functions** *Protects/enhances riparian areas and health of aquatic and terrestrial species. Lets the floodplan flood, provides room for the river, allows the river to flood*	1	-1	-1	-1	-4	-4	-4	-4	-6	-6	1	-2	4	0a
	Water quality and contamination prevention	**Protects river water quality and prevents contamination of air, land, and water** *Does not have a short or long term detrimental impact on water quality and prevents contamination from spills, stormwater and groundwater flooding, transportation of goods, construction of scenario.*	-1	-2	-2	0	2	2	-2	-2	0	0	0	0	2	3
		TOTAL Environmental score	**2**	**-2**	**-2**	**32**	**24**	**24**	**-14**	**-14**	**-24**	**-24**	**4**	**28**	12	2
Implementation	Timeliness of Implementation	**Contributes to orderly implementation of investments.** - *Timeliness and ease of implementation. How quickly can it be implemented and does it complement future measures?*	-2	5	4	-3	-5	-5	1	1	-4	-4	-1	-2	4	1
	Adaptability/Flexibility	**Contributes to flexibility of implementation.** *How **adaptable** the solution is - ease of future adaptability and flexibility (can it be raised/improved, can it address climate change issues?)*	1	2	2	4	3	3	2	2	-1	-1	3	5	3	7
	Jurisdictional control	***How easy it is for the City to implement.*** *Jurisdictional ability of The City to implement; financial ability for The City to implement; dependent on other jurisdictions to commit to/implement/fund.*	4	0	1	-3	-2	-2	1	1	3	3	2	-2	3	0a
	Regulatory complexity	**Complexity of regulating land use and development with respect to different structural mitigation measures.** *(City: bylaws; At the Provincial and Federal levels: environmental and land/building regulations, mapping, funding, disaster relief programs)*	-3	-2	-2	3	-3	-3	-3	-3	2	2	-1	4	2	7
		TOTAL Implementation score	**1**	**22**	**21**	**-3**	**-23**	**-23**	**7**	**7**	**-6**	**-6**	**9**	**9**	12	1
Economic	Economic Environment	**Indirect Protection of Calgary's economic engine (attracts businesses, business continuity)** *Protects the downtown and business continuity. Protects critical infrastructure and essential services, transportation corridors.*	-1	3	5	5	2	2	2	2	2	2	-1	5	3	1a
	Economic Efficiency	*Benefit/Cost Ratio*	6	5	0	-2	-4	-4	2	0	-1	-2	-6	-3	3	0a
	Damages Averted	*Total Benefits*	-6	3	4	6	3	5	5	7	3	6	-5	6	3	4a
	Total Cost	*Present Value of deveopment and operating costs*	6	5	2	-4	-5	-6	2	1	1	-2	-3	-4	3	0a
		TOTAL Economin score	**15**	**49.19**	**33.4**	**13.73**	**-9.231**	**-8.53**	**35.9**	**29.13**	**14.69**	**12.42**	**-44.1**	**12.94**	12	1
		Total Score	**23**	**90.2**	**53.4**	**92.7**	**-36.2**	**-35.5**	**10.9**	**4.13**	**-33.3**	**-35.6**	**-34.1**	**98.94**		**7**
		Rank	5	3	4	2	12	10	6	7	8	11	9	1		

TBL Scenario Ranking

Scenario		0a	1	1a	2	3	3a	4	4a	5	5a	6	7
Goal	**Criteria**	Non-structural	SR1	SR1 + DT barrier	SR1 + Bow Res	Bow Res + Elbow barriers	3 w/ GW	SR1 + Bow barriers	4 w/ GW	Barriers on Bow+ Elbow	5 w/ GW	Flood-way buyouts	SR1, Bow Res, Select barriers
Social	Complete communities Equitable protection Vulnerable populations River aesthetics Recreation access Emergency access Risk transparency	4	3	5	1	11	11	7	7	7	7	6	2
Environmental	Water security Riparian health and ecosystem functions Water quality and contamination prevention	6	7	7	1	3	3	9	9	11	11	5	2
Implementation	Timeliness of Implementation Adaptability/Flexibility Jurisdictional control Regulatory complexity	7	1	2	8	11	11	5	5	9	9	3	3
Economic	Economic Environment Economic Efficiency Damages Averted Total Cost	5	1	3	7	11	10	2	4	6	9	12	8
	Overall Rank	**5**	**3**	**4**	**2**	**12**	**10**	**6**	**7**	**8**	**11**	**9**	**1**

Benefit/Cost Analysis for Scenarios 7 - 9

Indicator	Scenario				
	7	7a	8	8a	9
	SR1 + Bow reservoir + select 1:25 Bow barriers	#7 without Bow reservoir	#7 + gw mitigation @ Sunnyside + 1:200 Downtown barriers	#8 without Bow reservoir	#8 + 1:100 barriers @ Bowness/ Sunnyside
Development Cost	$1,447,534,050	$547,534,050	$1,469,585,414	$569,585,414	$658,376,945
O&M*	$14,100,000	$5,100,000	$14,100,000	$5,100,000	$5,100,000
PV Benefits (average annual damages)	$2,688,400,000	$2,324,665,000	$2,704,393,000	$2,352,214,000	$2,463,578,000
PV Costs (development & operating total cost)	$2,026,531,000	$756,959,000	$2,048,582,000	$779,010,000	$867,801,000
Benefit / Cost Ratio	1.33	3.07	1.32	3.02	2.84
Net Present Value	$661,869,000	$1,567,706,000	$655,811,000	$1,573,204,000	$1,595,777,000

10 Recommendations

10.1 Non-Structural Options

10.1.1 Contingency Measures

Contingency measures are an essential part of the non-structural flood mitigation approach because they provide a flexible, low-cost option that is relatively fast and easy to implement, and is adaptable to local conditions. Many of the specific recommendations offered in Section 3.7 of Phase 2 are centred on the formalization and implementation of a clear, effective, and up-to-date warning plan; keeping citizens safe and informed, particularly those in the flood hazard area; defining roles in the event of a flood; and creating connections and partnerships to enhance flood preparedness.

10.1.2 Land Use Regulations

Based on the principle outlined in the 2014 Floodway Development Regulation Discussion Paper that, "it is most effective to keep people and property away from the flood water, rather than attempting to keep the flood water away from the people and property", development in the floodplain should be limited as much as possible (Floodway Development Regulation Task Force, 2014).

Through a combination of land use regulations and property level mitigation, over time The City has the ability to drastically reduce the amount of basement damage due to flooding and related events. By implementing land use regulations that eliminate the development of below grade space, and requiring sump pumps and sewer backflow preventers, in addition to bylaws already in place, The City could significantly reduce or eliminate basement damages in the flood hazard areas over time.

10.1.3 Property Level Mitigation/Floodproofing

Property level flood mitigation practices encourage property owners to undertake floodproofing measures at an individual, property-level scale. They have shown to be cost-effective and keep flood readiness front of mind.

To alleviate flooding and seepage in basements in the flood hazard area, it is recommended that The City initiate a program to encourage the voluntary installation of sump pumps and backflow preventers for existing residents and businesses within the flood hazard area while making this requirement mandatory for significant renovation and redevelopment initiatives.

Other potential options for property level floodproofing include elevation of main floors, removal of basements and installation of seals and closures for commercial and larger buildings where appropriate.

10.1.4 Flood Insurance

Risk due to hazards such as flooding are best reduced using a combination of mitigation strategies, where the responsibility is spread among stakeholders. The viability of insurance as a flood mitigation risk is challenged by a lack of randomness and the mutuality of flood losses resulting in adverse selection. Providing flood insurance does not reduce flood damages, however, after applying other cost-effective measures, it may be an appropriate mechanism to help redistribute residual risks and, if implemented effectively, may discourage risky development in the floodplain.

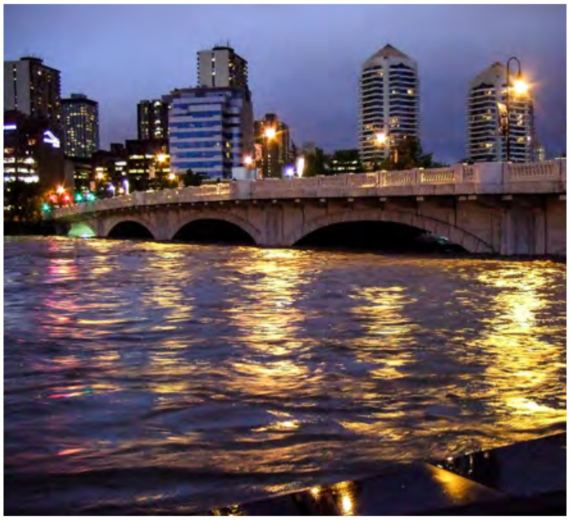
Information from the industry suggests that the majority of homeowners at risk do not have flood coverage and that coverage decreases as risk increases due to the high cost. Insurers consider the estimated annual loss and add profit and expenses. As a new product, loading on flood insurance is relatively high with reports that the average amount is between 1.5 and 2 times the annual loss. Hypothetical insurance premiums were calculated based on these loading factors and annualized damages. The average annual full-coverage premium for all residential houses within the 1:1000 year risk area would be between $4,650 and $6,200 but vary greatly with risk. Within the 1:50 year risk area, it would average between $15,000 and $20,000.

For all possible insurance options, the required premium would be a perpetual cost. It would also likely be a perpetually increasing cost as the quantity and value of at-risk properties increases. Given the costs and level of uncertainty, insurance for high risk of flood damages is not a viable option for property owners. It may remain an option for individual purchase once the risk has been mitigated to an acceptable level through structural or regulatory options. In other words, insurance should not be relied upon to achieve the acceptable level of protection.

10.2 Structural Options

It is recommended that The City pursue implementation of Scenario 7 which entails water storage facilities along both the Bow and Elbow Rivers upstream of the city. Development of these facilities should include consideration of multi-functional aspects including recreation and water supply in addition to flood mitigation as a means of increasing the benefits of these facilities. Scenario 7 will benefit from the addition of groundwater control for the Sunnyside community.

In the absence of an upstream reservoir on the Bow River, Scenario 9 should be considered for implementation.



Phase 1

REPORT

Flood Mitigation Options Assessment - Phase 1

Prepared for the City of Calgary
by IBI Group and Golder Associates Ltd.

38737 | May 2016

CALGARY FLOOD, 2013

CONTENTS

CONTENTS (CONTINUED)

INTRODUCTION

1

1 Introduction

1.1 Background

The flood of June 2013 was the largest flood in Calgary since 1932, causing estimated damage of $409 million to City of Calgary infrastructure as well as extensive damage to private property in the city. This event also caused a significant amount of social, environmental and economic damage and disruption and put the safety of Calgarians at risk. Global climate change models predict extreme rain events are likely to become more frequent and severe in the future, potentially leading to higher flood risks; therefore it is imperative that there be proactive approaches to increasing flood resiliency.

Since the 2013 flood, The City and The Government of Alberta (The Province) have been reviewing several flood mitigation options. The City has been directing its focus on solutions within city limits including:

1. The Glenmore Reservoir diversion tunnel;
2. The design of permanent flood barriers throughout the city;
3. Replacing gates on the Glenmore Dam to increase storage capacity;
4. How changes in land use policy could limit the damage during a flood event; and
5. Updating the emergency response plan for temporary barriers.

The Province has been reviewing flood mitigation options outside of the city including:

1. Changes to reservoir management on the Bow River system;
2. The Springbank off stream storage reservoir;
3. The McLean Creek dry dam, and
4. The Room for the River initiative.

In October 2014 the Province announced that the Springbank off-stream storage project would be constructed. In addition, The City and The Province have been working together to update the hydrology and flood inundation mapping for the Bow and Elbow rivers considering the changes that have occurred since the 2013 flood. The estimated flows for the 1:100 year (or 1% annual probability) flood and flows for other return periods have significantly higher values due to the inclusion of the 2013 flood into statistical analyses. This has resulted in increased flood extents and depths which should be accounted for in any analysis of flood mitigation options.

In February 2015, The Province released a draft final report by IBI Group that detailed estimates of flood damage derived from a calculation model and depth versus damage curves for various types of building or development in Calgary. The report was intended in part to provide a basis for evaluating the cost effectiveness of flood mitigation projects. *The Provincial Flood Damage Assessment Study City of Calgary: Assessment of Flood Damages* draft report examines damage across Calgary for a range of flood return frequencies. These estimates were subsequently employed to evaluate large-scale mitigation options for the Elbow River.

In light of the changing dynamics of the floodplain and the City's desire to better understand flood risk costs and benefits and to continue evaluating a range of structural and non-structural mitigation options, IBI Group and Golder Associates were retained in July of 2015 to undertake the Flood Mitigation Options Assessment study.

1.2 Project Objective

This analysis is critical to making informed decisions on prioritizing and implementing flood risk reduction strategies. This will include determining which structural options are the most appropriate and providing direction for land use policy changes or other non-structural mitigation approaches in flood prone areas. The main objectives of the project are to:

1. Develop and apply a reliable, transparent and repeatable calculation process to understand and quantify flood risk costs and benefits across Calgary including aspects related to public safety, community planning and function, damage to buildings and infrastructure, service disruption, direct and indirect economic impacts, and the environment.
2. Provide guidance on what levels of protection are appropriate (i.e., what return period to protect to) for various flood affected communities based on the cost benefit ratios.
3. Analyse and compare which individual or combined flood mitigation options are the most cost beneficial at specified levels of service (e.g., 1:50, 1:100, 1:200, 1:350, etc.).
4. Provide a triple bottom line prioritization of key structural and non-structural investments and actions to increase flood resiliency.
5. Provide guidance in prioritizing structural and non-structural flood mitigation

1.3 Project Scope

The project has been subdivided into two phases:

1. Phase 1 provides an update of the existing flood damage model created by IBI Group on contract for the Province.
2. Phase 2 involves an assessment of flood mitigation options within Calgary through a triple bottom line analysis that includes community consultation considerations and the creation of a prioritized list of investments and actions.

Both phases of the assessment have been performed in the context of current flood resiliency conditions, such as protection provided by the Glenmore Dam, permanent flood barriers in the city and 2014 changes to the Municipal Development Plan and the City of Calgary Land Use Bylaw 1P2007.

1.4 Study Area

The study area encompasses all flood prone communities and undeveloped land along the Elbow and Bow Rivers through the City limits as identified by the most recent flood inundation mapping which includes those areas impacted by the 1:1000 year flood event.

1.5 Categorization of Damages

The categorization of loss still varies among hazard research communities. However, they are commonly divided along two main criteria into tangible or intangible and direct or indirect.

Tangible damages have a market value or a monetary value can readily be applied, such as a structural damage or business interruption losses. Intangible damages do not have a market value and are not readily quantified in monetary terms.

Direct damage is generally any loss that is caused by the physical contact of flood water with humans, property, and the environment. Indirect damages are then losses induced by the direct losses and may occur outside of the flood event in space and time. There is, however, disagreement over the nature of what these definitions include.

Some prefer to make the distinction that direct damages include all losses within the flooded area[1]. This includes the business disruption due to a damaged building. The impact on suppliers or consumers outside the flooded area would then be indirect damages. Others prefer classifying damage to stocks as direct and to flows as indirect[2]. For a business, stocks would represent the building and contents while flows would be its operations. To overcome this, some have recast damages as temporal rather than spatial and divided them as primary or secondary.

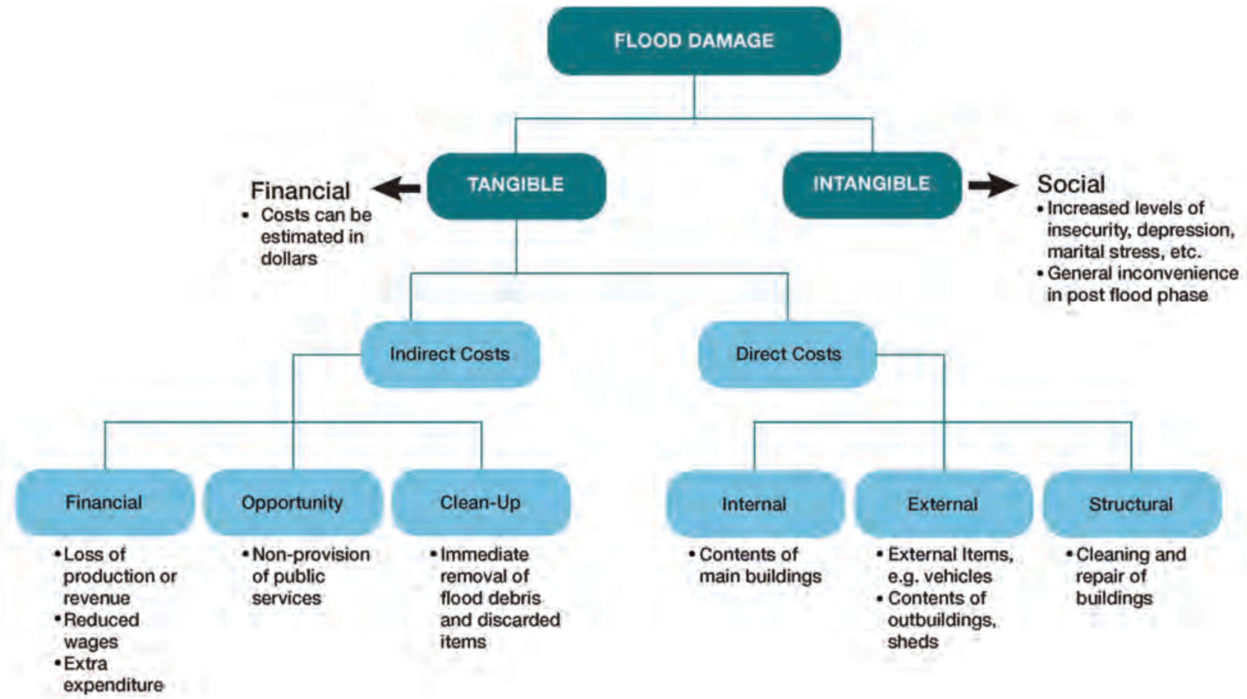
For the purposes of consistency and clarity in this report, direct damages will be limited to all physical property damaged by floodwaters. All other induced losses will be referred to as indirect.

An injury or the loss of fish habitat may be the direct result of floodwaters, but the assessment of intangible losses is significantly different than direct damages to property. Because intangible damages are difficult to assess and controversial, they will be treated as a separate category. This is done to avoid reporting a sum total of "direct damages" that includes intangible factors. Throughout, all individual components of both direct and indirect damages will be dealt with individually for transparency of assumptions. A summary of the damage categorization and measurements is provided below in **Exhibit 1.1.**

1. Jonkman, S. N., et al. "Integrated hydrodynamic and economic modelling of flood damage in the Netherlands." Ecological economics 66.1 (2008): 77-90.

2. Messner, F. Evaluating flood damages: guidance and recommendations on principles and methods. Helmholz Unweltforschungszentrum (UFZ), 2007.

Exhibit 1.1 - Types of Flood Damage



1.6 Financial Impact

Evaluations of flood damages are purpose-related and therefore context-dependent. Flood impacts are not experienced equally by all and not spatially contained. It is therefore critical to determine the perspective of loss and purpose of the study. Economists, individual households and businesses, insurance companies, and those responsible for disaster relief or flood risk management all have different perspectives for flood damage assessment. The choice of study scale and perspective will determine the metrics used and the outcome.

Within a perfect economy, trade lost by a flooded firm would be gained by another with no net economic loss. Additionally, reconstruction activity and improvements could be an economic gain. The spatial boundaries are thus important, as a flood may devastate one community but be an economic boon for an adjacent community. The agricultural industry is familiar with this – a weather disaster in one area can significantly raise prices for those with successful crops. In 1993 when floods impeded river barge traffic in the US Midwest, several trucking companies gained about 13 million US$ in additional revenue for picking up the transport demand[3].

A full economic perspective would need to consider inherently complex linkages and measure the net change for a defined region. There are econometric models used for this purpose including simple input-output models, Computable General Equilibrium models, and some more elaborate hybrids. However, these are generally 'perfect' models with a number of assumptions that may not capture the dynamics of a flood recovery. It is argued that such complex modelling is of limited use for local impact assessments as they are more applicable to large scales. Additionally, in many cases the economic metrics fail to meet the needs of local stakeholders[4].

While an estimation of economic impacts is often used to represent net welfare for benefit cost analysis, there are other methodological issues applying it to assess mitigation options. These include consideration of opportunity cost; the distinction between costs and transfers; the future benefits of new construction and equipment post-flood; avoidance of double counting stocks and flows; and the effect of the production capacity in the economy at the time the event.

Due to limited budgets, time, and a lack of reliable data, no flood damage estimate can ever be considered complete. The City of Calgary has decided to reduce the amount of at-risk assets. Therefore, the primary purpose of this study is to inform decisions on mitigation options based on reducing impacts, not to reach a conclusion on the economic impact of flooding. As such, the assessment of damages takes a financial impact approach, rather than an economy-wide perspective. Financial impact refers to the sum of losses experienced by individuals or organisations as a result of a flood. The scale of this study is the flood-affected area and the goal is to reduce the damages upon impacted properties and individuals.

3.Pielke Jr., R. A.: Flood impacts on society, in: Damaging floods as a framework for assessment, edited by: Parker, D. J., Floods, Routledge Hazards and Disasters Series, 133–155, 2000.

4.Green, Colin, Christophe Viavattene, and Paul Thompson. "Guidance for assessing flood losses." Guidance for assessing flood losses. CONHAZ Consortium, 2011.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UPDATING OF RAPID FLOOD DAMAGE ASSESSMENT MODEL

2

2 Updating of Rapid Flood Damage Assessment Model

The following section is devoted to a discussion of the updates and modifications made to the 2014 Rapid Flood Damage Assessment Model developed for the Province of Alberta. The updates include revised hydrology and hydraulics for the Bow and Elbow Rivers; a re-allocation of spill areas for damage estimation purposes; additions to the building inventory as a result of the expanded flood hazard area, recalculation of flood elevations for individual structures based on the latest 3D modelling; a re-computation of basement damages based on groundwater modelling; and finally, the addition of a module for evaluating social and environmental aspects of flood damage.

These enhancements and potential impacts on damage estimates are elaborated upon in the following sub-sections which are prefaced with a description of the Rapid Flood Damage Assessment Model and the original City of Calgary flood damage estimates.

2.1 Provincial Flood Damage Assessment Study 2014

In July of 2014 IBI Group along with Golder Associates were retained by the Alberta Government - ESRD Operations, Resilience and Mitigation Branch to undertake the Provincial Flood Damage Assessment Study. The purpose of the study was threefold:

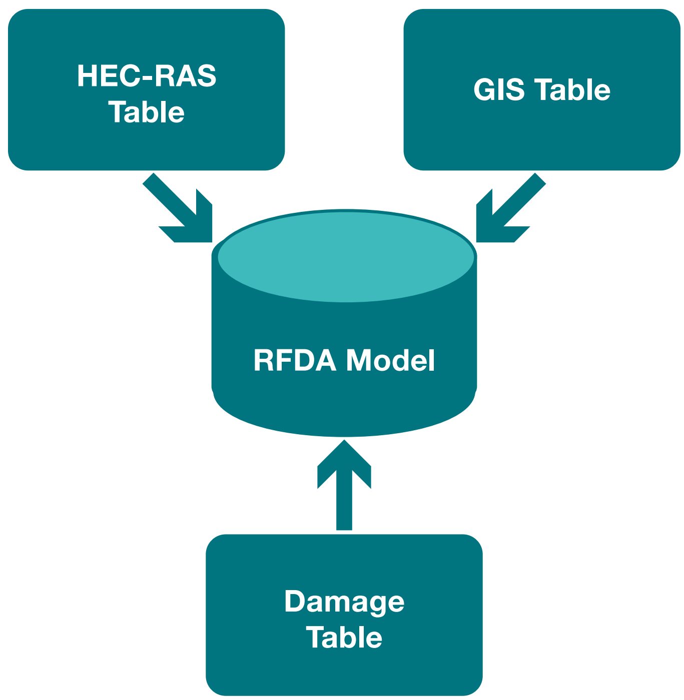
1. to update/develop flood damage curves in select communities at risk of flooding to 2014 economic values and establish adjustment indices for their use in different flood prone communities across Alberta;
2. to develop a computerized model for estimating flood damages; and
3. to undertake flood damage estimates for select communities throughout Alberta.

New depth-damage curves were created along with a computerized model. The City of Calgary was also identified as a high priority centre and selected as the pilot municipality for the updating of flood damage curves and development of the Rapid Flood Damage Assessment Model. In addition, flood damages were estimated for a range of flood events and average annual damages computed and employed in subsequent benefit/cost analyses of potential flood mitigation alternatives.

2.1.1 Rapid Flood Damage Assessment Model (RFDAM)

The RFDA model works with three input tables: (1) the GIS inventory table of residential, and commercial/retail buildings in the study area; (2) the specific depth-damage curves for contents and structures indexed to that community; and (3) the hydraulic flood-frequency-elevation table derived from the HEC-RAS model (see **Exhibit 2.1**).

Exhibit 2.1 - RFDAM Input Tables

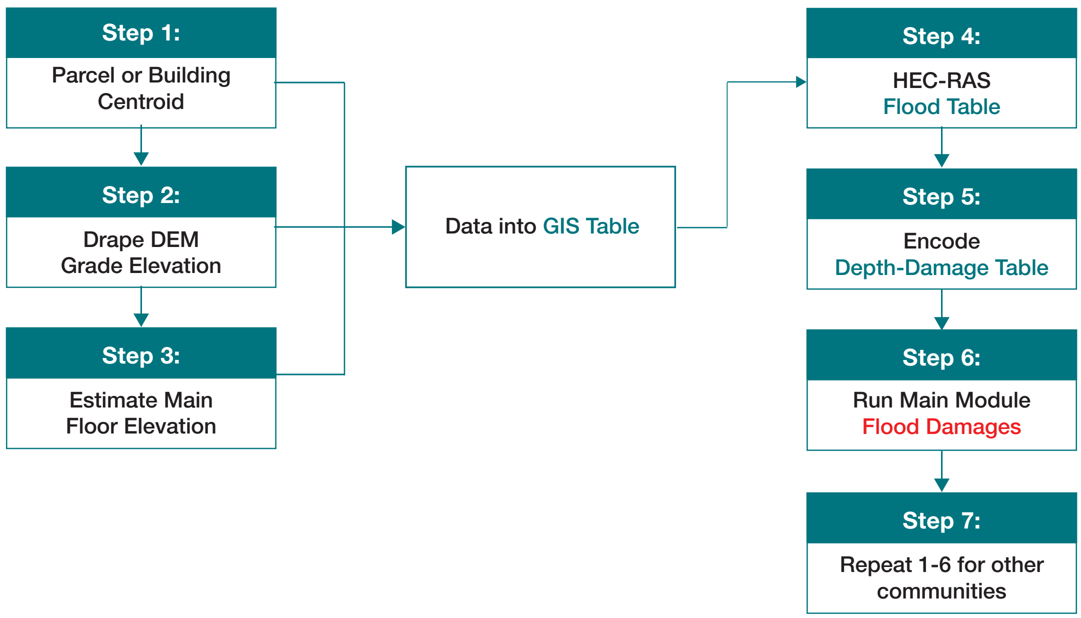


Municipalities in flood risk areas have access to high resolution satellite imagery, or orthophotos, which can clearly show the location of all buildings in their community. In addition they can overlay the images with property parcel boundaries. Many local governments have replaced contour mapping with LiDAR DEMs, which provide dense 3D points scanned by airborne radar with higher accuracies than traditional photogrammetry. This means that buildings in the floodplain and adjacent-to areas can be geocoded to a coordinate system.

The GIS building inventory table was designed to provide maximum flexibility in data collection input to the model. In the case where assessment data is available, main floor and basement areas can be extracted for use in the model. In cases where that is not available, the areas can be estimated via remote sensing.

Similarly, the elevation grade for the property can be extracted by draping on the 3D surface from LiDAR or other DEMs. Naturally the denser the ground points are, the more accurate the elevation will be. In the worst case elevations can be extracted from contour maps. The process for estimating flood damages using the model is shown in **Exhibit 2.2** and is described on a step-by-step basis as follows:

Exhibit 2.2 - RFDAM Damage Estimate Steps



1. Load parcel base map coverage in GIS to generate centroid for draping. If the main floor area is available from assessment then this value should be used. This is available in larger communities but may not be readily available in smaller ones. In addition the building outline may be available. If not the building area could be digitized and automatically computed using GIS if necessary.

2. Drape centroids on LiDAR DEM bare earth (BE) coverage to obtain grade elevation. BE coverage is created by applying sophisticated algorithms to compute the ground elevations without structures or vegetation.

3. Grade to main floor height may be estimated from a windshield level loop survey or Google Earth type street level photography. If that is not possible then an average grade height from past observations can be used in the model. The information from steps 1 to 3 are added to the 'GIS Inventory Table'.

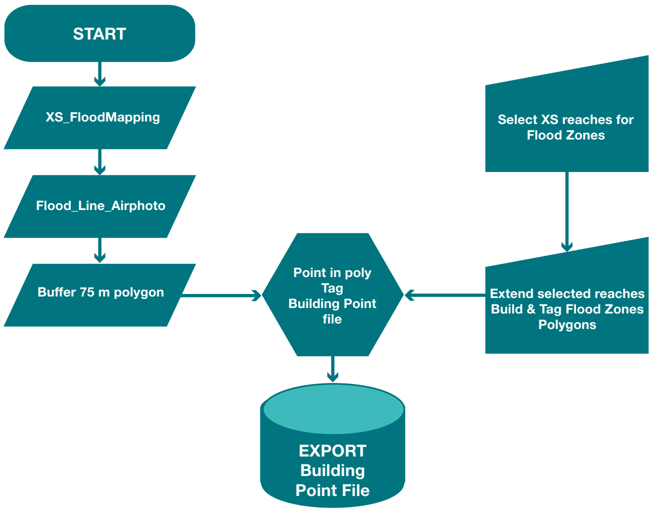
4. Use the HEC-RAS model sections to define floodplain zones in the community, include the adjacent-to areas using a buffer zone on the left and right of the cross-sections. Input table of flood elevations for the different return flood levels that will be used for flood damage calculations. This can be referred to as the 'Flood Table' (see **Exhibit 2.3**).

5. Code updated depth-damage curves for structure and contents for residential and commercial buildings into a 'Depth-Damage Table'. Damage curves developed specifically for Alberta were employed in the 1980s These have been updated to 2014 values for use within the entire Province through place-to-place indexing. These are the most current and accurate synthetic flood damage curves for depicting damages in Alberta.

6. Once the three key tables are generated the RFDAM model can be run to calculate the flood damages to residential and commercial structures within the floodplain and adjacent-to areas for various return floods. From these, the average annual damages (AAD) can be estimated.

7. Steps 1 to 6 are repeated for each flood risk community. The RFDAM system has been developed using Free and Open-Source Software (FOSS). Quantum GIS (QGIS) has been selected as the GIS application of choice. RFDAM has improved significantly on the previous FDDBMS and provides a user-friendly, made in Alberta approach to flood damage assessment.

Exhibit 2.3 - Flood Cross-Sections and Hydraulic Data Preparation Process



2.1.2 City of Calgary Flood Damage Estimates 2014

2.1.2.1 Floodplain Mapping

Nine flood elevations were employed to compute flood damages, including the 1:2, 1:5, 1:10, 1:15, 1:20, 1:50, 1:100, 1:200, 1:500, and 1:1000 year flood events. Flood elevation data was based on the hydraulic output of the HEC-RAS Model provided by the City of Calgary and based on the Bow and Elbow River updated hydraulic model project by Golder Associates dated April 2012.

2.1.2.2 Inventory of Buildings

Within the identified flood hazard area, which includes the 1:100 year design flood plus a 75 m buffer, the number of buildings totals approximately 7,200 (excluding outbuildings such as garages and storage sheds) and is comprised of 5,620 single-family residential dwellings; 728 semi-detached, triplex and townhouse-style dwelling units; 275 multi-family apartment buildings; and 564 non-residential (commercial/industrial/institutional) buildings.

2.1.2.3 Damage Estimates

Total damages for the Bow and Elbow Rivers with the sewer backup condition are detailed in **Exhibit 2.4** and summarized as follows.

Exhibit 2.4 - Total Damages, Bow and Elbow Rivers, With Sewer Backup

Categories of damage		Return frequency, in years								
		2*	5*	10**	20	50	100	200	500	1,000
Residential	Direct	$0	$0	$0	$268,753,000	$414,798,000	$686,791,000	$947,786,000	$1,329,201,000	$1,496,364,000
	Indirect 15%	$0	$0	$0	$40,313,000	$62,220,000	$103,019,000	$142,168,000	$199,380,000	$224,455,000
	Total	$0	$0	$0	$309,066,000	$477,018,000	$789,810,000	$1,089,954,000	$1,528,581,000	$1,720,819,000
Commercial	Direct	$0	$0	$0	$15,210,000	$37,446,000	$111,079,000	$271,990,000	$493,624,000	$572,607,000
	Indirect 323%	$0	$0	$0	$49,128,000	$120,951,000	$358,785,000	$878,528,000	$1,595,052,000	$1,849,521,000
	Total	$0	$0	$0	$64,338,000	$158,397,000	$469,864,000	$1,150,518,000	$2,088,876,000	$2,422,128,000
Infrastructure	Direct	$0	$0	$0	$101,508,000	$170,620,000	$299,100,000	$452,626,000	$686,656,000	$780,711,000
	Indirect 20%	$0	$0	$0	$20,302,000	$34,124,000	$59,820,000	$90,525,000	$137,331,000	$156,142,000
	Total	$0	$0	$0	$121,810,000	$204,744,000	$358,920,000	$543,151,000	$823,987,000	$936,853,000
Stampede	Direct	$0	$0	$0	$10,200,000	$42,200,000	$68,900,000	$91,900,000	$166,853,000	$193,472,000
	Indirect 185%	$0	$0	$0	$18,860,000	$78,030,000	$127,400,000	$169,928,000	$308,521,000	$357,741,000
	Total	$0	$0	$0	$29,060,000	$120,230,000	$196,300,000	$261,828,000	$475,374,000	$551,213,000
Total	Direct	$0	$0	$0	$395,671,000	$665,064,000	$1,165,870,000	$1,764,302,000	$2,676,534,000	$3,043,154,000
	Indirect 73%	$0	$0	$0	$128,603,000	$295,325,000	$649,024,000	$1,281,149,000	$2,240,284,000	$2,587,859,000
	Total	$0	$0	$0	$524,274,000	$960,389,000	$1,814,894,000	$3,045,451,000	$4,916,818,000	$5,631,013,000

* No Actual damages occur at these flow levels
** Flood Flow primarily contained within the river

Residential Damages

Direct residential damages equate to $687 million under 1:100 year flood conditions and constitute some 59% of total direct damages.

Commercial Damages

Commercial direct damages equate to $111 million for the 1:100 year flood event or just under 10% of total direct damages.

Infrastructure Damages

Infrastructure damages for the 1:100 year flood are estimated at $299 million or 26% of total direct damages.

Damages to Stampede Park

Direct damages to Stampede Park, including the Saddledome, for the 1:100 year flood equate to $69 million or 6% of total direct damages.

Indirect Damages

Indirect damages by themselves constitute some $649 million or 56% under 1:100 year flood conditions. (Indirect damages equate to a higher proportion of direct damages for the lower frequency floods; the unweighted average indirect share is 73% across the range of events.) This is an exceptionally high proportion, driven by commercial indirect damages and Stampede indirect damages in particular.

Total Damages

Total damages including direct and indirect damages for the 1:100 year flood are estimated at $1.815 billion for the Bow and Elbow Rivers combined, with sewer backup damages included.

Average Annual Damages

Average annual damages for the Bow and Elbow combined are $84,431,000 and for the Elbow by itself, $30,111,000.

Alternative Damage Scenario

The previous damage assessment is reflective of worst case conditions, in particular as it relates to commercial indirect damages, Stampede indirect damages and infrastructure damage, especially at the higher flood frequencies. An alternative damage scenario has been developed which reduces damage in these categories.

Exhibit 2.5 describes the reduced total damage estimates. As evidenced, total damages for the Bow and Elbow Rivers for the 1:100 year event have been reduced from $1.815 billion to $1.237 billion with a concomitant reduction in average annual damage from $84,431,000 to $56,342,000. For the Elbow the average annual damage has been reduced from $30,111,000 to $21,729,000.

Exhibit 2.5 - Alternative Damage Scenario - Total Damages, Bow and Elbow Rivers, With Sewer Backup

Categories of damage		Return frequency, in years								
		2 *	5 *	10 **	20	50	100	200	500	1,000
Residential	Direct	$0	$0	$0	$268,753,000	$414,798,000	$686,791,000	$947,786,000	$1,329,201,000	$1,496,364,000
	Indirect 15%	$0	$0	$0	$40,313,000	$62,220,000	$103,019,000	$142,168,000	$199,380,000	$224,455,000
	Total	$0	$0	$0	$309,066,000	$477,018,000	$789,810,000	$1,089,954,000	$1,528,581,000	$1,720,819,000
Commercial	Direct	$0	$0	$0	$15,210,000	$37,446,000	$111,079,000	$271,990,000	$493,824,000	$572,607,000
	Indirect 45%	$0	$0	$0	$0	$16,851,000	$49,986,000	$122,396,000	$222,221,000	$257,673,000
	Total	$0	$0	$0	$15,210,000	$54,297,000	$161,065,000	$394,386,000	$716,045,000	$830,280,000
Infrastructure	Direct	$0	$0	$0	$21,639,000	$90,929,000	$159,400,000	$241,219,000	$365,941,000	$416,066,000
	Indirect 20%	$0	$0	$0	$4,328,000	$18,186,000	$31,880,000	$48,244,000	$73,188,000	$83,213,000
	Total	$0	$0	$0	$25,967,000	$109,115,000	$191,280,000	$289,463,000	$439,129,000	$499,279,000
Stampede	Direct	$0	$0	$0	$10,200,000	$42,200,000	$68,900,000	$91,900,000	$166,853,000	$193,472,000
	Indirect 38%	$0	$0	$0	$3,908,000	$16,170,000	$26,400,000	$35,213,000	$63,932,000	$74,132,000
	Total	$0	$0	$0	$14,108,000	$58,370,000	$95,300,000	$127,113,000	$230,785,000	$267,604,000
Total	Direct	$0	$0	$0	$315,802,000	$585,373,000	$1,026,170,000	$1,552,895,000	$2,355,819,000	$2,678,509,000
	Indirect 22%	$0	$0	$0	$48,549,000	$113,427,000	$211,285,000	$348,021,000	$558,721,000	$639,473,000
	Total	$0	$0	$0	$364,351,000	$698,800,000	$1,237,455,000	$1,900,916,000	$2,914,540,000	$3,317,982,000

* No Actual damages occur at these flow levels
** Flood Flow primarily contained within the river

2.2 Updates to River Flood Hydrology and Hydraulics

2.2.1 Flood Hydrology

The latest estimates of the flood peak discharges and hydrographs for the Bow and Elbow Rivers (Golder, September 2014 and January 2015) were used in this study. This latest hydrology study included consideration of the preliminary data for the June 2013 flood event. The flood peak discharge estimates were available for various return periods ranging from 2 to 1,000 years. The design flood hydrographs were available for four return periods (i.e., 50, 100, 200 and 500 years).

The latest estimates of the river flood peak discharges supersede those obtained in the previous hydrology study by Golder (March 2010). A comparison of the flood peak discharges estimated in these studies is provided in **Exhibit 2.6.** The magnitudes of the 2015 estimates are generally greater than the 2010 estimates.

2.2.2 Flood Hydraulics

The latest hydraulic modelling and flood inundation mapping results for the Bow and Elbow Rivers in Calgary (Golder, July 2015) were used in this study. The 2015 hydraulic model developed using HEC-RAS involved use of the 2015 flood peak discharge estimates, the June 2013 flood high water marks, the latest Light Detention And Ranging (LiDAR) data for the river floodplains, and the river cross-sectional survey post the 2013 flood.

The updated 2015 hydraulic model and flood inundation maps supersede those previously prepared by Golder (April 2012). To illustrate the differences of the simulated flood water surface profiles using the 2015 and 2012 hydraulic models, **Exhibits 2.7** and **2.8** present the comparison of the simulated 100 year flood water surface profiles along the Bow and Elbow Rivers, respectively. The simulated water levels using the 2015 model are on average 0.27 m and 0.38 m higher than those using the 2012 model for the Bow and Elbow Rivers, respectively.

Exhibit 2.6 - Comparison of Flood Peak Discharge Estimates

Return Period (Years)	Flood Peak Discharge (m^3/s)					
	Elbow River below Glenmore Dam		Bow River below Bearspaw Dam		Bow River below Elbow River	
	2010 Study	2015 Study	2010 Study	2015 Study	2010 Study	2015 Study
2	52	64	423	369	475	433
5	99	143	606	659	705	802
10	193	234	774	927	967	1,160
20	274	275	983	1,230	1,260	1,500
50	445	494	1,350	1,660	1,790	2,150
100	699	803	1,710	2,020	2,410	2,820
200	922	1,130	2,170	2,390	3,090	3,520
500	1,220	1,690	2,980	2,920	4,200	4,610
1,000	1,490	2,270	3,810	3,340	5,290	5,610

Source: Golder Associates Ltd., September 2014, Bow River and Elbow River Basins – Hydrology of 2013 Flood Event, Prepared for The City of Calgary.

Golder Associates Ltd., March 2010, Hydrology Study, Bow and Elbow River Updated Hydraulic Model Project, Prepared for The City of Calgary and Alberta Environment.

Exhibit 2.7A - Comparison of Simulated Water Surface Profiles for the 100-year Flood along the Bow River

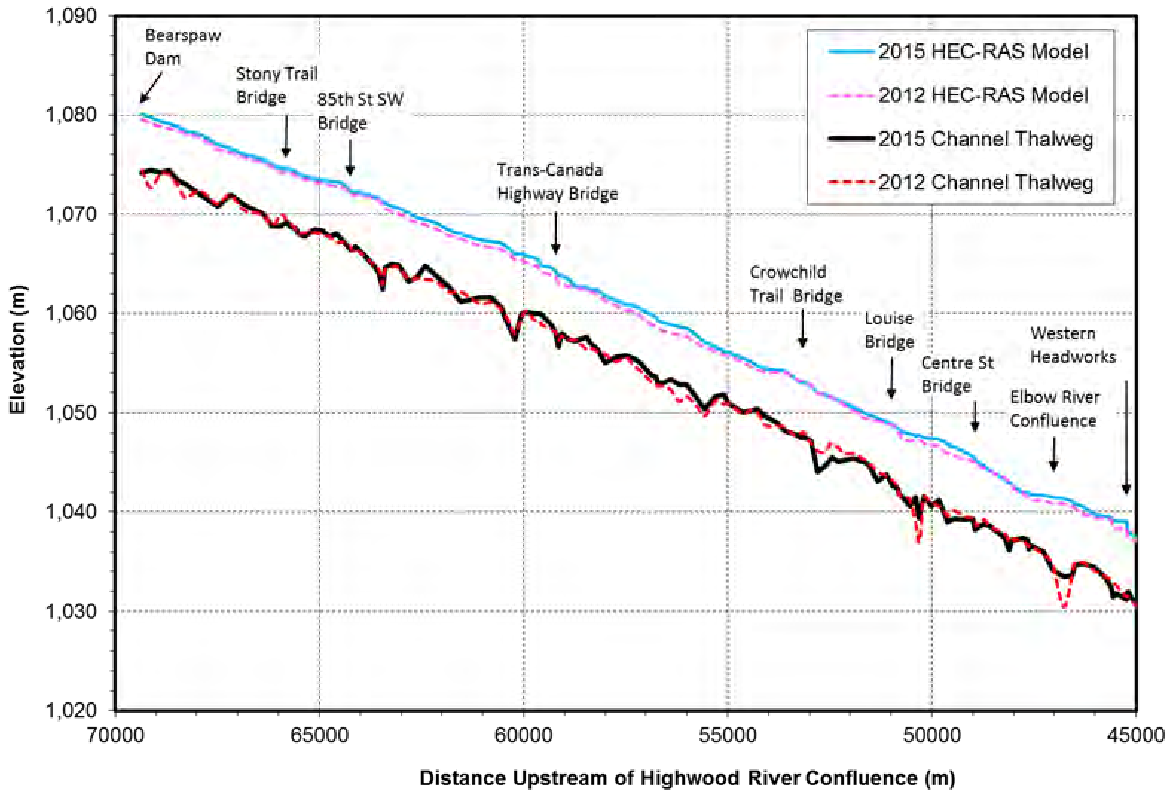
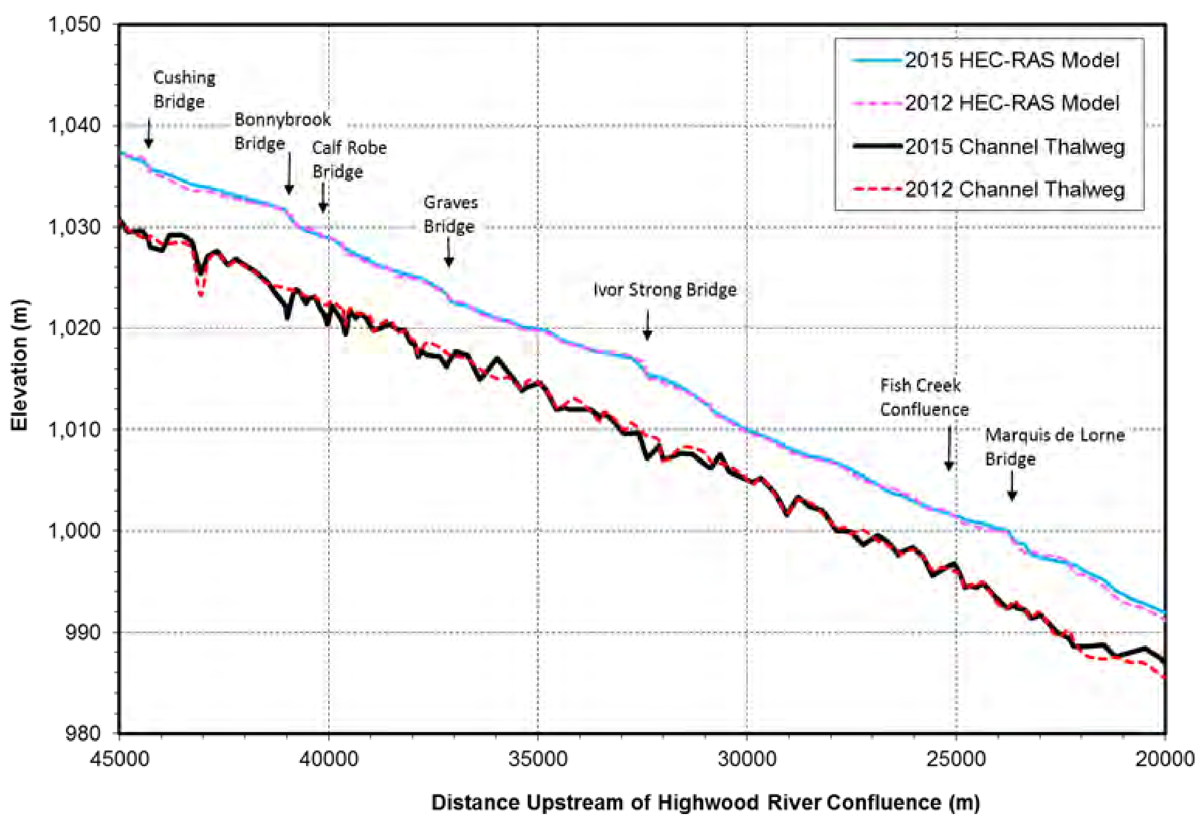


Exhibit 2.7B - Comparison of Simulated Water Surface Profiles for the 100-year Flood along the Bow River



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Golder Associates Ltd., March 2010, Hydrology Study, Bow and Elbow River Updated Hydraulic Model Project, Prepared for The City of Calgary and Alberta Environment.
Golder Associates Ltd., July 2015, Bow River and Elbow River Hydraulic Model and Flood Inundation Mapping Update, Prepared for The City of Calgary, and Alberta Environment and Parks.
Golder Associates Ltd., April 2012, Bow and Elbow River Updated Hydraulic Model Project – Hydraulic Modelling and Inundation Mapping, Prepared for The City of Calgary, and Alberta Environment and Water

Exhibit 2.7C - Comparison of Simulated Water Surface Profiles for the 100-year Flood along the Bow River

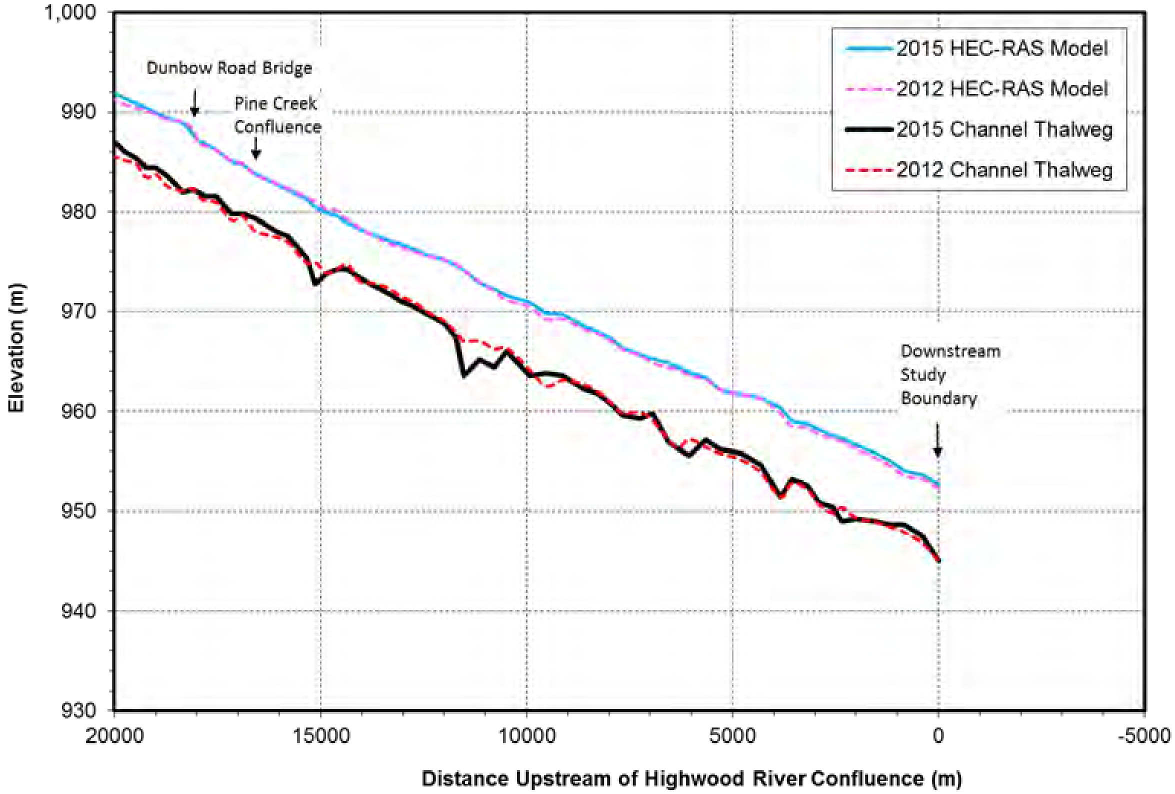
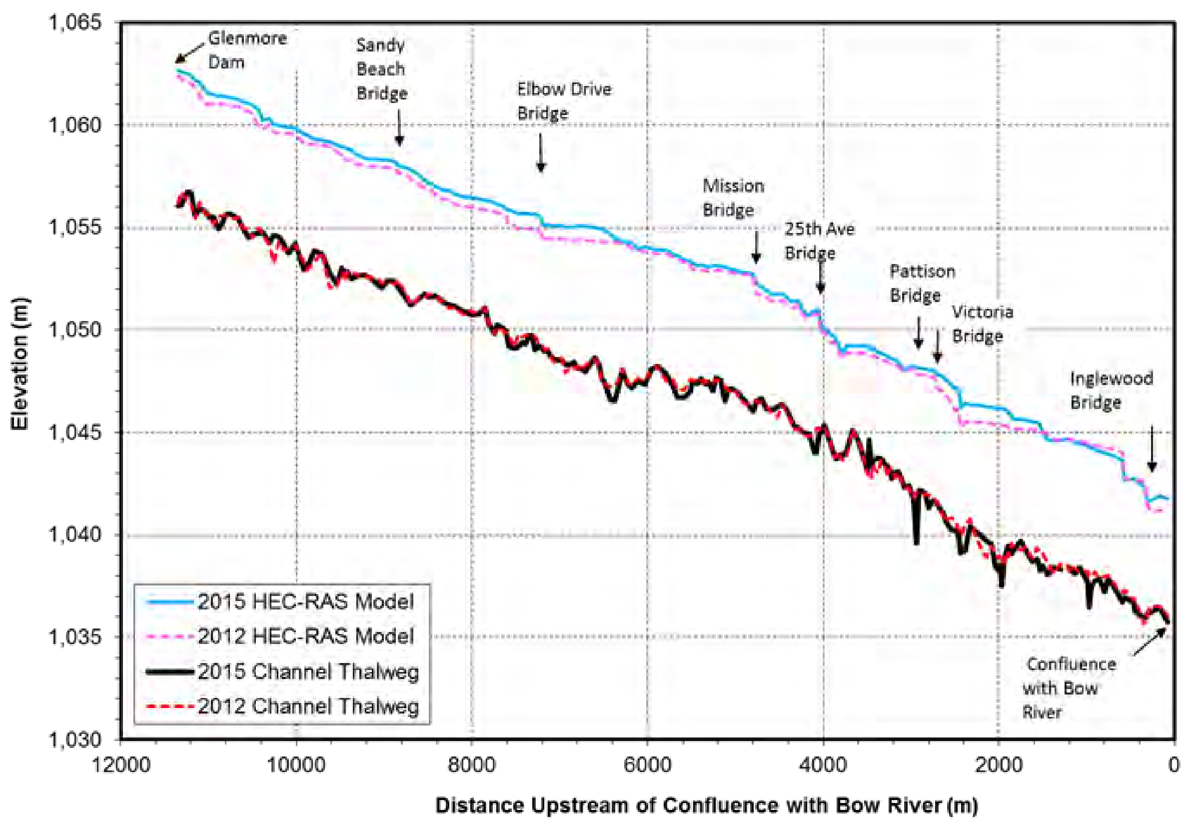


Exhibit 2.8 - Comparison of Simulated Water Surface Profiles for the 100-year Flood along the Elbow River



References:
Golder Associates Ltd., January 2015, Bow River and Elbow River Basins – Hydrology of 2013 Flood Event, Prepared for The City of Calgary.
Golder Associates Ltd., March 2010, Hydrology Study, Bow and Elbow River Updated Hydraulic Model Project, Prepared for The City of Calgary and Alberta Environment.
Golder Associates Ltd., July 2015, Bow River and Elbow River Hydraulic Model and Flood Inundation Mapping Update, Prepared for The City of Calgary, and Alberta Environment and Parks.
Golder Associates Ltd., April 2012, Bow and Elbow River Updated Hydraulic Model Project – Hydraulic Modelling and Inundation Mapping, Prepared for The City of Calgary, and Alberta Environment and Water

2.3 Comparison of Flood Extent 2012 vs 2015 Modelling

Exhibit 2.9 illustrates the expanded flood hazard area based on the updated modelling. As evidenced, the aereal extent of inundation has increased substantially, and particularly within the downtown area for the lower frequency events >1:200 year. For the 1:100 year event, the largest increases occur in Hillhurst and the Beltline, with lesser increases evident in the area just north of the Deerfoot Meadows commercial development in S.E. Calgary.

The other area of note is related to a large area of spill at the 1:500 year return period, which covers several hundred acres in the Manchester, Alyth, Bonnybrook, Highfield and Inglewood industrial areas.

Exhibit 2.10 focuses in on the aforementioned areas.

The expanded flood hazard area includes more than double the amount of buildings as the 2014 inventory. As discussed in Section 2.4.3, the inventory methodology was changed to a parcel-based approach. The new inventory contained a total of 14,022 parcels. This includes 14,225 ground-oriented units (single-family, duplex, townhouse), 950 apartment buildings, and 1,970 non-residential buildings (main floor classification). The estimated total number of residential units in the hazard area is 52,883.

2.4 Calculation of Damages in Expanded Flood Impacted Zone

2.4.1 Correlation of Damages to Flows

The previous damage assessment for the City of Calgary undertaken in 2014 employed flood elevations derived from the 2012 HEC-RAS model, using hydrologic data from 2010. As discussed in Section 2.2, since the 2013 flood, hydrologic studies have been updated resulting in an increase in the return flood flows.

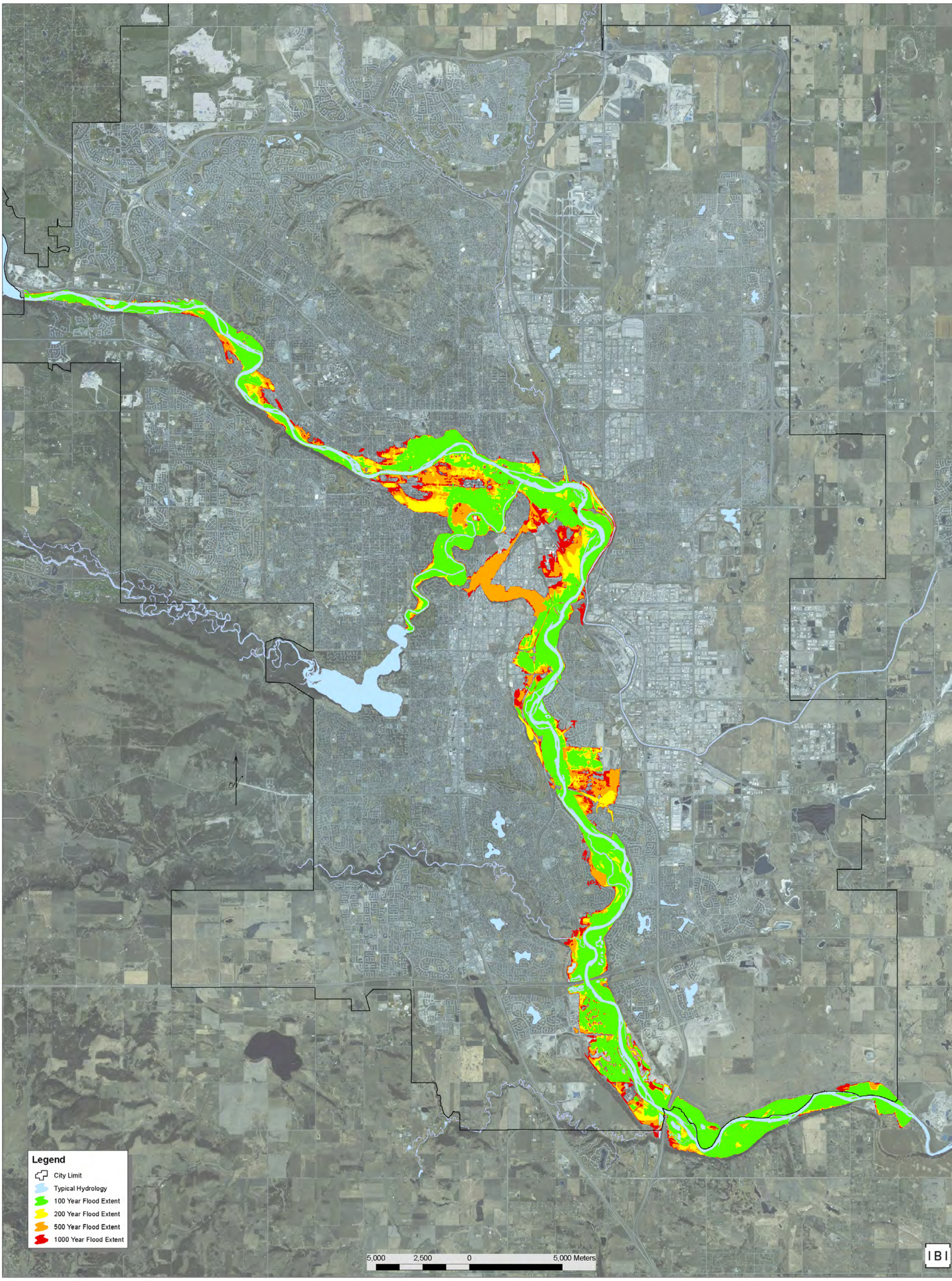
A least squares fit, using a 3 degree polynomial, was applied to estimate flood damages resulting from a given flow for both the high and low damage scenarios. The results of the polynomials for both the high and low scenarios rendered a correlation coefficient of 0.999. Consequently, an estimate of damages that could result from the increased flows was compiled using statistical extrapolation. The results are for comparative purposes only, but demonstrate the order of magnitude impact for the Elbow River under the high and low damage scenarios.

The area under the damage probability curves (see **Exhibits 2.11 and 2.12**) for the 2010 and 2014 average annual damages are $32,403,207 and $55,605,956 respectively (note that the average annual damage related to the 2010 hydrology for this calculation is slightly higher than reported for the 2014 damage study, as different plotting software was used).

The increased flows resulting from the revised 2014 hydrology increases the average annual damage by approximately 70% from the 2010 hydrology for the high scenario.

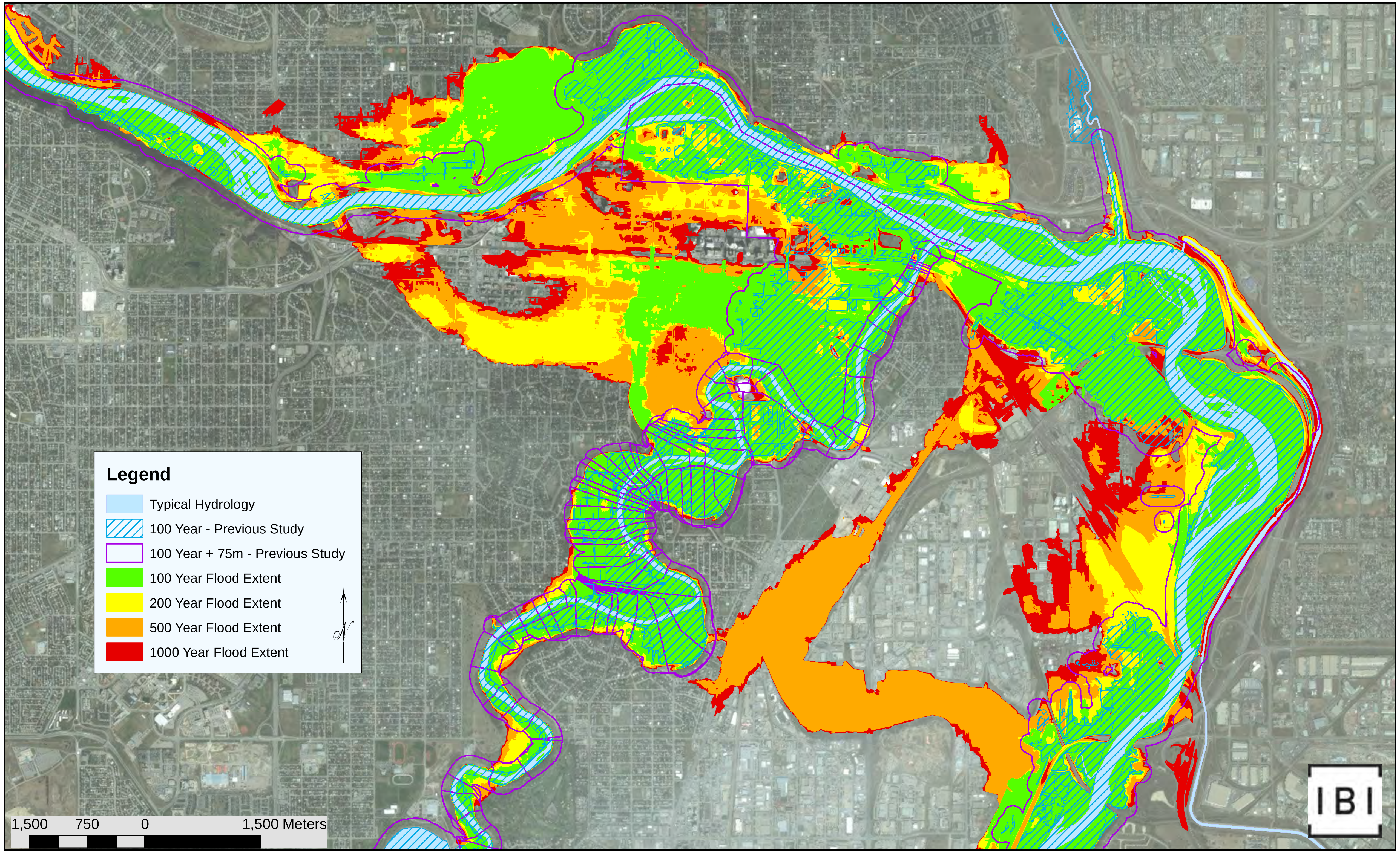
For the low damage scenario (see **Exhibit 2.12**) average annual damages for the 2010 and 2014 model flows are $23,550,795 and $37,232,195 respectively. As evidenced, the increased flows from the revised 2014 hydrology result in an increase in the average annual damage of approximately 60% from the 2010 hydrology for the low damage scenario.

Calgary Flood Extents



Source: Golder Associates Ltd., September 2014, Bow River and Elbow River Basins – Hydrology of 2013 Flood Event, Prepared for The City of Calgary.

Flood Extents Used for Previous and Current Study



Source: Golder Associates Ltd., September 2014, Bow River and Elbow River Basins – Hydrology of 2013 Flood Event, Prepared for The City of Calgary.

Exhibit 2.11 - Elbow River High Damage Scenario

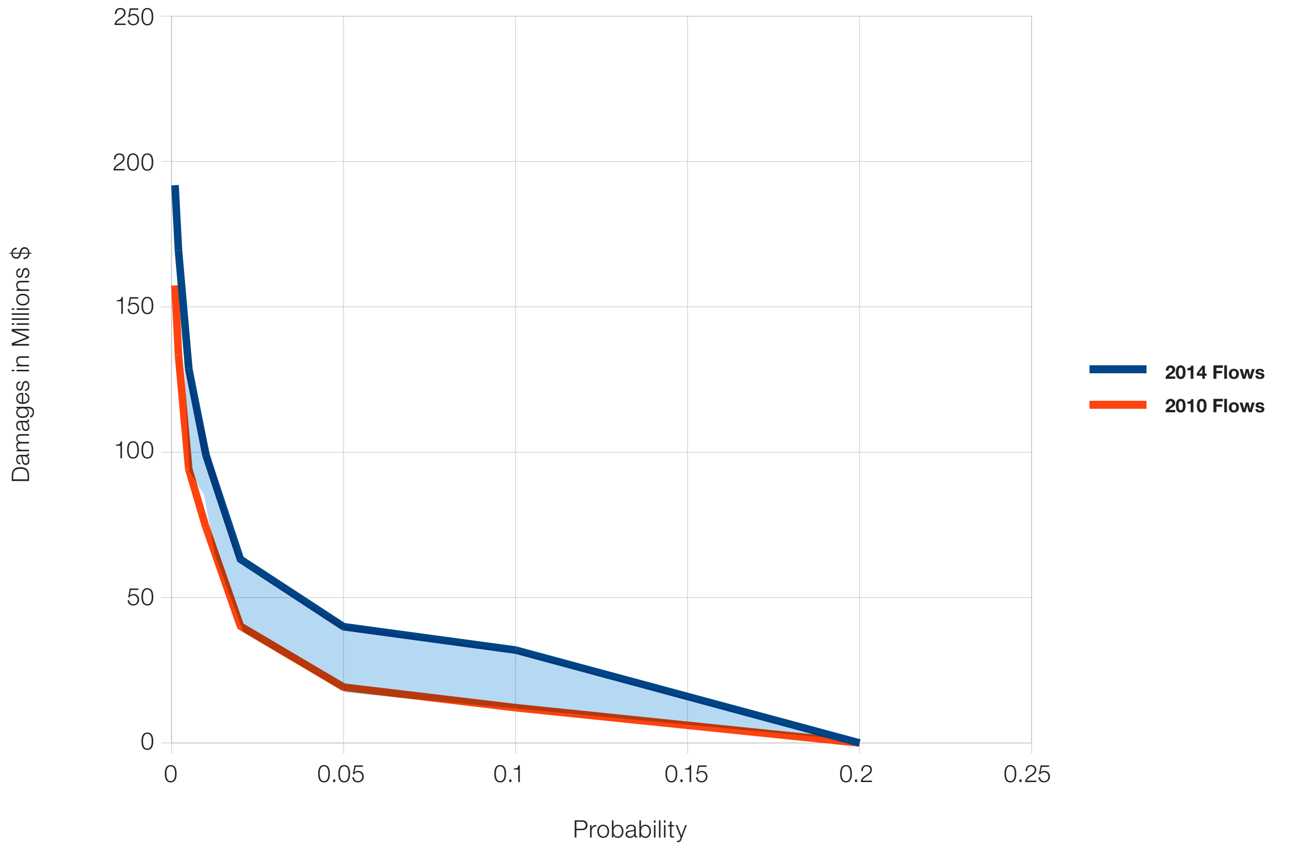
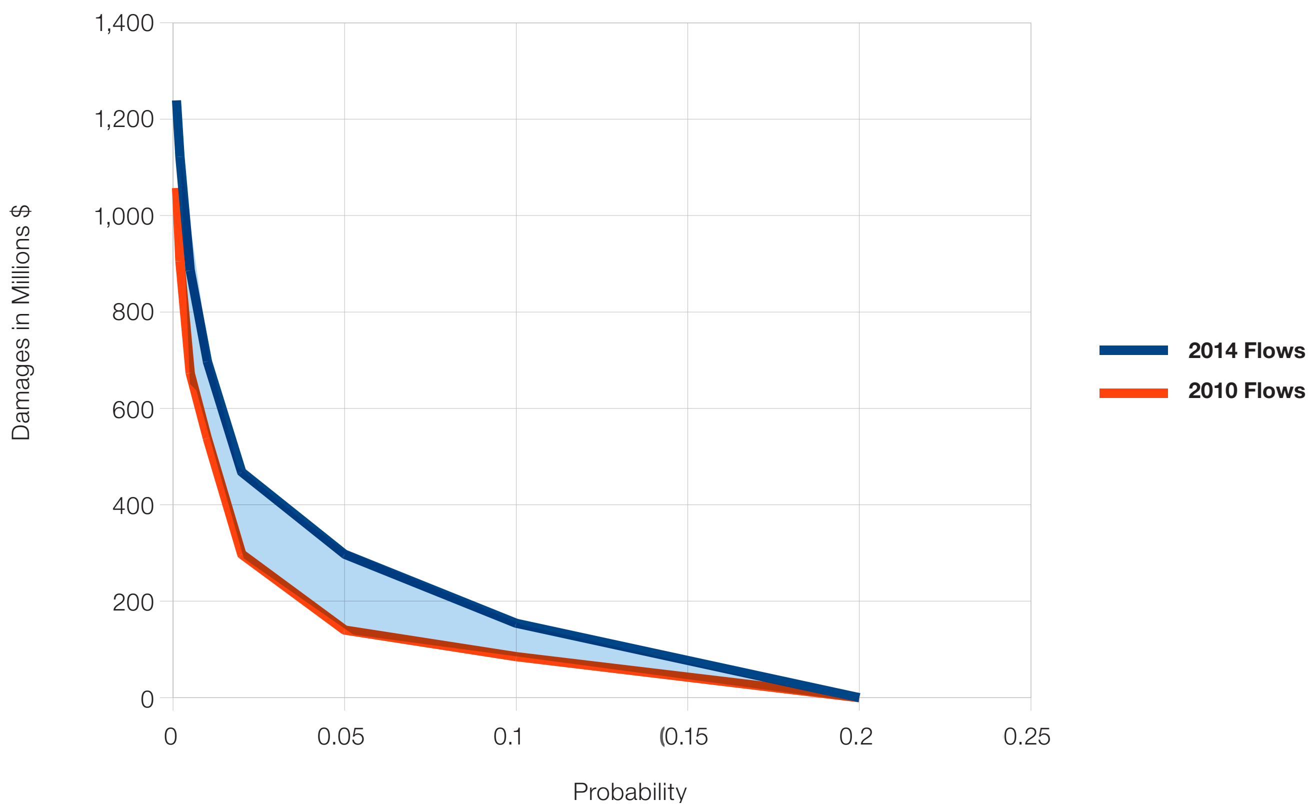


Exhibit 2.12 - Elbow River Low Damage Scenario



2.4.2 Preliminary Estimate of Increased Damages

A high level preliminary estimate of increased damages was performed to demonstrate the impact of the expanded flood hazard area in the downtown and Beltline for the 1:500 and 1:1000 year events. In terms of methodology, building square footages were calculated based on building outlines and then classified as either residential or commercial. A miscellaneous commercial damage curve and appropriate residential curves were applied (either MW or B). Commercial first floor elevations were established at .1 m and residential first floor elevations at .6 m, with parkade flooding assumed for one half of the commercial buildings. Indirect damages were estimated at 45% of direct damages for commercial and 15% of direct damages for residential. Finally, the previous damage estimates were increased by 1.7 times and the new damage estimates for the expanded areas added to the 1:500 year and 1:1000 year events. Notwithstanding the significant damages incurred, because of the low probabilities, the increases for these events amount to approximately 2.5% of the expected average annual damages.

In spite of the limited impact on the average annual damages, there is significant uncertainty within the City core as it contains the highest densities and mix of uses in the study area which is expected to have a significant impact on the indirect damage calculations. Accordingly, it was decided to inventory the expanded flood hazard area for all identified return periods to the same level as the initial study inventory.

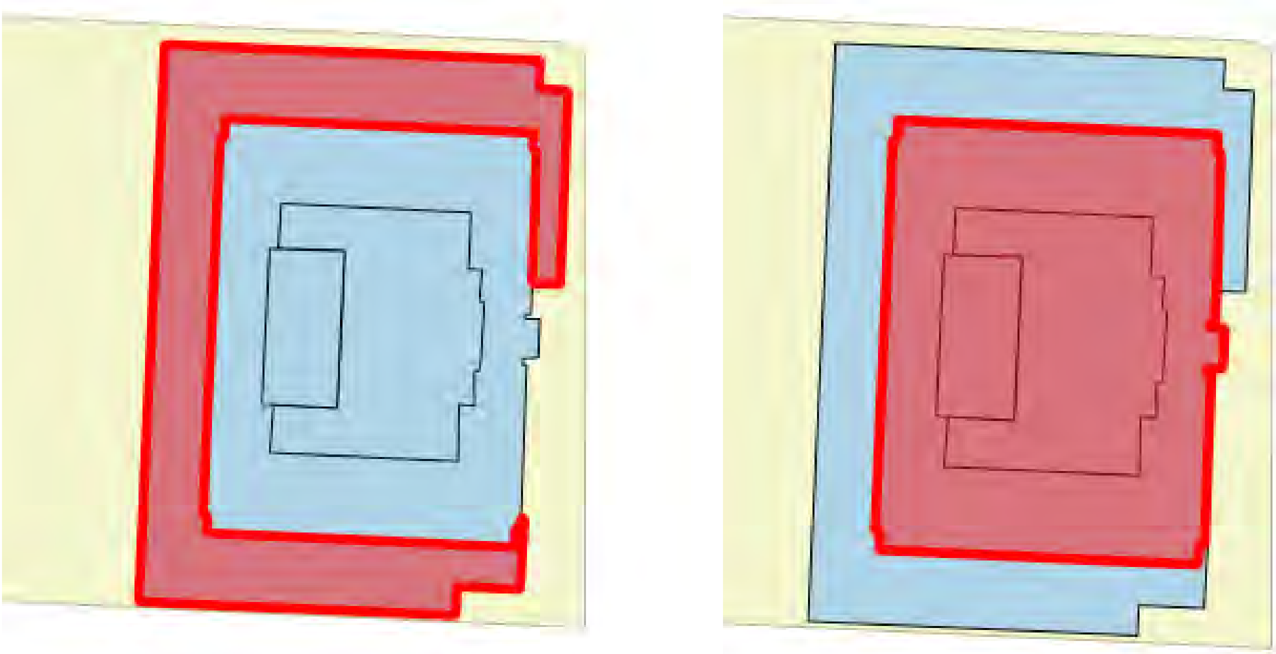
2.4.3 Inventory Methodology and Discussion

2.4.3.1 GIS and Assessment Data

The assembly of the GIS building inventory is, in theory, relatively straightforward. However, in practice it has proven to be one of the most challenging tasks of the assessment. The challenges are largely related to the quality of data available and the amount of data processing required. In most municipalities these challenges would be easy to overcome but the study area in Calgary contains large areas of dense and complex multi-use building arrangements throughout the Downtown and Beltline districts.

The initial goal was to create a base GIS layer of buildings from a digital aerial survey (DAS) shapefile. The building polygons would provide the building area (footprint) as well as the centroid x/y coordinates. However, the format of the provided shapefiles is problematic, particularly in high density areas such as the downtown core. These issues became apparent during the previous study and even more so with the greatly expanded area for this study. One of the issues is that the shapefile is comprised of individual polygons for every roof part or elevation with inconsistent overlapping. An example of such a building is illustrated in **Exhibit 2.13.**

Exhibit 2.13 Building Polygon Isues



The inconsistency of the building shapes precludes a method of calculating the area of an individual building from the polygons alone: no one polygon provides the total area and they cannot be summed due to overlapping. Furthermore, the polygon attributes contain no identifying information that can be used to group them by building or perform a merge/ dissolve within GIS programs. This creates difficulties where there are many contiguous building groups.

In addition to the footprint area and location of a building, information such as total use area and residential building type is required from the assessment records. Because there is no link between the building polygons and these records, another identifier must be used. The GIS address files would logically be the most suitable but, as experienced in the previous study, the addresses are also problematic.

There are three types of addresses: Parcel Address, Suite Address, and Building Address. Unfortunately, not all buildings have addresses, many cover multiple parcels, and the assessment records do not correspond to the actual address in many cases. **Exhibit 2.14** is an example of a property that illustrates these issues.

In this example:

- One building does not have any address points
- The building on the right has 146 address points (145 in the centre at the same spot). This includes suites and multiple building addresses.
- In the assessment records, all eight of the parcels shown have the address 395 7 St. SW, the parcel address in the top right corner.
- All eight parcels also have the same roll number in the assessment records.
- That roll number has 992 records: a set of 124 for each parcel with the same details except for the parcel ID.
- All 992 records have building totals for office, retail, and storage space.

To avoid the known issues with building polygons and addressing and to align the GIS inventory with the assessment records, a parcel-based approach was used. The parcel ID (CPID) is a reliable link to the assessment records. The (simplified) steps taken to create a new inventory base are as follows:

- All parcels in the assessment records with the same roll number are merged into one shape.
- If the parcel contained multiple roll numbers, the space areas are summed. For residential condominiums, the number of records is counted as the number of units.
- The assessment records are then reduced to one record for each parcel or grouping of parcels with a single unique CPID.
- The building footprint area is then calculated as a function of combined parcel coverage.

There are some instances of multiple buildings on a single parcel or group of combined parcels. Therefore, the building classification must be based on the predominant use and type. Similarly, the elevation is considered at the centroid of the parcel. This is slightly less precise in some cases but consistent with the judgments required to choose a classification when there is variation in use and elevation within individual buildings.

Having an inventory that reflects the data provided in the assessment records is of greater importance for this study due to the required estimates for indirect costs to businesses and households. Direct damage due to flooding impacts the main and below-grade floors while upper floors will incur other losses depending on the extent of the damage. As discussed further in Sections 4.3 and 4.4, this requires two inventory records for each multi-storey building. One relating to the main floor and the other for upper floors.

A residential unit count is also required to determine the number of impacted households. In the case of condominium multi-family, each unit will have an assessment record that can be counted as a unit. Rental buildings normally only have one record and when a unit count was not indicated or otherwise determined, the total living space is divided by an average unit size of $75m^2$ to determine the approximate number of units.

2.4.3.2 Building Classification

Several internet tools were used to assist in the identification and classification of such a large number of records. The City of Calgary's online mapping (cityonline.calgary.ca) site was used to reconcile parcel and address information. Google Earth Pro's Street View was the primary method of determining the main floor use. Internet searches of addresses was often relied on to identify uses that were not clear from the street view.

To facilitate the entry of building classification and estimated main floor elevation, IBI Group developed a special application for use within Google Earth Pro. The GIS inventory was converted into a KML file with a field containing HTML code that allowed for data entry from the Google Earth interface. A user could then click on a particular parcel and enter the building classification, type, main floor elevation, presence of basement or underground parking, and other notes. **Exhibit 2.15** illustrates a screenshot of this tool in use.

Exhibit 2.14 Building, Parcel, Address and Assessment Record Issues

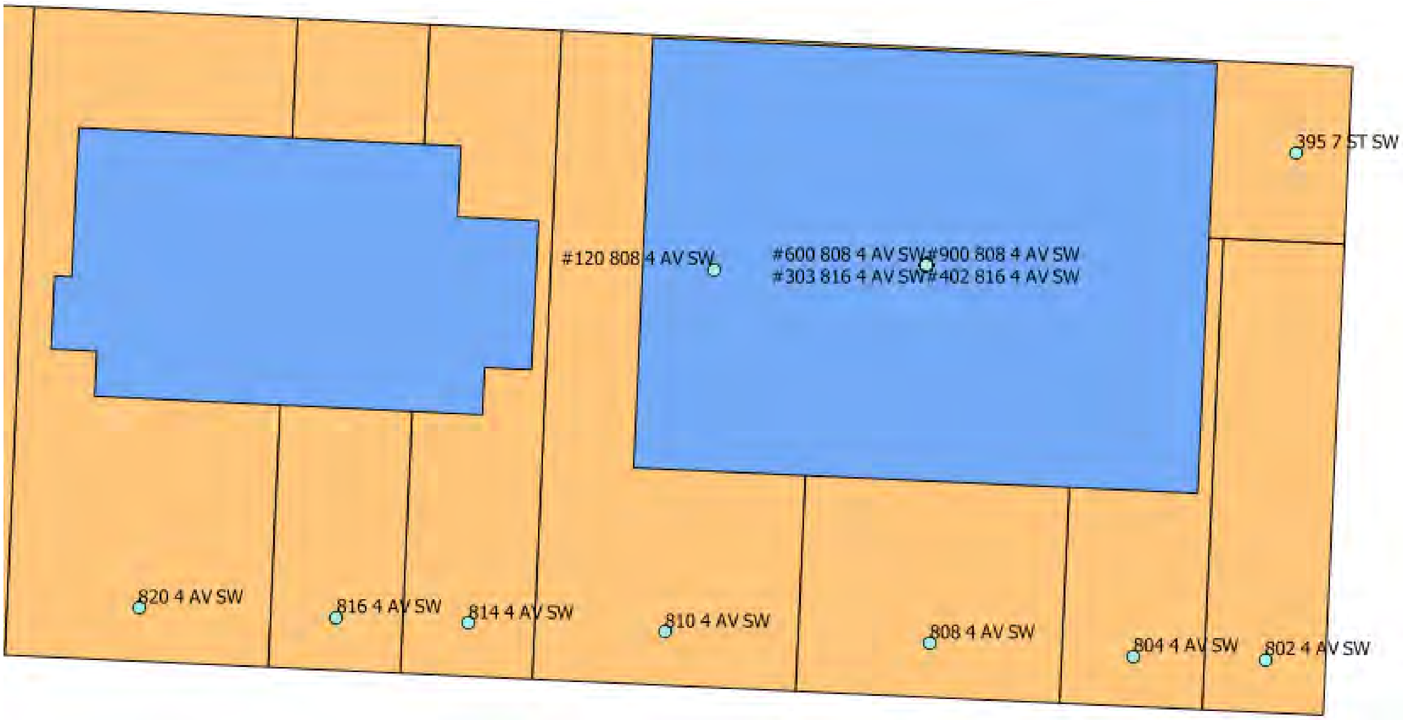
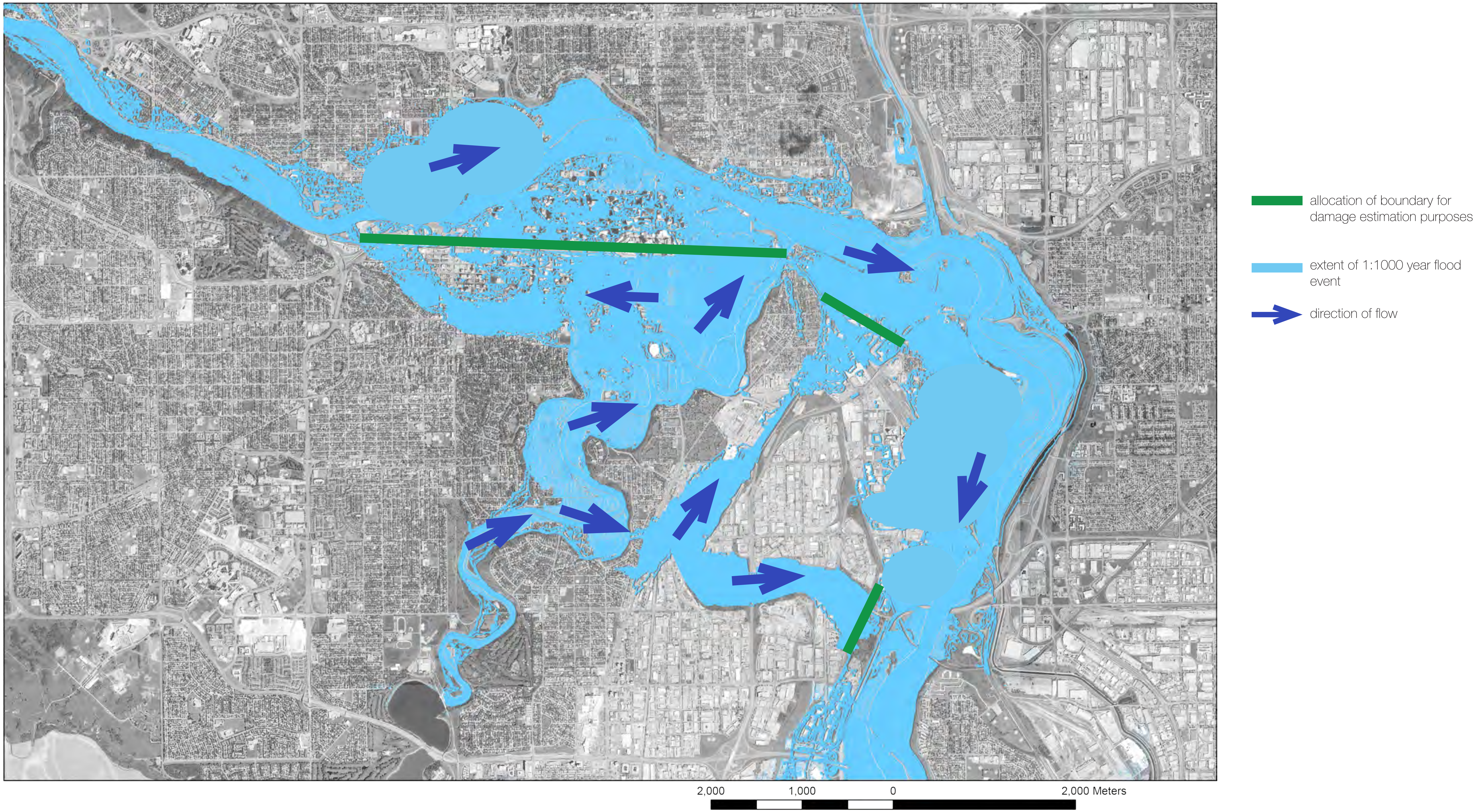


Exhibit 2.15 GE Tool in Use

Estimate of Flooding Attributed to Bow & Elbow River



2.5 Allocation of Flood Inundation Areas for Damage Estimation

Along the majority of the Bow and Elbow River reaches in Calgary, overland flooding is caused by the flood water either from the Bow River or the Elbow River respectively. However, along some of the river reaches (e.g., in and around the downtown areas as well as near the Bow and Elbow River confluence), the source of overland flood water can be a mixture of the Bow and Elbow River water, particularly during extreme flood events (e.g., 1,000 year flood).

Application of the flood damage model for evaluating some of the potential flood mitigation measures (e.g., upstream flood detention storage facility along the Elbow River) requires definition of the overland flood inundation areas attributed to one of the rivers (e.g., the Elbow River).

The existing hydraulic modelling results were obtained using the one-dimensional HEC-RAS model on the basis of simultaneous occurrence of the flood peak discharges in both rivers with the same return period. The following limitations of the existing hydraulic modelling results were considered in estimating the flood inundation areas attributed to one of the rivers where the river flood waters are mixed on the floodplains:

- Approximate definition of the flood inundation extents in large floodplain areas (e.g., downtown) during extreme flood events (e.g., 1,000 year flood);
- Approximate estimates of the overland flow directions and the boundaries of mixing of the flood waters from the two rivers; and
- No modelling results for the cases where flood peak discharges on the two rivers have different return periods (e.g., the return period of the flood flow in the Bow River may be 75 years when the 100 year flood peak discharge occurs in the Elbow River).

Consequently, estimation of the flood inundation areas attributed specifically to one of the rivers involved judgement and approximation. **Exhibit 2.16** presents the estimated boundary lines separating the flood inundation areas attributed to the Bow River or Elbow River for those areas where mixing of the river flood waters may occur. These boundary lines were used to attribute the flood inundation areas to either one of the rivers for the purpose of flood damage modelling.

2.6 Verification of HEC-RAS and GIS Tables

The 2014 Rapid Flood Damage Assessment Model (RFDAM) was designed to accommodate the traditional approach using the average flood depth between HEC-RAS sections for the computation of flood damages. GIS data are more accurate, detailed and comprehensive today. Although HEC-RAS continues to be the primary hydraulic model for flood mapping, there are two dimensional models available which provide 3D flood surfaces.

One objective of Task 2 was to verify if it was feasible to modify RFDAM so that it could work with 3D flood surfaces in addition to the traditional step approach. Because there was insufficient budget to apply a true two dimensional model to generate a 3D flood surface, Golder generated flood surfaces from the HEC-RAS sections including the surface levels of the inundation and spill areas. A ten metre TIN grid was created and saved as a GeoTIFF file for each return flood event.

Changes were required in the process of creating the flood input table which was designed for flood reaches between HEC-RAS sections. Instead of a reach between two sections with many buildings being flooded by the average flood depth, a unique flood depth was estimated for each building within the study limits for each return flood event. It was verified that this could be completed using QGIS and LibreCalc for both the HEC-RAS and GIS tables.

Exhibits 2.17 and 2.18 illustrate the existing and modified RFDAM protocols.

2.7 Discussion of RFDA Model Enhancements

A concern at the beginning of this study was the extent of the enhancement modifications that would be required to have RFDAM accommodate 3D flood surfaces. As it turns out RFDAM is flexible enough to accommodate the estimation of and inclusion in the digital input files. No additional code modifications are necessary for this component; however, it should be noted that the use of two dimensional 3D flood surfaces increases the data processing and computational times.

A second enhancement is the use of RFDAM for the computation of displacement and disruption costs. A new series of damage curves has been created and will be tested in Phase 2 of the study once community profiles have been generated. There may be some code modifications required to complete the process; however, at this time no major changes are anticipated.

Exhibit 2.17: Process for Creation of Flood and GIS Table Using the HEC-RAS Section Step Approach

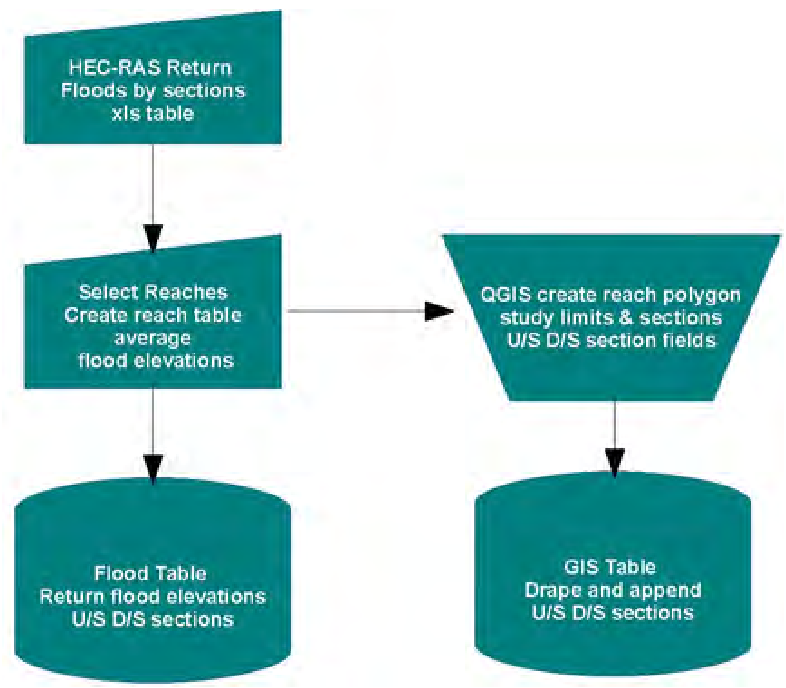
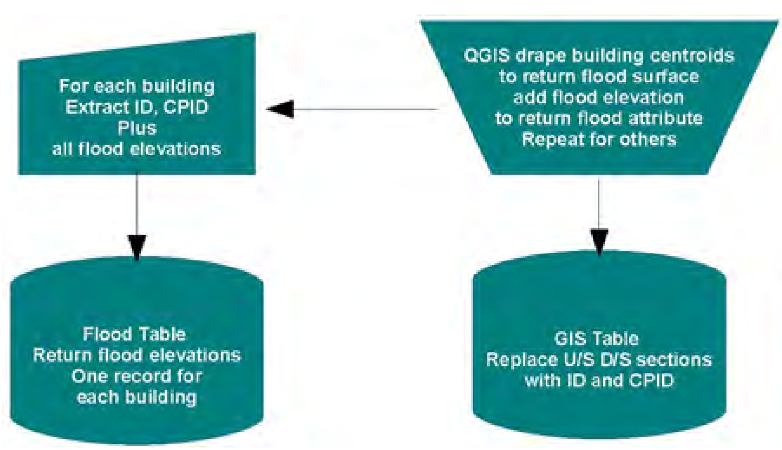


Exhibit 2.18: Process for Creation of Flood and GIS Table Using the 3D Flood Surface approach



GROUNDWATER FLOOD DAMAGE MODELLING

3

3 Groundwater Flood Damage Modelling

3.1 Introduction

Areas outside the surface flood inundation extents can be subjected to basement flooding due to sewer backup or groundwater seepage through basement cracks. Sewer backup can be caused by higher groundwater pressures in hydraulic connection with the fluid in the sanitary system (e.g. through leaks in sewer fittings or connectors) or the sewer may be hydraulically connected with surface water. Therefore, potential groundwater flood damage can be influenced by both surface and groundwater flood levels.

The Bow and Elbow River channels in Calgary are underlain by a permeable alluvial aquifer. The groundwater levels in the alluvial aquifer may rise as the river water levels rise during river floods. Modelling of groundwater flood levels is conducted in this study to generate the following information to support groundwater flood damage modelling:

- Definition of the maximum extents of the alluvial aquifer where potential groundwater flooding might occur as a result of rising river flood levels; and
- Estimation of maximum groundwater levels in the alluvial aquifer, which are caused by rising river flood levels.

Detailed documentation of the groundwater flood modelling conducted in this study is presented in Appendix C, which describes the basis, methodology, results, conclusions and recommendations. The information in Appendix C is summarized and highlighted in Sections 3.3 through 3.6, following a review of the 2104 groundwater flood damage estimation in Section 3.2.

3.2 Review of the 2014 Groundwater Flood Damage Estimation

3.2.1 Adjacent-To Areas

Areas outside the floodplain can be subjected to basement sewer backup flooding, primarily through seepage of floodwaters into the sanitary sewer system. To account for this potential flood damage, an adjacent-to area was delineated based on a distance of two dwelling units or ±75 m from the specified return period flood line (1:10, 1:20, 1:50, etc.). Essentially, with the sewer backup condition, basements with floor elevations lower than the floodwaters will automatically suffer damages. **Exhibit 3.1** depicts this relationship for the 1:100 year flood line.

The 2014 Calgary Flood Damage Study estimated average annual damages with the inclusion of sewer backup. As indicated, flooding was assumed for basements below the surface water level of the specific design flood. To assess the contribution of basement flooding to total damages and average annual damage, damages with and without the sewer backup condition were examined and are summarized in the accompanying exhibits (see **Exhibits 3.2, 3.3, 3.4 and 3.5**). As indicated, average annual damage with sewer backup for the Bow and Elbow Rivers combined was calculated at $84.4 million. Without the sewer backup condition, the average annual damages decreases to $64.8 million, resulting in average annual damages of $19.6 million related to basement damage. This constitutes some 23% of the total average annual damage.

Exhibit 3.1 - 'Adjacent - To' Area Definition Diagram

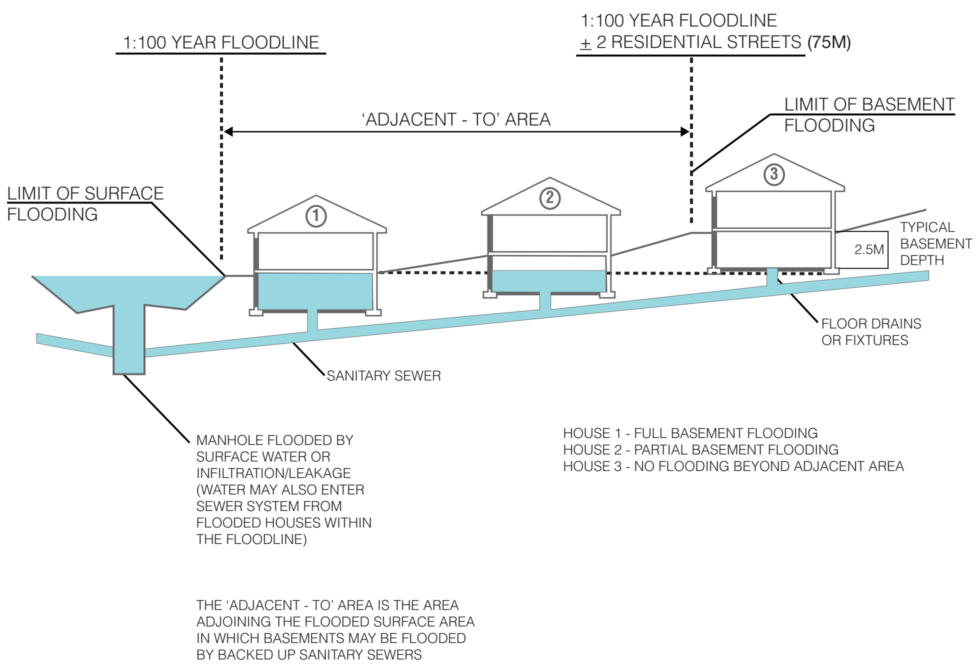


Exhibit 3.2 - Sewer Backup Portion of AAD

AAD With Sewer Backup	$84.4 million
AAD Without	$64.8 million
AAD from Sewer Backup	$19.6 million
% of Total AAD	23%

Exhibit 3.3 - Sewer Backup Amount by Return Frequency

	Return Frequency					
	20	**50**	**100**	**200**	**500**	**1000**
Sewer Backup Damages	$254,040,000	$291,814,000	$241,531,000	$173,850,000	$174,298,000	$158,661,000
% of Total Damages	82%	61%	31%	16%	11%	9%

Exhibit 3.4 - Flood Damages Probability Distribution, Bow and Elbow Rivers, No Sewer Backup

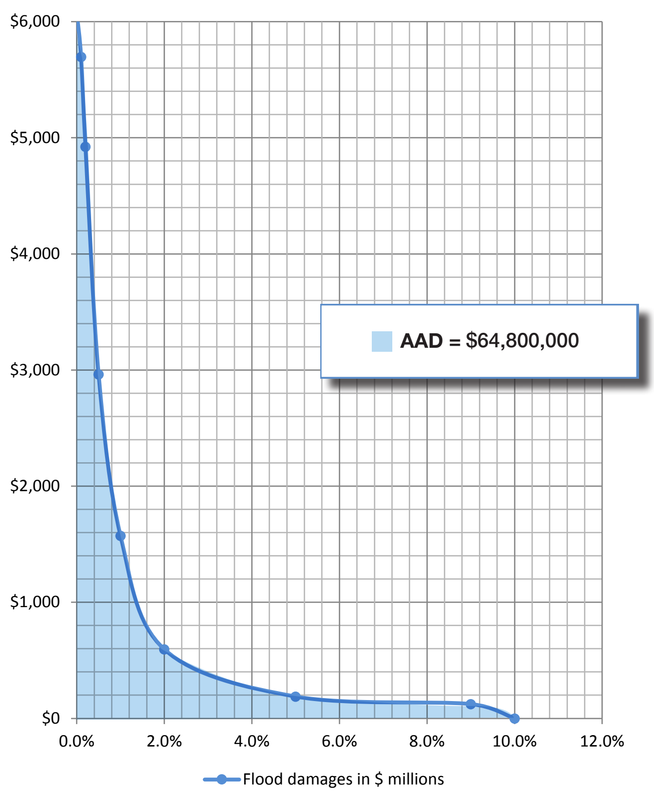
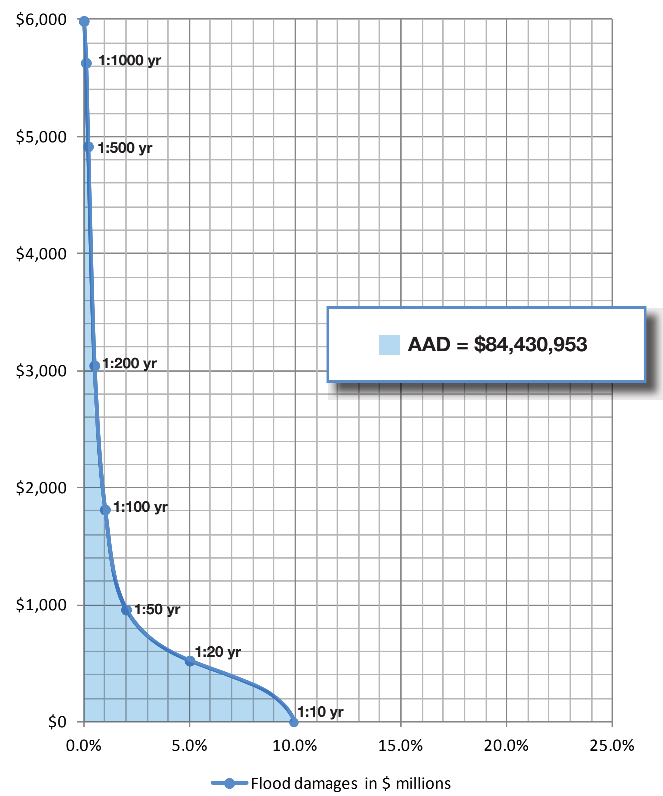


Exhibit 3.5 - Flood Damages Probability Distribution, Bow and Elbow Rivers, With Sewer Backup



3.3 Past Studies on Groundwater Flooding in Calgary

There are a number of past studies on groundwater flooding in Calgary (see Appendix C). These studies indicate that groundwater flooding occurs when the water levels within alluvial aquifer sediments connected to the river increase due to hydraulic gradients induced by high river water levels. The high groundwater tables may affect basements, underground parking garages and other constructed areas below grade, either directly through structural cracks and openings, or via artificial pathways created by water/stormwater/wastewater subsurface infrastructure, causing damage to infrastructure and private property.

Abboud et al. (2014) conducted door-to-door surveys of homes affected by groundwater flooding in June 2013 and conducted aerial photographic analyses to differentiate the flood damages caused by surface water and groundwater. The survey results for the Elbow River indicated that approximately 88% of the damaged homes were initially flooded by groundwater and later by overland flow, and 12% flooded exclusively by groundwater.

3.4 Alluvial Aquifer Characterization

According to Moran (1986), during the early Pleistocene, the Bow River cut its level near the current valley floor leaving buried gravel deposits beneath the glacial till. Later, during the glaciation melting, the Elbow and Bow Rivers cut their valleys near the current levels depositing and re-eroding gravels. The Paleocene Paskapoo Formation bedrock beneath the river-connected alluvial aquifer underlying the Bow and Elbow Rivers in Calgary consists of local and widespread weathered sandstones, siltstones, shales and mudstones as defined by Meyboom (1961).

The thickness of alluvial sediment was estimated using a constraint mapping procedure whereby the krigging interpolated surface of the Paskapoo Formation and overlying localized accumulations of glacial till was subtracted from the ground surface topography. **Exhibit 3.6** shows the approximate alluvial aquifer thickness contours and the extents of the aquifer. The thickness of alluvial deposits varies up to 20 m, from the edges to the center of the alluvial plain.

3.5 Groundwater Flow Modeling

A limited number of representative geological cross sections were selected, including two cross sections along the Bow River, and one cross section along the Elbow River (see **Exhibit 3.7**). A two-dimensional (2D) groundwater flow program (i.e., MODFLOW) was used to develop the groundwater models at these cross sections. The river water level hydrographs estimated at these cross sections were used as hydraulic head boundary condition for the groundwater flow modelling. Three selected flood events (e.g., 20-, 100- and 500-year floods) were modelled.

The groundwater modelling results were analyzed in terms of the delta H versus distance for the simulated flood events. Delta H represents the difference between the simulated peak of the groundwater level hydrographs at various locations and the peak levels of the Bow/Elbow River flood hydrographs. The distance for all delta H plots was calculated from the edge of surface flooding.

The estimated delta H values are influenced by the hydraulic conductivities of the various hydrostratigraphic units. The pressure transient effect in relatively low conductive materials (e.g. silt or clay) is delayed and muted resulting in a larger delta H value. Conversely, the pressure transient effect in relatively high conductive materials (e.g., sand or gravel) is more immediate and unimpeded resulting in a smaller delta H value. The modelling results are illustrated in **Exhibit 3.8 and Exhibit 3.9.**

3.6 Groundwater Modelling Input for Flood Damage Estimation

In consideration of the overall characteristics of the alluvial aquifer and limitations of the cross-sectional information for representing the entire aquifer geology, a consistent Delta H versus Distance relationship is selected for application throughout the study domain based on the 20-, 100-, and 500-year flood curves shown in **Exhibit 3.10**. This relationship was used to estimate or approximate the maximum groundwater table rise within the alluvial aquifer for the various flood return periods.

Exhibit 3.11 illustrates the estimated alluvial aquifer extent, and surface and ground water levels for the 100-year flood event. The groundwater levels estimated for the entire study are approximate because of the following:

- A limited number (i.e. three) of geological cross sections are used for setting up the groundwater flow models;
- The selected cross sections are indicative of the typical alluvial aquifer configurations, but they are not expected to capture the spatial variability of the alluvial aquifer throughout the study area;
- The selected cross sections are indicative of the typical types of the alluvial sediments, but they are not expected to capture the lithological variability in the alluvial aquifer throughout the study area;
- The hydraulic parameter values and water levels simulated in the models have not been calibrated using field measurements;
- The 2D approach is inherently approximate as the actual groundwater flow conditions are three dimensional; and
- The Delta H versus Distance relationships for return periods other than 20, 100 and 500 years are not based on groundwater modelling results but rather estimated from the model results developed for the 20-, 100- and 500-year floods.

3.7 Comparison with the 2013 Survey Data

After the June 2013 flood, Professor Ryan's University of Calgary researcher team conducted a survey in a number of communities in Calgary. Part of the survey involved determining the type of flooding and estimating the maximum water elevation in basements. Since the June 2013 floods on the Bow and Elbow Rivers are estimated to have return periods of between 50 and 100 years (closer to 100 years), the survey data are used to compare with the modelled groundwater elevations as shown in **Exhibit 3.12**.

Exhibit 3.12 shows that the 100-year flood results provide a reasonable match between the modelled and surveyed groundwater elevations. Although there are discrepancies between the modelled and surveyed groundwater elevations, the match is considered reasonable in consideration of the limitations and approximations of the simplified modelling approach. Filling in data gaps and a more refined modelling approach (discussed below) would improve the match between modelled and surveyed groundwater elevations.

The results of the University of Calgary 2013 Calgary flood survey data indicate approximately 7% of the homes were resistant to groundwater flooding (or had "impermeable" basements). A range of between 4% and 10% to estimate the number of homes resistant to groundwater flooding is suggested for use in the Flood Damage Model.

3.8 Conclusions and Recommendations

3.8.1 Conclusions

The following conclusions are drawn based on the analysis and results of the groundwater flow modelling conducted in this study:

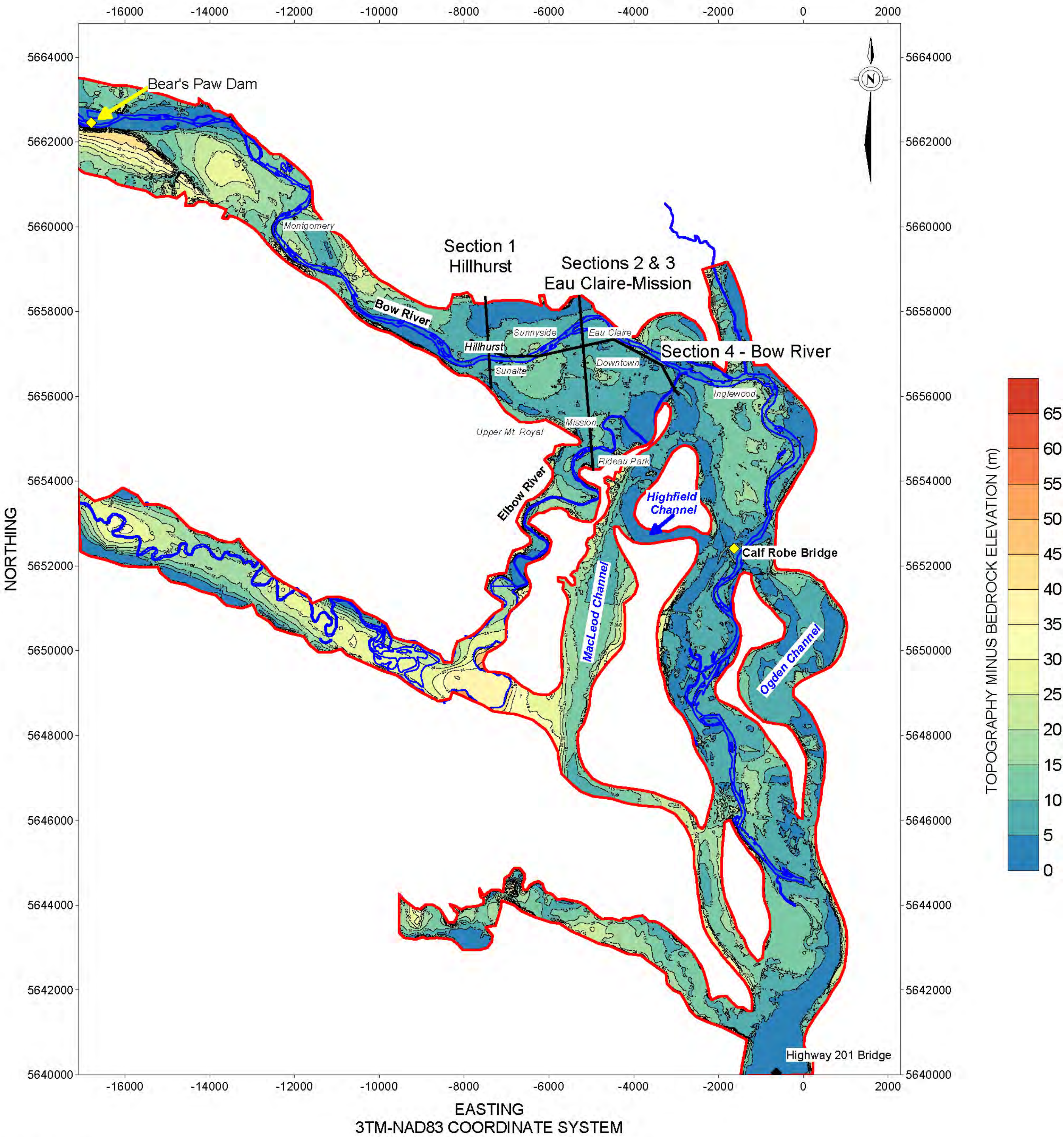
- The estimated maximum extents of the alluvial aquifer and maximum groundwater flood levels provided an improved basis for updating the groundwater flood damage model.
- The simulated groundwater levels are most sensitive to the hydraulic conductivity values. The level of certainty associated with the groundwater modelling results will be increased if the appropriate groundwater monitoring data are used for calibrating the models.
- A limited number of geological cross sections were used for the groundwater flow modelling. They represent typical geological conditions of the alluvial aquifer only. They are not expected to capture the spatial variability of the alluvial aquifer hydraulic conditions and lithologic variability throughout the entire study area.
- The groundwater flow analysis was completed using a two-dimensional vertical cross-section approach. While simpler to implement, and therefore less costly, the approach implicitly assumes flow into and out of the cross-section is negligible. Even if the alluvial aquifer is completely homogenous (which it is not) the variable river stage elevations along different reaches of the river will cause some component of flow into or out of any vertical cross-section perpendicular to the river. The relative importance of the three-dimensional nature of the groundwater flow dynamics can only be assessed with a three-dimensional groundwater flow model.
- The modelled groundwater flood levels are approximate because of the limited number of geological cross sections used, only three flood return periods were modelled, and the 2D modelling approach (as opposed to 3D modelling approach).

3.8.2 Recommendations

The following recommendations are made:

- The estimated extents of the alluvial aquifer should be used in the groundwater flood damage model to define where potential groundwater flooding might occur as a result of rising river flood levels.
- The modelled maximum groundwater levels in the alluvial aquifer should be used to estimate maximum groundwater levels throughout the study area. The modelled groundwater levels for the various flood return periods should be used in the Flood Damage Model.
- A range of 4% and 10% to estimate the number of homes resistant to groundwater flooding should be used in the Flood Damage Model.
- A number of data gaps and opportunities to address these gaps are identified in this study. In its future efforts, The City should consider the following opportunities to improve the understanding, characterization and modelling of the groundwater conditions in the study area:
  - detailed geologic mapping using the ESAR database;
  - constraint mapping for estimating groundwater flood risk areas;
  - additional groundwater monitoring; and
  - additional groundwater flow modelling including application of a 3D groundwater flow model based on detailed geologic mapping.

Thickness Distribution of the Alluvial Sediments



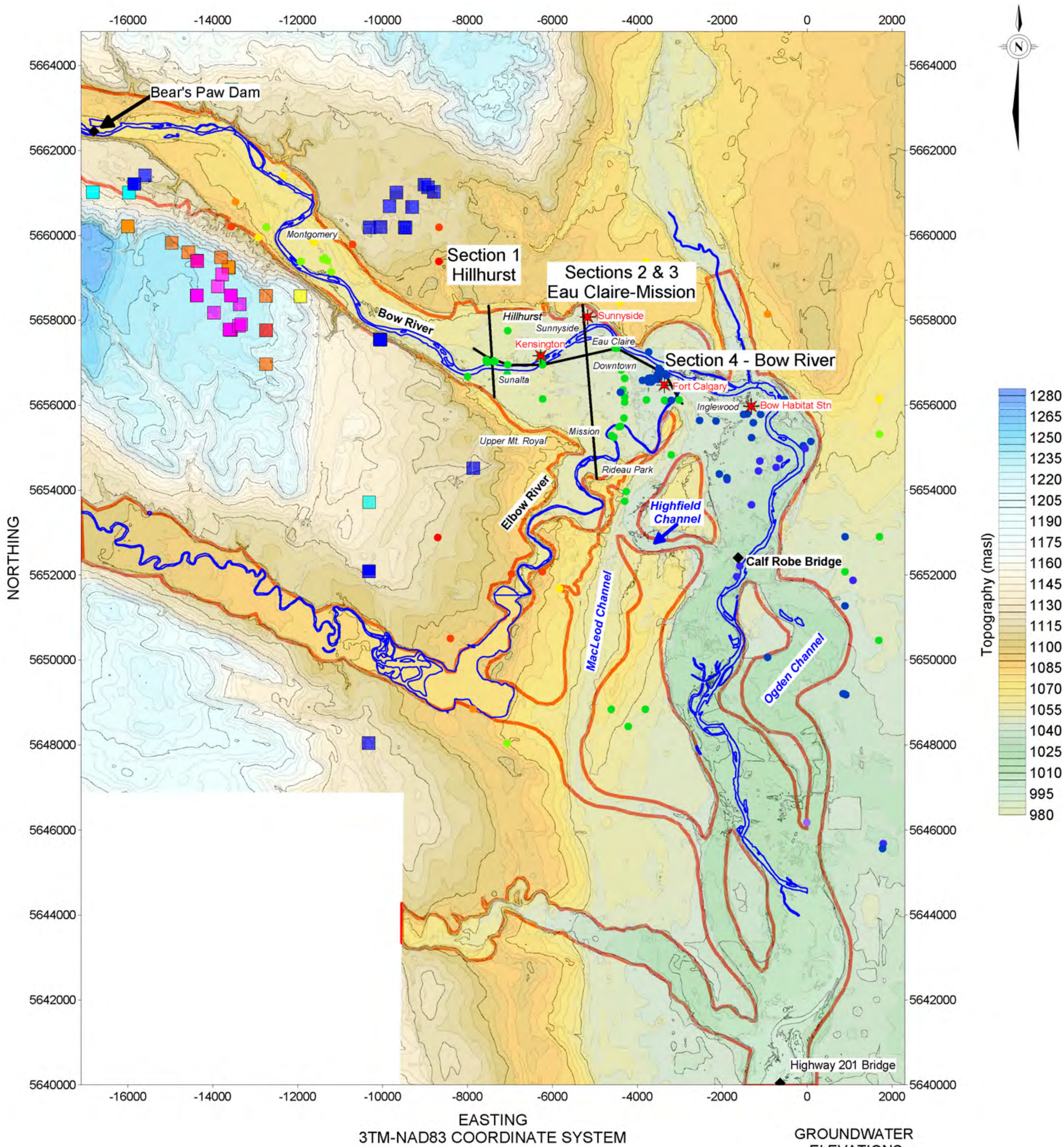
LEGEND

- Alluvial Aquifer Boundary
- River or Stream
- Cross-Section

REFERENCES

1. BEDROCK ELEVATION BASED ON MORAN (1986) AND MAYBOOM (1961) WITH ADDITIONAL DATA FROM ALBERTA ENVIRONMENT AND PARKS, THE CITY OF CALGARY, AND THE ESAR DATABASE.
2. ALLUVIAL AQUIFER BOUNDARY BASED ON MEYBOOM (1961).
3. LIDAR DEM OBTAINED FROM THE CITY OF CALGARY. ADDITIONAL DEM FROM ALTALIS 1:20.000 DEM © GOVERNMENT OF ALBERTA 2014. ALL RIGHTS RESERVED.

Measured Groundwater Elevations 1993 to 2012 and Locations of 2015 Seepage Study Monitoring Wells



LEGEND

- Alluvial Aquifer Boundary
- River or Stream
- Cross-Section
- 2015 Bow River Seepage Study Well

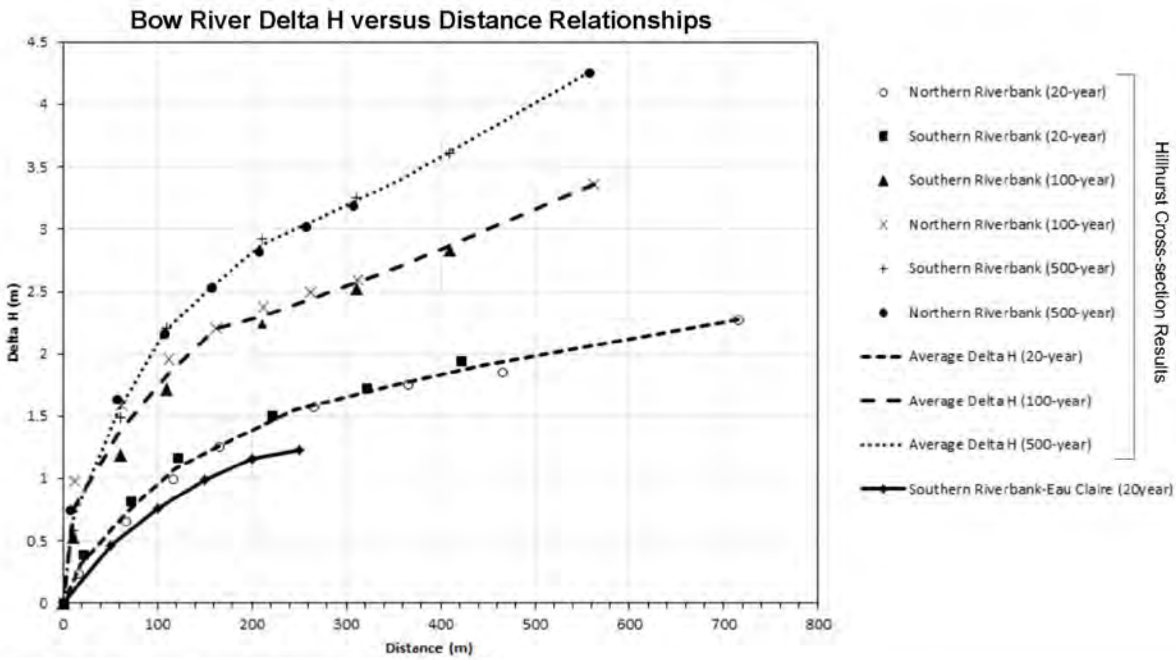
GROUNDWATER ELEVATIONS MEASURED BETWEEN 1993 AND 2012 (masl)

- 1010 to 1020
- 1020 to 1030
- 1030 to 1040
- 1040 to 1050
- 1050 to 1060
- 1060 to 1070
- 1070 to 1080
- 1080 to 1090
- 1090 to 1100
- 1100 to 1120
- 1120 to 1140
- 1140 to 1160
- 1160 to 1180
- 1180 to 1200
- 1200 to 1220
- 1220 to 1235

REFERENCES

1. ALLUVIAL AQUIFER BOUNDARY BASED ON MEYBOOM (1961).
2. GROUNDWATER ELEVATION DATA FROM ALBERTA ENVIRONMENT AND PARKS AND ESAR DATABASES AND DATA PROVIDED BY THE CITY OF CALGARY. MEASUREMENT DATES VARY OVER A PERIOD OF 20 YEARS (1993 TO 2012).

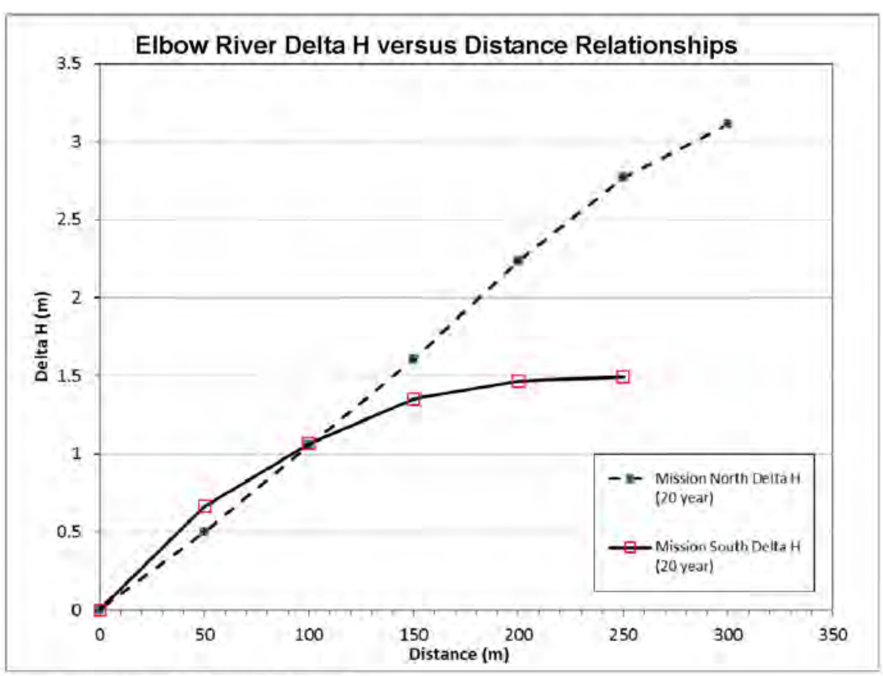
Exhibit 3.8 - Groundwater Flow Modelling



Notes:

1. Delta H represents the difference between the simulated peak of the groundwater hydrograph and the peak of the simulated (HEC-RAS) Bow River hydrograph.
2. Greater delta H values represent a greater capacity of the alluvial aquifer to attenuate the groundwater flooding and vice versa.
3. The X-axis is the distance from the edge of surface water inundation and not the distance from the edge of the pre-flood river channel. Distances on this plot, therefore, are not the same as those shown on Figure 13 since the edge of surface inundation varies between the cross-sections north and south of the river and for different return periods.

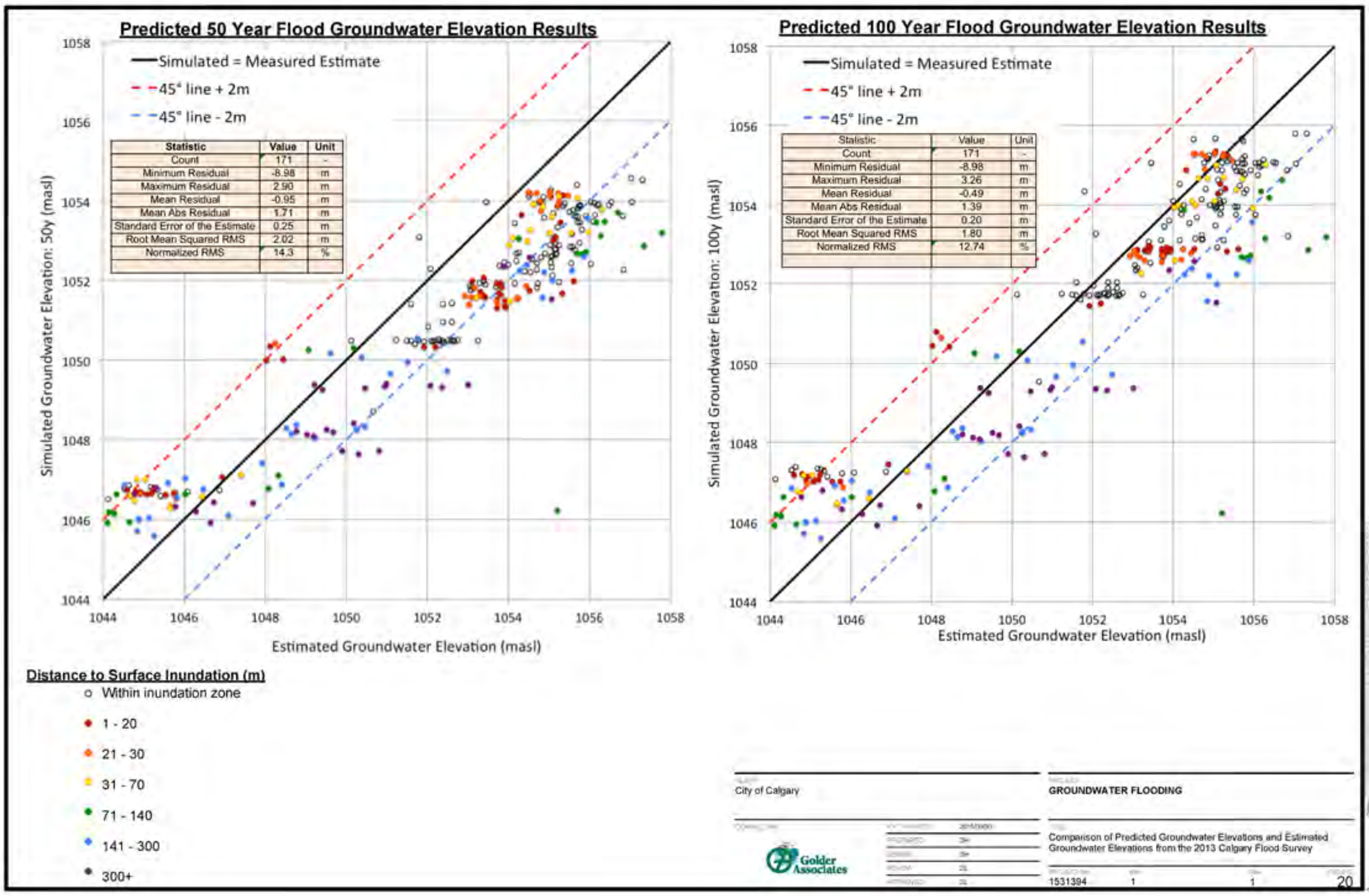
Exhibit 3.9 - Groundwater Flow Modelling



Notes:

1. Delta H represents the difference between the simulated peak of the groundwater hydrograph and the peak of the simulated (HEC-RAS) Elbow River hydrograph.
2. Greater delta H values represent a greater capacity of the alluvial aquifer to attenuate the groundwater flooding and vice versa.
3. The X-axis is the distance from the edge of surface water inundation and not the distance from the edge of the pre-flood river channel. Distances on this plot, therefore, are not the same as those shown on Figure 15 since the edge of surface inundation varies between the cross-sections north and south of the river and for different return periods.

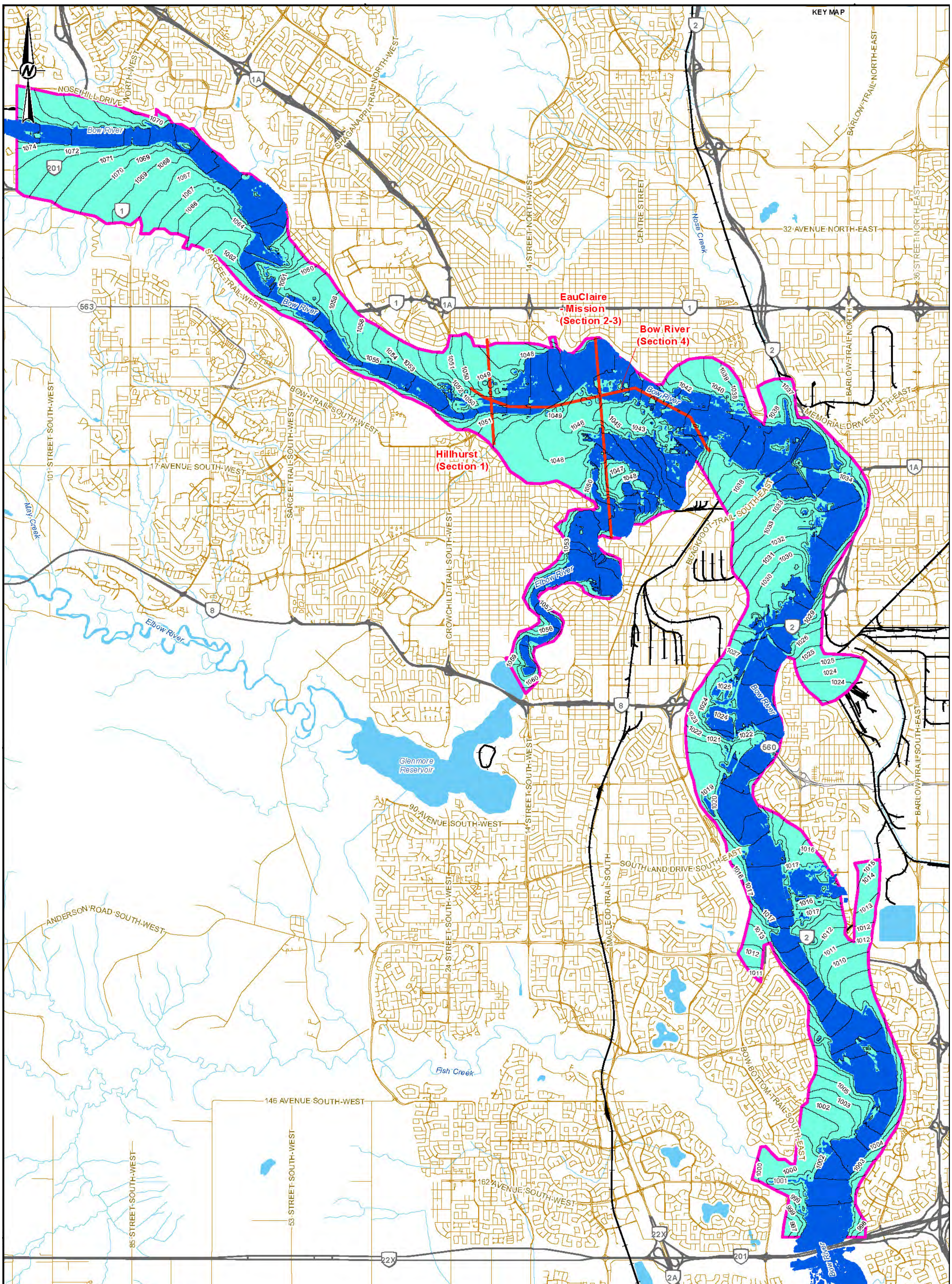
Exhibit 3.10 - Predicted Flood Groundwater Elevation Results



Statistic	Value	Unit
Count	171	-
Minimum Residual	-8.98	m
Maximum Residual	2.90	m
Mean Residual	-0.95	m
Mean Abs Residual	1.71	m
Standard Error of the Estimate	0.25	m
Root Mean Squared RMS	2.02	m
Normalized RMS	14.3	%

Statistic	Value	Unit
Count	171	-
Minimum Residual	-8.98	m
Maximum Residual	3.26	m
Mean Residual	-0.49	m
Mean Abs Residual	1.39	m
Standard Error of the Estimate	0.20	m
Root Mean Squared RMS	1.80	m
Normalized RMS	12.74	%

Alluvial Aquifer, Flood Inundation Extent and Modelled Ground Water Elevations for 100-Year Flood



LEGEND

- RAILROAD
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- 1m GROUNDWATER CONTOUR
- GROUND WATER CROSS SECTION
- 100-YEAR INUNDATION EXTENT
- MODELLING DOMAIN

0 2,000 4,000

1:75,000 METRES

REFERENCE(S)

1. ROADS OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
2. HYDROGRAPHY © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED.

CLIENT
CITY OF CALGARY

PROJECT
FLOOD MITIGATION OPTIONS ASSESSMENT

TRIPLE BOTTOM LINE MODEL ENHANCEMENTS

4

4 Triple Bottom Line Model Enhancements

4.1 Introduction

The benefit-cost approach to disaster mitigation assessments theoretically requires a complete enumeration of all gains/ benefits and losses/costs associated with a project.[5] In practice, however, it is not possible to even identify all potential impacts much less quantify and monetize them.

The convergence of social, environmental, and economic issues with disaster mitigation under the umbrella of climate change adaptation has stimulated the field of risk assessment. Indirect impacts are receiving greater attention and, in some cases, shown to be as significant as direct costs.[6] Despite this, there remains very limited useful data upon which to assess indirect or intangible damages and no consensus on methodologies.[7] This leaves a tremendous gap between current theory and practice as well as great disparity within practice.

A major reason there are no practical examples of studies that reflect the most robust and detailed disaster loss estimate theory may be that it is necessarily location-specific. Thus the great time and cost make it prohibitive and the necessary data may be unattainable.

Due to these limitations, arriving at the 'total cost' of a flood by summing estimates for all the components is not feasible. Recognizing this, past studies have utilized a percentage of direct property damage to estimate indirect damages. The values are arrived at by reviewing available literature and other assessments which included relevant quantification of the various components.

The City of Calgary has a Triple Bottom Line (TBL) policy framework to incorporate economic, social, and environmental impacts into all decisions and actions. To meet its TBL objectives, the City has requested a more explicit assessment of these impacts. This section details the research findings and enhanced estimation methodology for the following damage components:

- Intangible Damages (Health and Environment)
- Business Disruption
- Residential Displacement
- Traffic Disruption
- Waste Disposal
- Flood Fighting and Emergency Response and Recovery
- Infrastructure Damages

4.2 Intangible Damages

Intangible damages are those for which there is no market value. Human health impacts and damage to the environment all have intangible aspects.

Quantification of these impacts for a flood event is challenging. Floods do not lend themselves well to controlled studies that connect population and flood characteristics to outcomes.[8] The intangible human impact of flooding is highly dependent on variables beyond the flood characteristics including an individual's prior health, income, family/community support, preparedness/experience, and a host of other social indicators or behaviours.

Once the risk of an intangible impact is estimated, there are several ways it may be included in a mitigation assessment. This sub-section reviews the potential public health and environmental impacts, possible methods of evaluation, and the new damage calculation method employed in this study.

4.2.1 Public Health

The intangible impacts on people include mortality, injury, disease or infection, and psychological or mental health. For the purposes of this study, a flood-related impact is defined as one that would not have occurred in the absence of the flood event. It may be a direct result of the waters, such as drowning, or otherwise induced by the event, such as an accident during cleanup activities or post-flood depression and sleep disorders.

Epidemiological evidence on the health impacts of flooding are surprisingly lacking.[9,10] As such, there is limited data upon which predictive models can be built and the few that exist are related to the risk to life.[11]

4.2.1.1 Mortality

Globally, floods are the leading cause of natural disaster fatalities but the factors that contribute to flood-related mortality are diverse and multifaceted.[12] It is common sense that depth and velocity are factors that contribute to the risk of death. However, estimating the probability of an individual drowning in a certain depth and velocity of water is only of use when it is expected that the individual will be in the water.

After Hurricane Katrina, the relationship between flood characteristics and mortality were studied. The characteristics of each fatality were analyzed along with post-flood simulations of depth, velocity, and rise rate. As could be expected, mortality increased with water depth as well as velocity (more victims adjacent to levy breaches). Overall, the functions produced an average mortality associated with this type of flooding to be 1.2% of the exposed population.[13]

5. Ganderton, Philip T. 'Benefit-cost analysis' of disaster mitigation: Application as a policy and decision-making tool. Springer Netherlands, 2005.

6.

7. Gall, Melanie, and Sönke Kreft. "Measuring What Matters? A Suitability Analysis of Loss and Damage Databases for the Climate Change Convention Process." Loss and Damage Working paper (2013).

8. Tapsell, Sue. Developing a conceptual model of flood impacts upon human health. Middlesex University, 2009.

9. Ahern, Kovats, Wilkinson, Few, Matthies. Global Health Impacts of Floods: Epidemiologic Evidence. Epidemiologic Reviews, 2005; 27: 36-46.

10. Alderman KB, Turner LR, Tong S. Floods and human health: A systematic review. Environment International, 2012; 47: 37-47.

11. Hammond, Michael J., et al. "Urban flood impact assessment: A state-of-the-art review." Urban Water Journal 12.1 (2015): 14-29.

12. Jonkman, S. N., and J. K. Vrijling. "Loss of life due to floods." Journal of Flood Risk Management 1.1 (2008): 43-56..

13. Jonkman SN, Maaskant B, Boyd E, Levitan ML. Loss of Life Caused by the Flooding of New Orleans After Hurricane Katrina: Analysis of the Relationship Between Flood characteristics and Mortality. Risk Analysis, 2009; 29(5): 676-698.

There have been several other methods of varying complexity developed or suggested in the past to estimate the potential loss of life due to flood events using these factors. Most of the models reviewed for this study rely on available data from past events to create statistical mortality fractions. These models are generally designed for large scale floods such as defense failure in low lying coastal regions or catastrophic dam failures. In these cases, it is expected that a large number of people will be exposed and a uniform mortality function can reasonably be applied.

In 2006, a Flood Risk to People model was developed in the UK by the Department for Environment, Food, and Rural Affairs (DEFRA) and the Environment Agency[14]. This model is different in that it calculates fatalities as a function of injuries, which are estimated from characteristics of the flood (depth, velocity, debris, etc.), location (housing types, warning, etc.), and population (age, disabled, etc.).

The European Council's FLOODsite initiative used the Risk to People model as a base for modelling flood risks in a wider European context. While the model had produced reasonable estimates for UK case studies, it was found that the floods in Continental Europe differ in several ways and that the model would be erratic, often severely over-predicting fatalities and injuries. The higher hazard ratings in Europe, where floods are often faster, deeper, and more extensive than in the UK required a new model.

Despite creating the largest dataset of flood mortality in Europe to date, it was very difficult to attribute conditions to the deaths. Through various amendments, the correlation of the model to known events was improved. However, it was acknowledged that such a model cannot fully explain the situation leading to death and it would not be accurate enough to apply across a wider range of events in Continental Europe.

Instead of a mathematical function, it was proposed that a 'threshold' approach to the assessment of risk to life be taken. While still conceptually similar to the Risk to People model, the aim is to develop a matrix of variables to assist in the assessment of the risk. Instead of a quantity of deaths, this model allows for an assessment of risk that includes low, moderate, high, and extreme values. It is created by combining the hazard and exposure thresholds with the mitigation factors such as warning time.

In the development of the U.S. Hazus Flood model, casualty data was analyzed with the aim of incorporating estimates into the model. This information was primarily drowning deaths and usable information on injuries was not available. A fatality model for drowning deaths was proposed, but its implementation deferred by the Flood Model Oversight Committee. It was deemed that the methodologies available were based on too few events and there was too much uncertainty attributing characteristics to the deaths and no information on injuries.[15]

Depth and velocity are only characteristics of the hazard. Risk is a combination of hazard, exposure, and vulnerability¬ – and this is very evident in New Orleans. The entire city was under evacuation orders and while it is estimated that 80-90% of residents were evacuated, it is believed that over 70,000 remained. It has been widely illustrated that the evacuation was a self-help operation that left behind the poor, infirm, and elderly.[16]

The Katrina mortality study focused on the deaths within the flooded areas and exposed to flood waters. In addition to those, 19% of the recovered fatalities were outside the flooded area and likely died due to the deterioration of the public health situation, with possible causes being lack of medical services or supplies, stress-induced heart attacks or strokes, and violence. Similarly, 17% of the fatalities within the flooded area were recovered from locations such as public shelters, hospitals, or nursing homes. Furthermore, a substantial number of victims recovered from residences inside the flooded area were found in attics or floors that were not flooded. Age was a significant factor in New Orleans; 85% of the victims of whom age is known were over 50, compared to 25% of the pre-Katrina population.

Clearly deaths and injuries result not only from the physical characteristics of the event but are also determined by the prevailing socioeconomic and health conditions of the community.[17] While there may be models that incorporate the stability of humans in a given depth and velocity of floodwater, the question is really how many people are in the water and why.

Hurricane Katrina does not fit the historic pattern of American flood mortality. Unlike the poorer parts of the world, mortality in wealthier locations is often associated with males in vehicles. People in vehicles represent more than 50% of all flood-related deaths in both the United States and Australia, with some estimates as high as 75%. In most cases, the driver underestimates the risk and enters the flood.

14. DEFRA/Environment Agency. Flood Risk to People, Phase 2. 2006. Available at: http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=12016

15. Hazus 2.1 Flood Model Technical Manual

16. See, for example: Quigley WP. Thirteen Ways of Looking at Katrina: Human and Civil Rights Left Behind Again (2007); Bullard R, Wright B. Race, Place, and Environmental Justice after Hurricane Katrina (2009); Brunkard J, Namulanda MS, Ratard R. Hurricane Katrina Deaths, Louisiana, 2005 (2008); Curtis A, Mills JW, Leitner M. Katrina and vulnerability: The Geography of Stress (2007);

17. Jonkman S, Kelman I. An analysis of the causes and circumstances of flood disaster deaths. Disasters, 2005; 29(1): 75-97.

In developed nations, large coastal or sudden flash flooding is responsible for the majority of deaths. Slower-rising floods have much lower mortality rates. Drowning is still a leading cause of death but the numbers are relatively low and in many low-mortality events the cause of death is often a risk-taking behavior or a unique scenario that occurs. With small numbers of fatalities being recorded, fortuitous or unfortunate circumstances leading to more or fewer fatalities may greatly impact upon the total recorded numbers of deaths.[18] Consider the following instances of death that occurred as a result of flooding:

- In the two known studies where flood victims' blood-alcohol levels were measured (Texas 2001 and Puerto Rico 1992), the majority (29 of 39, or 74%) of victims had been drinking.
- Flooding in the Georgian capital of Tbilisi in June of 2015 damaged the zoo and a man was killed by an escaped tiger. [19]
- During a 1991 flood in Texas, a fatality in a non-flooded mobile home resulted from fire ants being flushed out of the ground by the flood, which subsequently invaded the victim's house and caused a short circuit in the electrical wiring that started a fire that killed the occupant.[20]
- During the 2015 flooding, a children's hospital in Dallas said that it experienced 12 times the usual number of snake bite cases as the snakes sought refuge in dwellings.[21]
- During 2015 Oklahoma flooding, highway patrol troopers fatally shot a man who authorities say attacked officers as they arrived to help with a vehicle trapped in floodwaters.

Studies of flood deaths in Europe and North America frequently state that with the lack of details, reported drowning deaths may include unknown health conditions or behaviours in combination with the flood waters and a substantial proportion of the flood related deaths is believed to be attributable to unnecessary risk-taking behaviour. Furthermore, most of the deadly floods occur in combination with other phenomena such as hurricane winds.

The 2013 floods claimed one victim within the City of Calgary. An 83-year-old woman drowned inside her apartment in the 100 block of 25 Avenue S.W. The apartment was partially below-grade and thus would have been quickly inundated as soon as surface water reached the building. Police had been to the apartment as part of the evacuation effort and she indicated that she planned to leave, didn't have mobility issues, and there were no indications that she needed help. Reports suggest that the victim stayed because she didn't want to leave her cat behind. This incident is consistent with studies that have found that those drowning in their own homes are largely the elderly[22], and that people with pets may be less likely to evacuate.[23]

The evidence from various flood events analyzed around the world indicates that warning time, ability to seek shelter, individual behaviour, and maintenance of public order and health systems are key determinants of the mortality risk. Calgary has a state-of-the-art emergency management system with sophisticated monitoring and warning mechanisms in place that provides people with sufficient time to evacuate at-risk areas. In 2013, agencies caring for vulnerable residents were provided with additional emergency response support to ensure evacuation and continued care.

The methods or models available to predict mortality are calibrated based on past events with similar characteristics. The risk to life is therefore thought to be very low, as evidenced during the 2013 floods, and the level of awareness and preparedness is higher now than before. It is likely reasonable to associate the flow rate or flood characteristics, such as the number of below ground units, flooded in 2013 to one death and apply this to the other return periods modeled.

4.2.1.2 Injury

Injuries can occur before, during and after the flood, throughout the cleanup phase and also during repopulation. The most common flood-related nonfatal injuries are sprains, cuts, falls, or being struck by debris. Little is known about the frequency and characteristics of nonfatal flood injuries, as they are mostly not reported or identified as flood related.[22] There is no known source information on flood-related physical injuries following the 2013 flood and only two studies were found to report such data, one from the Midwest United States and the other from France.

In 1993 the Mississippi and Missouri rivers and tributaries flooded, affecting 84 of the 115 counties in Missouri. It is estimated that around 60,000 persons were displaced. A public health surveillance system was initiated to monitor emergency shelters and hospitals. Of the 250 reported injuries, the most common were sprains/strains (34%), lacerations (24%), "other" (11%), and abrasions/contusions (11%).[24] The number of reported injuries equates to 0.4% of the estimated 60,000 people displaced. However, this monitoring was limited to shelters and emergency rooms and would not account for unreported, self-treated or clinic and private physician-treated injuries.

18. FLOODsite T10 Risk to Life Model, p. 45
19. BBC News. Georgia Floods: Escaped Tiger Kills Man. 2015-06-17. Available at: http://www.bbc.com/news/world-europe-33166224
20. Jonkman SN, Kelman I. An analysis of the causes and circumstances of flood disaster deaths. Disasters, 2005; 29(1): 75-97.
21. NBCDFW.com. Snake bites increasing with more north Texas rain. 2015-05-29. Available at http://www.nbcdfw.com/news/local/Snake-Bites-Increasing-with-More-North-Texas-Rain-305544181.html
22. Ahern, Kovats, Wilkinson, Few, Matthies. Global Health Impacts of Floods: Epidemiologic Evidence. Epidemiologic Reviews, 2005; 27: 36-46.
23. Heath SE, Kass PH, Beck AM, Glickman LT. Human and Pet-related Risk Factors for Household Evacuation Failure During a Natural Disaster. American Journal of Epidemiology, 2001; 153(7): 659-665.
24. United States Centers for Disease Control and Prevention (CDC). Morbidity Surveillance Following the Midwest Flood – Missouri, 1993. Morbidity and Mortality Weekly Report, 1993; 42(41): 797-798.

In 1988 a sudden flash flood caused massive destruction in the region of Nîmes, France. The flood damaged the homes of 45,000 people and destroyed more than 1,100 vehicles. However, only three severe injuries and nine deaths were reported. Post-flood surveillance of the population's health was conducted with a community survey. This survey also collected information about factors that may have limited the number of deaths and the reactions of the population to the disaster. This flood occurred rapidly and the vast majority of people (93%) were in their homes when they realized they were in danger and 30% required rescuing. Despite this, only six percent of all respondents reported suffering mild injuries with 70% of these occurring during the impact. The low number of health problems and injuries during the post-impact phase is attributed to the response of trained personnel and the distribution of gloves and boots to others.[25]

Other reported post-flood injuries are largely a result of incorrect use of lighting, heating, or generating equipment, resulting in exposure to carbon monoxide, gasoline, or lamp oil.[26] In North Dakota, the use of gasoline powered pressure washers to clean basements resulted in carbon monoxide poisoning of 33 individuals[27] whom experienced nausea, fatigue, dizziness and headache.

Direct injury from floodwaters is far less likely in Calgary than flash flood events. As discussed in relation to mortality risk, it is expected that there is sufficient time to seek shelter. The majority of injuries are assumed to occur during the cleanup and restoration phases.

During the 2013 floods, Calgary maintained protective services with the assistance of firefighters from Edmonton and military task forces whom also helped safely pump out water from facilities and homes and conducted rapid damage assessments. This support would have reduced the number of residents involved in dangerous activities. Re-entry to impacted areas was coordinated by CEMA after they had been deemed safe. Community Support Centres were established and provided residents with information on assessing safety, gloves, masks, flood restoration documents, and other equipment.

The overall risk of injury due to flooding in Calgary is considered to be very low and could largely be mitigated through increased awareness. For quantification purposes, an estimate of 1% of the population in the flooded areas or involved in cleanup activities is considered reasonable.

4.2.1.3 Disease, Infection, & Exposure

As previously noted, there is a weak epidemiological evidence base to assess the health impacts of flooding, particularly for disease and infection in wealthy urban areas. Many of the recognized health concerns are primarily due to widespread infrastructure damage, significant population displacement, lack of clean drinking water, and low public health capacity leading to overcrowding, poor sanitation, and lack of medical care.[28] Additionally, many pathogens are endemic to specific locations or climates. Disease outbreak or a breakdown of the public health situation is not anticipated in Calgary.

Flooding of industrial and agricultural facilities can contaminate waters with chemicals. Additionally, flood waters may act as a trigger, releasing and carrying pollutants that were previously present in the environment. Flood waters have been found to contain contaminates associated with cancer, cardiovascular, gastrointestinal, kidney, liver, and neurological diseases.[29] However, multiple studies have failed to find a relationship between flood events and population morbidity.

Compared to most cities, Calgary is situated in a less-developed watershed with relatively little industrial or intensive agricultural uses upstream. However, flooding of sewers and sewage treatment facilities can pollute floodwaters and potentially cause bacterial infections if ingested and there is the potential for mould growth in damp buildings after a flood. The probability of both these risks are highly dependent on a number of factors, including individual behaviour, building construction, restoration methods, and prior health of individuals.

Elevated levels of fecal indicator bacteria and microbial pathogens have been found in flood waters and in sediments left in the urban environment after floods.[30] Studies of contaminated water impacts have been conducted for combined sewer overflows. Combined sewer overflow water will likely have higher concentrations than overland river flooding but may be comparable to water within flood basements.

Health risks associated with exposure to contaminated flood water were recently researched in Utrecht, a large low-lying Dutch city with frequent combined system flooding. The study simulated accidental ingestion for a pedestrian being splashed by a passing car and a child playing in the water. The risk of gastrointestinal illness was found to be 0.00005 for cryptosporidium, 0.01 for giardia, and 0.2 for campylobacter.[31] These microbes can cause nausea, diarrhoea, and vomiting. The values are in the range of other similar exposure studies and the authors suggest that public awareness is the most effective way to control exposure.

25. Duclos P, Vidonne O, Beuf P, Perray P, Stoebner A. Flash flood disaster – Nimes, France, 1988. European Journal of Epidemiology, 1991; 7(4): 365-371.

26.

27. Daley, W. Randolph, Larry Shireley, and Rod Gilmore. "A flood-related outbreak of carbon monoxide poisoning—Grand Forks, North Dakota." The Journal of emergency medicine 21.3 (2001): 249-253.

28. Alderman KB, Turner LR, Tong S. Floods and human health: A systematic review. Environment International, 2012; 47: 37-47.

29.

30. Abraham, Wolf-Rainer, and Dirk F. Wenderoth. "Fate of facultative pathogenic microorganisms during and after the flood of the Elbe and Mulde rivers in August 2002." Acta hydrochimica et hydrobiologica 33.5 (2005): 449-454.

31. Ten Veldhuis, J. A. E., et al. "Microbial risks associated with exposure to pathogens in contaminated urban flood water." Water research 44.9 (2010): 2910-2918.

Other studies have attempted to quantify the increased incidence of gastrointestinal infection after a major flood but the findings vary greatly, from no increase to an odds ratio of 6.2.[32] The correlation between flood characteristics and reported illness isn't clear but the security of drinking water is assumed to be important. In one case where no illnesses were reported, a public awareness campaign was noted.

It is widely acknowledged that floods create conditions for mould growth and that mould can impact health through respiratory infection or reaction to the toxins it produces. However, the relationship between flooding and health effects of mould are inconclusive or contradictory.

Two Canadian studies using surveys found that the prevalence of all respiratory symptoms were consistently higher in homes with reported moulds or dampness. In adults, the odds ratio for upper and lower respiratory symptoms was 1.5 and 1.62[33]. For children, the odds ratio ranged from 1.32 for bronchitis to 1.89 for cough.[34] The self-reported dampness was from a variety of causes and would include persistent issues such as leaks or condensation and may not be relevant to a single flood event and restoration.

Other reports have concluded that adverse effects following floods have not been found among healthy adults and only among susceptible persons, such as asthmatics and children. Studies after hurricanes Katrina and Rita also failed to show fungal infections among residents whose homes were flooded. A series of reports linked previously water-damaged homes with pulmonary hemorrhage in infants, leading to great concern and publicity. However, more recently the CDC and others found shortcomings in these investigations and there is currently little evidence for causation.

A recent study from the UK proposed a model to predict microbial contamination after major urban flooding based on the content of the water (amount of pathogens), and the properties of the contaminating microbes (survival times, pathways, etc.), building materials (drying times, absorption rates, nutrients, etc.), and the environment (temperature, humidity, etc.).[35] Rather than provide a prediction of human infection risk, such research provides insight into the importance of cleaning and drying buildings after a flood and the relative severity of risk among building types and locations.

The longer-term impacts of floods on mortality is complex and not well understood. In general, the exacerbation of existing non-communicable conditions (cardiovascular, cancer, diabetes, etc.) presents the greatest risk. There are very few studies that examine the longer-term effects of floods on an entire population. One found a 50 percent increase in all-cause deaths in the year after the 1969 floods in Bristol, UK, while other studies have revealed no such effects.

Compared to many of the locations that have been studied, Calgary has a very high level of public sanitation, watershed purity, and building restoration standards. The City maintained the supply of clean drinking water throughout the 2013 flood due to a recently upgraded treatment process. The Bonnybrook wastewater treatment plant was inundated and significantly damaged, allowing untreated wastewater to flow into the Bow River. It took several weeks to repair the facility and bring wastewater discharge within compliance. However, no impact on downstream drinking water supplies was reported.

As noted in relation to injuries, residents were provided with safety equipment and information about safe restoration of homes. Anecdotally, the removal of damaged materials and drying of buildings was completed with much more urgency and community support in 2013 than previous flood events.[36] Also, the observed restoration processes tended to err on the side of caution. For example, drywall was removed for the entire wall rather than just to the flood water level to hasten the drying process. The City maintained an inspection process for re-occupancy despite the number of flooded buildings.

Considering the available information on illness or infection due to urban flooding and the local context, it is believed that the overall risk level is very low in Calgary. Awareness and proper recovery and restoration procedures are likely the key determinants of physical health impacts due to flooding. Accurate quantification of mould impacts is not feasible and the risk of gastrointestinal illness from the Dutch study could be employed to quantify the impact of exposure to sewage contamination.

4.2.1.4 Mental Health / Quality of Life

There is a growing recognition that the psychological effects of a flood event on residents can be significant. Mental health studies relating to disasters come mainly from developed or industrialised countries where evidence suggests that mental health impacts are the most significant effect on households and communities.[37]

32. Fewtrell, L. J., D. Kay, and R. Ashley. "Flooding and Health an evaluation of the health impacts of urban pluvial flooding in the UK." Health impact assessment for sustainable water management (2008).

33. Dales, Robert E., Richard Burnett, and Harry Zwanenburg. "Adverse Health Effects Among Adults Exposed to Home Dampness and Molds1, 2." (1991).

34. Dales, Robert E., et al. "Respiratory health effects of home dampness and molds among Canadian children." American journal of epidemiology 134.2 (1991): 196-203.

35. Taylor, Jonathon, et al. "Flood management: prediction of microbial contamination in large-scale floods in urban environments." Environment international 37.5 (2011): 1019-1029.

36. Sandink, Dan. "Diary of Urban Flooding" Canadian Underwriter. December 2007: 62-63.

37. Tapsell, Sue. Developing a conceptual model of flood impacts upon human health. Middlesex University, 2009.

Calgary Counselling Centre provided counselling services for 523 Calgarians affected by the 2013 floods.[38] The number of referrals peaked well after the flood as people transitioned from dealing with immediate needs to trying to get back to normal. The Government of Alberta committed to an increase of $50 million in mental health supports. They reported an unspecified increase in access to mental health services in affected communities, including a significant increase in access to crisis lines, increase in dispensed prescriptions for mental health drugs, and an increase in noticeable anxiety and depression among school children.[39] Several social agencies have attributed a rise in domestic violence during the year after the floods to the stress of the event.[40]

One major psychological impact of disasters is post-traumatic stress disorder (PTSD). A 2005 global review of studies published from 1980 to 2003 found that the prevalence of PTSD after a disaster is 30-40% for direct victims, 10-20% among rescue workers, and 5-10% in the general population.[41] Flood-specific incidences among victims have been reported at 19% following the 1997 California floods and 22% following the 1993 Midwest Floods.[42] A Canadian study utilized telephone surveys four months after the floods in Saguenay Quebec. The prevalence of PTSD was almost 20% in the flooded population, compared to 3.8% in a control group.[43]

Exhibit 4.1 - Subjective Rating of Severity on Households

Effect	Mean Rating*
Getting house back to normal	7.8
Stress of flood	7.1
Having to leave home	7.0
Worry about flooding	6.6
Damage to replaceables	6.5
Damage to house itself	6.4
Irreplaceable item loss	5.6
Builder problems	4.9
Insurance problems	4.7
Loss of or distress to pets	4.6
Loss of house value	4.6
Effects on health	4.5
Overall effect	7.3

*1(no effect) to 10 (extremely serious effect)

Symptoms beyond those defined as PTSD are very common. A number of studies conducted in the UK across multiple flood events found the following self-reported psychological health effects:

- anxiety (e.g. during heavy rainfall);
- increased stress levels;
- sleeping problems;
- depression;
- panic attacks;
- flashbacks to flood;
- difficulty concentrating on everyday tasks;
- lethargy/lack of energy;
- feelings of isolation;
- increased use of alcohol or other drugs;
- nightmares;
- anger/tantrums;
- mood swings/bad moods;
- increased tensions in relationships; and
- thoughts of suicide.

Perhaps the most comprehensive study of the intangible health impacts of flooding was conducted in 2002 by the UK Department for Environment, Food, and Rural Affairs and the Environmental Agency.[44] 1,510 households were interviewed in 30 locations across England and Wales that had been subject to flooding in the past five years. The study included households that had been flooded (983) or were at risk of flooding (527). The level of flooding previously experienced was relatively severe with a mean depth of 55 cm in the main room of the house.

Questionnaires were developed using proven, standardized diagnostic scales to assess respondents' health at the time of the interview and at the time when the flooding was the most severe for them. This was done to indicate the long and short term effects of flooding. The number of people who had been flooded meeting the threshold of suffering from some degree of mental health problems was 64% at the worst time (generally within three months of the event) and 25% at the time of assessment. This compares to only 10% meeting the threshold among at-risk households. 72% of all respondents reported experiencing some form of psychological effects as a result of the flooding with many citing stress and anxiety during heavy rains.

In subjective terms, acknowledged health effects were rated among the lesser effects of flooding on the households but, in contrast, the stress of the flood event itself features as one of the most serious effects, along with all the problems and discomfort whilst trying to get the house back to normal and having to leave home. **Exhibit 4.1** summarizes the subjective rating of severity of the effects of flooding.

38. Calgary Counselling Centre media release June 17 2015. http://www.calgarycounselling.com/wp-content/uploads/2015/06/Calgary-Counselling-Centre-Flood-Research_June-17_2015.pdf
39. http://alberta.ca/release.cfm?xID=3523164740483-D80A-5566-F819A0C841FEDDEA
40. CTV News June 25 2014. Increased domestic violence and stress in the aftermath of last year's Alberta floods. http://www.ctvnews.ca/canada/increased-domestic-violence-and-stress-in-aftermath-of-last-year-s-alberta-floods-1.1885861
41. Galea, Sandro, Arijit Nandi, and David Vlahov. "The epidemiology of post-traumatic stress disorder after disasters." Epidemiologic reviews 27.1 (2005): 78-91.
42. Ahern, Mike, et al. "Global health impacts of floods: epidemiologic evidence." Epidemiologic reviews 27.1 (2005): 36-46.
43. Auger, Caroline, et al. "[Post-traumatic stress disorder. After the flood in Saguenay]." Canadian Family Physician 46.12 (2000): 2420-2427.
44. Floyd, P., and S. Tunstall. "The appraisal of human-related intangible impacts of flooding." Report of Project FD (2005).

These subjective ratings are consistent with recent literature suggesting that the intangible impacts can have a more severe effect on a household than the direct tangible flood damage itself. It is generally agreed that mental health is broader than a lack of mental disorders and includes people's general well-being; which is clearly effected by flooding in many ways. Several studies have reported that the financial losses were often less important than the loss of personal items and the stress of evacuation.

People have an emotional attachment to their homes and it is often perceived as a static, safe, and personal space. Flooding transgresses the boundaries of home and can be a shock that undermines an individual's sense of self and place.37 When flood victims were unaware of the risk prior to flooding, they can be left with an extreme sense of insecurity and a new relationship with their community and home as places once familiar are now unfamiliar and fearful. [45]

A household's recovery process and the intangible effects are often invisible and behind closed doors. If flooding only impacts a minority of residents, a feeling of isolation can occur and divide a community between 'insiders' and 'outsiders'. Qualitative studies have shown that feeling a lack of community or official support and understanding after a flood can have detrimental health and social effects.

On the other hand, because major floods usually do affect many people, the experience of support from family, community, or other social groups can have a positive impacts. A major review of the mental health impacts from flooding by the UK Health Protection Agency noted that the idea of collective psychosocial resilience is new and requires further research but it is clear that the experience varies greatly by community.

Some of the UK research reports a community-wide tendency for people to feel less positive about their surroundings and a sense of community breakdown with some residents stating that "nobody helped" or even "I wish I never heard of [this town]".This is in stark contrast to the overall reaction and display of resiliency after the floods in Calgary. Thousands of people volunteered to assist residents with the cleanup and recovery. Social and traditional media was filled with feel-good stories about help and appreciation, including that towards municipal staff and officials.

A sense of increased pride was apparent city-wide and also within affected communities. Residents rallied around events occurring shortly after the flood such as Canada Day and the Stampede. Communities with an already strong sense of identity, such as Bowness or Sunnyside, showed signs of a strengthening rather than breakdown. Despite the obvious negative impacts on many and tendency for research to thus far focus on the negatives at a household level, Calgary has provided strong evidence to support the notion of social resilience at the community level.

45. Tapsell, Sue M., and Sylvia M. Tunstall. ""I wish I'd never heard of Banbury": The relationship between 'place' and the health impacts from flooding." Health & place 14.2 (2008): 133-154.

Outside support is one of the many aspects of social vulnerability. Social vulnerability is widely recognized as a major factor that will influence or modify the impact of floods on individuals. It refers to the degree to which some people, or classes of people, are more susceptible to, or suffer a greater degree of harm from, some hazards than do other people.[46] Overall, this is of particular concern when the most vulnerable are those who are at risk of not meeting basic needs, such as in developing countries, or when there is a great disparity of resources and segregation within the population, such as New Orleans. For mental health impacts, there are a number of indicators that have been shown to influence the risk for distress.

Personality and previous flood experiences are strongly correlated to vulnerability but not easily measured. The same is true for pre-existing conditions, trust in authorities or access to decision making, and awareness/preparedness. Census based assumptions can, however, be made in relation to some of the other influential indicators including gender, age, household type, and socio-economic status.

Floods have been shown to have more adverse impacts on women than men, including increased incidences of PTSD. It is suggested that women, regardless of employment status, take a greater role, both materially and emotionally, in management of the household leading to greater distress. Another similar theory is that during and after a disaster, women are commonly relegated to the private domain and closer to the disruption while men take on more decision-making roles.[47] Traditional roles also appear to influence the impact on men. Dealing with a disaster can change self-perception from the identity as protector of the family to helplessness.

Age is a commonly cited risk factor for psychological impacts but the literature is inconsistent as to how. A clear distinction between physical and mental impacts is not always made but is important when assessing risk to children and the elderly. Many suggest that there is a greater psychological impact on the elderly. The reasons are unclear but may be related to length of time in their residence. Others suggest that children are also at greater risk of distress but again, they point to related factors such as increased sensitivity to other family members' stress. Several comprehensive reviews conclude that middle aged adults are most at risk because they have greater stress and burdens before the disaster strikes and they assume even greater obligations afterwards.[48] It is even suggested that rather than viewing older adults as an at-risk group, they could be viewed as a resource with greater life experiences to draw from, experience in local issues or strategies, a wide network of friends and family, and personal strength drawn from many years of life.

Taken together, evidence on gender and age-related impacts indicates that family structure is likely the best indicator of demographic factors that may contribute to a more or less severe mental health impact of flooding. While a family can provide an individual with support, families with children at home would generally experience the highest level of distress. Currently, there are several ongoing studies on the impact of the 2013 floods on families, children, and youth. These studies are part of the Alberta Resilient Communities project and should prove a valuable resource for future assessments.

Socio-economic status, including income and education level, has been found to affect disaster resiliency significantly. Lower socio-economic status is consistently associated with greater post-disaster distress. Financial stress is a major factor impacting people's psychological health and well-being following flooding. High-income earners may be more likely to consider themselves 'self-insured' because they could afford to replace things straight away, pay extra bills, and have more choice about their alternative accommodation.[49] Of particular concern for the economically vulnerable is the potential for floods to throw households into a poverty trap in which the initial set-back creates further obstacles for recovery in an amplifying feedback loop.

Of course flood characteristics and post-flood variables will also be major determinants of the impact to residents' well-being. Damage to or loss of valued community amenities such as schools, local retail, or parks and natural areas can impact quality of life. Post flood issues such as dealing with builders, insurers, or governments can either ease or exacerbate the stress of recovery.

It is important to note that mitigation of health impacts, especially mental health, is not merely a matter of protection from floodwaters. The factors that contribute to these impacts are significantly affected by preparedness and support. Thus the most efficient mitigation may be social supports rather than structural options.

4.2.2 Environment

Flooding is a natural phenomenon and where it regularly occurs it is an essential part of structuring and maintaining a riverine ecosystem. The removal of sediment from a streambed can provide new spawning areas for fish and the eventual deposit of that sediment can restore fertility to the floodplain. Erosion of banks and the resulting entry of roots and trees into the river can also enhance habitats.

Alberta's cottonwoods are a good example of a species that has evolved to be heavily dependent upon the natural cycle of flooding in order to grow and thrive.[50] These trees require areas of bare, moist sediment deposits to either seed or asexually reproduce. High flood levels are necessary to create these conditions in a location far enough from the river for the tree to survive the more frequent floods before it matures.[51]

46. Messner, F. Evaluating flood damages: guidance and recommendations on principles and methods. Helmholz Unweltforschungszentrum (UFZ), 2007.

47. Fordham, Maureen H. "Making women visible in disasters: problematising the private domain." Disasters 22.2 (1998): 126-143.

48. Norris, F. H., et al. "Risk factors for adverse outcomes in natural and human-caused disasters: a review of the empirical literature." National Center for PTSD, USA (2004). Accessed at: http://www.georgiadisaster.info/MentalHealth/MH12%20ReactionsafterDisaster/Risk%20Factors.pdf

49. Joseph, Rotimi, David Proverbs, and Jessica Lamond. "Assessing the value of intangible benefits of property level flood risk adaptation (PLFRA) measures." Natural Hazards 79.2 (2015): 1275-1297.

50. Alberta Environment and Parks. http://esrd.alberta.ca/lands-forests/trees-plants/trees/western-plains-cottonwood.aspx

51. Scott, Michael L., Gregor T. Auble, and Jonathan M. Friedman. "Flood dependency of cottonwood establishment along the Missouri River, Montana, USA." Ecological Applications 7.2 (1997): 677-690.

On the other hand, the flooding of human development within the floodplain can have negative environmental impacts. Inundation of buildings and infrastructure can introduce contaminants into the river water and surrounding lands. Habitat can be lost when riverbank erosion is artificially prevented or reclaimed to protect adjacent human use.

4.2.2.1 Water Contamination

Urban runoff is a regular and significant source of water pollution, carrying contaminants from urban surfaces into the river. When the river exceeds its banks and floods buildings or other facilities, the water can pick up and distribute many more contaminants. Residential, industrial, and commercial buildings may contain products or waste that includes hydrocarbons, heavy metals, fertilizers, or other chemicals. These pollutants can harm fish, wildlife, and vegetation. They can also impact downstream users' drinking water supply or recreational uses of the river.

A detailed estimate of potential pollutants and their effects on the ecosystem is beyond the scope of this study but the ESRD conducted detailed ambient water quality testing of the Bow and Elbow rivers, sampling from July 2-5, 2013.[52] Contaminants of concern included human sewage, livestock manure, fuel from flooded vehicles, and leakage from facilities storing fuel, pesticides, fertilizers, and industrial chemicals.

E.coli and fecal coliforms were high downstream of Calgary, declining further downstream. This is most likely due to the failure of the Bonnybrook treatment facility. The Elbow River had low values. The levels downstream on the Bow River exceeded Canadian Council of Ministers of the Environment guidelines for irrigation and contact recreation. No Giardia, Cryptosporidium, or fecal material of cow origin were detected.

Nutrient levels were within guidelines for aquatic life, contact recreation, livestock watering, and irrigation. Total dissolved solids and electrical conductivity were within irrigation use guidelines. Some metals exceeded the Protection of Aquatic Life chronic guidelines. These were mostly in particulate form and less available for exposure to organisms. The guidelines are for chronic exposure and although subsequent sampling is not yet available, acute exposure during the flood is of less concern. No pesticides exceeded guidelines and were within normal range. Organics, including hydrocarbons, were found to increase downstream to Medicine Hat but these values were below the guidelines for protection of aquatic life.

No information regarding post-flood contaminate levels in the soil as a result of sediment deposits was found. The impact of acute contamination on users of the water for irrigation and recreation is likely to be minimal because major flooding typically occurs during the wettest part of the year when the river is consistently high. During this time, there is normally no recreational use, such as fishing, and irrigation is not needed.

4.2.2.2 Habitat Loss

River bank erosion is a part of the natural process of sediment transport in a river, particularly during large floods. However, in an urban setting, some of the riverbanks are stabilized or reclaimed to protect urban infrastructure or buildings. Erosion protection projects typically involves the placement of rocks in the river to stabilize the bank. The surface may then be reclaimed and landscaped. The construction of such artificial banks disrupts the natural habitat of river life.

Under the conditions of the federal Fisheries Act, disruption of habitat requires the provision of funds for offsetting measures. On-site measures may include design and implementation of fish habitat features as part of the project while off-site measures could be the enhancement of other existing habitats or the creation of new habitat. Since these provisions are intended to offset the loss incurred, the associated costs are considered to represent a monetization of the original impact.

4.2.3 Evaluation Techniques

While it is understood that intangible damages from flooding can be significant and fundamentally alter the results of an assessment, there are no fully accepted and institutionalized methods for assigning them values. There is now a large body of work on statistical value of social and environmental goods but applying these to flood events remains problematic and controversial. An overview of the methods to evaluate intangible impact in non-monetary and monetary terms is provided below.

4.2.3.1 Non-Monetary Evaluation

Besides the extreme lack of reliable data, some agencies, such as the Red Cross, believe placing a monetary value on well-being or life itself is incompatible with their principles.[53] Other reasons for not quantifying or monetizing intangible impacts may include:[54]

- considering all the costs in a single economic assessment is considered to be too challenging and resource consuming;
- a one-dimensional result is not considered to be acceptable by a decision maker, especially when ethical implications are strong;
- to estimate the total cost could lead to the justification of every adaptation investment in a cost-benefit analysis context.

52. Alberta ESRD. Flood Recovery – Detailed Ambient Water quality Report, July 19, 2013

53. Vorhies, Francis. The economics of investing in disaster risk reduction. Working paper based on a review of the current literature commissioned by UNISDR. Geneva: Secretariat to the UN International Strategy for Disaster Reduction, 2012.

54. Balbi, S., et al. "The total cost of hydrological disasters: Reviewing the economic valuation methodologies and conceptualizing a framework for comprehensive cost assessments." KULTURisk Rep. 1.4, FP7-ENV-2010 (2011).

Exhibit 4.2 - Scoring Matrix

FLOODPLAIN MANAGEMENT ALTERNATIVES — SCORING MATRIX			IMPLEMENTATION AND INFORMATION REQUIREMENTS		OBJECTIVES RELATED TO FLOOD LOSSES				SOCIAL, ECONOMIC, POLITICAL WELL-BEING					
		COST TO FLOODPLAIN USER (RATED DIRECT HIGH SCORE TO INDIRECT LOW SCORE)	RELATIVE COMPLEXITY OF INSTITUTIONAL IMPLEMENTATION	DATA REQUIREMENTS	REDUCES PRESENT LOSSES	PREVENTS FUTURE LOSSES	PREVENTS FRAUD AND VICTIMIZATION	REDUCES RISKS (SAFETY AND ECONOMIC)	PROMOTES THE ORDERLY AND EFFICIENT DEVELOPMENT OF WATER AND LAND USE RESOURCES	MINIMIZES PUBLIC HEALTH DANGER FROM MALFUNCTIONING WATER SUPPLY & WASTE DISPOSAL SYSTEMS	ENVIRONMENTAL IMPACT	FLEXIBILITY FOR INTEGRATION WITH OTHER MEASURES	TOTAL SCORE	RANK
CATEGORY	MEASURE / WEIGHT	3	2	2	3	3	1	3	3	2	2	2		
MEASURES TO MODIFY THE FLOOD	STRUCTURAL FLOOD CONTROL	1 / 3	3 / 6	2 / 4	3 / 9	2 / 6	0 / 0	2 / 6	2 / 6	1 / 2	1 / 2	2 / 4	48	3
	WATERSHED TREATMENT	2 / 6	2 / 4	1 / 2	1 / 3	2 / 6	0 / 0	1 / 3	2 / 6	1 / 2	2 / 4	2 / 4	40	5
	METEOROLOGICAL MODIFICATION	0 / 0	1 / 2	0 / 0	0 / 0	1 / 3	0 / 0	1 / 3	1 / 3	1 / 2	1 / 2	1 / 2	17	10
MEASURES TO MODIFY THE DAMAGE SUSCEPTIBILITY	FLOODPROOFING	3 / 9	2 / 4	1 / 2	3 / 9	3 / 9	1 / 1	2 / 6	2 / 6	2 / 4	1 / 2	3 / 6	58	1
	FLOOD PLAIN REGULATIONS	1 / 3	1 / 2	1 / 2	0 / 0	3 / 9	3 / 3	2 / 6	3 / 9	3 / 6	3 / 6	3 / 6	52	2
	URBAN RENEWAL AND RELOCATION	1 / 3	1 / 2	2 / 4	1 / 3	2 / 6	0 / 0	2 / 6	2 / 6	2 / 4	2 / 4	2 / 4	42	4
	FORECASTING WARNING AND EMERG. MEAS.	1 / 3	2 / 4	1 / 2	2 / 6	2 / 6	0 / 0	2 / 6	1 / 3	1 / 2	0 / 0	2 / 4	36	6
MEASURES TO MODIFY THE LOSS BURDEN	FLOOD INSURANCE	2 / 6	1 / 2	1 / 2	0 / 0	0 / 0	1 / 1	3 / 9	1 / 3	0 / 0	0 / 0	2 / 4	27	8
	RELIEF/REHABILITATION	1 / 3	2 / 4	2 / 4	0 / 0	0 / 0	0 / 0	1 / 3	0 / 0	0 / 0	0 / 0	2 / 4	18	9
	TAX WRITE-OFFS	1 / 3	1 / 2	2 / 4	0 / 0	0 / 0	0 / 0	1 / 3	0 / 0	0 / 0	0 / 0	2 / 4	16	11
	PROTECTION FROM LOOTING	2 / 6	3 / 6	3 / 6	1 / 3	1 / 3	1 / 1	0 / 3	0 / 0	0 / 0	0 / 0	3 / 6	34	7

Source: M.M. Dillon Limited, James F. MacLaren Limited, Flood Plain Criteria and Management Evaluation Study, prepared for Ontario Ministry of Natural Resources, Ontario Ministry of Housing (December 1976)

Exhibit 4.3 - Evaluation Matrix: Non-Commensurable Objectives

ALTERNATIVES	DISASTER PREVENTION				ENVIRONMENTAL IMPACT					
	REDUCES CURRENT LOSSES	REDUCES FUTURE LOSSES	POTENTIAL RESIDENTIAL L.-0.-L.*	POTENTIAL NON-RESIDENTIAL L.-0.-L.*	BIO-PHYSICAL	SOCIAL	AESTHETIC	IMPLEMENTATION	INCIDENTAL BENEFITS	RANK
1. Ice Control Structure	H	H	L	L	H	VL	M	M	M	3
2. Dyking Inside River	H	H	M	M	M	L	VL	L	M	2
3. Dyking Outside River	H	H	M	M	VL	L	VL	L	M	1
4. Channel Improvements	L	L	H	H	H	VL	M	L	L	8
5. Storage Crooked Rapids*	VH	VH	L	L	VH	VL	M	VH	H	4
6. Storage Clearwater	H	H	L	L	H	VL	H	H	M	5
7. Ring Road and Dyke**	L	M	M	M	L	L	M	M	M	6
8. Flood Zoning	VL	M	VH	VH	VL	M	VL	M	VL	9
9. Relocation	VH	VH	VL	VL	VL	VH	L	VH	H	1
10. Flood Proofing-Fill	H	H	L	L	L	H	H	VH	H	6
11. Flood Proofing-Foundation	H	H	L	L	L	H	H	VH	H	6
12. Flood Proofing-Seals & Cls.	M	M	L	L	L	H	H	VH	H	7
13. Flood Proofing-Seals & Cls.	M	M	L	L	L	H	H	VH	H	7
14. Downstream Blasting	VL	VL	VH	VH	L	VL	VL	VL	VL	8
15. Contingency Measures	L	L	L	L	VL	L	VL	M	VL	5

*L.-0.-L.: Loss-of-Life

Source: IBI Group, Golder Associates: Feasibility Study - Athabasca River Basins (May 2014)

Some of the main non-monetary intangible evaluation methods are as follows:

4.2.3.1.1 Cost-Effectiveness Analysis (CEA)

Like a BCA, a CEA is an instrument for the evaluation of public projects with the aim to determine the best one. However, rather than attempting to measure overall welfare, a CEA measures the efficiency (costs) of meeting a certain goal or objective and can thus be multidimensional (evaluated against multiple goals). Furthermore, monetization of the goal(s) is not required and the impacts can remain in their respective dimensions.

If there is a single goal – the absolute protection of a settlement – a CEA becomes a simple comparison of project costs which have the same effectiveness at doing so. Other measures could be each projects cost per household, individual, or even square metre of building protected.

4.2.3.1.2 Multi-Criteria Analysis (MCA)

As the name implies, a MCA aims at a multidimensional goal system. Unlike a CEA, however, it is not restricted to evaluation of multiple goals independently. Weighted goals and degrees of performance for each are aggregated into one single number that indicates the overall effectiveness or utility value. This requires all partial effects to be measured at a uniform scale. MCA is often the preferred method for assessing social, environmental and cultural heritage. However, the method is highly dependent on the judgement and knowledge of the practitioners.

Previous MCA Approaches

A scoring matrix developed by the Ontario Ministry of Natural Resources for Flood Damage Reduction Studies is illustrated in **Exhibit 4.2.** For the purposes of flood damage reduction studies undertaken in Alberta by IBI Group/Ecos Engineering under the auspices of the Federal/Provincial Flood Damage Reduction Program, a non-monetary evaluation technique was employed in which non-commensurables were quantified but not in dollar values.

Essentially, this method evaluated the relative effects of alternative management strategies on triple bottom line objectives through the use of a ranking matrix. The procedure required that qualitative values (ranging from very high to very low) were established for each specific objective to enable a measure of achievement for each alternative in relation to these objectives. For the most part, individual objectives were unweighted (each received and equal weighting in the evaluation). These measurements were then translated into numerical values between 1 and 5 and then summed to determine a relative ranking for each alternative. For ranking purposes, 1 = first, 2 = second, etc. **Exhibit 4.3** details the evaluation matrix for non-commensurable objectives developed for the Fort McMurray Flood Damage Reduction Study.[55]

The potential residential and non-residential loss of life evaluation considered a large number of variables that would pose a threat to human lives or public health in the flood hazard and adjacent-to areas. These included:

- the speed of rise to flood peak;
- depth of flooding with respect to existing development;
- velocity of floodwaters;
- number of homes and businesses affected;
- flood warning and evacuation measures in place;
- effects of flooding of transportation access; and
- nature of facilities and land uses within the floodplain, i.e., hospitals and nursing homes situated within the flood hazard area creates significant risks associated with the flood event itself and even non-related events when these facilities are rendered inoperable.

This analysis was used in the identification of particularly vulnerable communities as well as to prioritize the emergency management efforts.

4.2.3.1.3 Disability Adjusted Life Years (DALY)

Health effects can be characterised quantitatively with a measure known as DALY. The DALY has been adopted by the World Health Organisation (WHO) as a metric to assess the burden of diseases, injuries, and risk factors on human populations. The DALY is described as combining the time lived with a disability and the time lost due to premature mortality.[56]

4.2.3.2 Monetary Evaluation

A benefit-cost analysis requires a monetization of the impacts. Despite its limitations, the BCA approach to disaster mitigation assessment remains the major decision-supporting tool with many advantages, particularly for assessing multiple alternatives. It is also suggested that the process of attempting to quantify social and environmental costs can itself be of value, forcing project proponents to clarify the logic relating proposed course of action to risk reduction.

That said, monetization of non-market impacts represent fundamental limitations that, because they involve basic ethical and personal perspectives, cannot be completely resolved through methodological, data, or other improvement in approaches.[57]

55. IBI Group/Ecos Engineering Services Ltd., Fort McMurray Flood Damage Reduction Program, Phase III-B Preliminary Appraisal of Alternatives, Alberta Environment, March 1983.

56. CORFU Collaborative research on flood resilience in urban areas: Health Impacts Model. 2014.

57. United Nations International Strategy for Disaster Reduction, Costs and Benefits of Disaster Risk Reduction (Geneva: Global Platform for Disaster Risk Reduction, 2007)

Monetization is more feasible for some assessments than others. It can be reasonably conceptualized in application to more predictable and discrete outcomes such as assessing the impact of air pollution levels on a large population or the loss of a particular environmental asset. Even then, one must be clear about what is and is not being counted and why. The U.S. EPA created controversy with their spectacularly complex attempt to monetize the effects of particulate air pollution. The many and highly technical calculations and descriptions were impenetrable to most, perhaps to bolster the impression that they were calculating a "true" cost of pollution with precision. The excruciatingly detailed monetization of a subset of benefits hides the scale of those not counted and the unavoidable uncertainty.[58] Further hidden in the details of the EPA monetization is the effects of using wage estimates as a factor in the value of illnesses. This makes a middle-aged male more valuable than a young adult or senior. Many found this offensive.

There are a number of methods available to monetize intangible effects. The required time and effort is often great, leading to "benefit transfers" being a common approach. A transfer is when a value determined in another, preferably very similar, location or situation. An overview of several main methods is provided below.

4.2.3.2.1 Expressed Preference Methods

Contingent valuation is a method of asking people directly about changes in their welfare. Through a series of questions, an attempt is made to get respondents to reveal their willingness to pay for a hypothetical scenario. For example, they could be asked how much they would pay for a certain reduction of the risk of contracting an illness. Conversely, the question could be posed as willingness to accept, in which case it seeks the amount a respondent would need to be paid to accept an increase in the risk.

Contingent valuation methods are often employed to value human health factors, including the determination of a statistical value of life. For example, suppose that the probability of exposure to a particular risk from a flood was 1 in 1,000. If 1,000 people subject to this risk were each willing to pay an average of $2,000 to reduce this risk to zero, the total value of preventing the risk completely for this population could be considered $2 million.

Willingness to accept questions tend to receive higher responses. Contingent valuation is a type of 'expressed preference' methods and, as such, there is potential for bias in the responses because of the hypothetical nature of the questions. Data from actual behavior is often preferred and several 'revealed preference' methods are available, including travel cost and hedonic price modeling.

4.2.3.2.2 Revealed Preference Methods

The travel cost method is useful for estimating the value for particular sites or activities for which there is no market price available. The principle is that people spend their time and money to travel to a site or partake in an activity. A survey can be used to determine how much an individual spent as well as their socio-economic characteristics. Statistical regression analysis is then used to develop a specific demand function.

Hedonic price modelling imputes the value of things such as hazard exposure from the value of a traded asset (often housing). Controlling for all other factors, housing prices will vary in relation to how buyers and sellers value the differential hazard exposure. Through their location decisions, and willingness to pay for alternative locations, people purchase bundles of hazard mitigation services that can be valued via the model. Data quality and controlling factors are issues with this method.

4.2.3.2.3 Opportunity Cost Methods

Environmental services can be partially evaluated based on an opportunity cost method. The value of ecosystems can be defined in terms of services:

- Supporting (nutrient cycling, soil formation, primary production)
- Provisioning (food, freshwater, wood and fiber, fuel)
- Regulating (climate regulation, flood regulation, water purification)
- Cultural (aesthetic, spiritual, educational, recreational)

Provisioning and regulating services can sometimes be evaluated in tangible economic terms. Lost production (provisioning) from agriculture or natural resource industries can be determined. Estimating the cost to either rehabilitate or recreate environmental services by other means is a type of opportunity cost method. This method values resources based on the cost of replacing the services they provide. For example, if a wetland cleans and filters runoff water, the benefit of that service can be given a value by calculating the least-cost alternative to provide the same level service. This could be the cost of recreating the wetland, an artificial alternative, or even the reduction of pollutants at the source.

4.2.4 2014 Calgary Study

The 2014 Provincial Flood Damage Assessment for Calgary identified the significance of intangible damages including the disruption to social services, community events, and household stress and anxiety. These impacts were considered in the selection of a 15% value for indirect damages in relation to direct.

58. Harrington, Winston, Lisa Heinzerling, and Richard D. Morgenstern, eds. Reforming Regulatory Impact Analysis. Routledge, 2010.

4.2.5 New Damage Calculation

4.2.5.1 Public Health

Before any impact can be monetized, it must first be quantified in terms of incidence rate and severity during and after a flood event in Calgary. As discussed above, there is little evidence to characterize most intangible outcomes of specific flood events/contexts. Nonetheless, an attempt was made to use appropriate quantitative means to estimate the probabilities for each factor, and then to convert this into a dollar value.

It was found that the process of quantifying the individual impacts relies on a high number of assumptions for each component variable. To then monetize these impacts requires further assumptions and transfer of values from other sources, most with no relation to flooding or the Calgary context.

The available monetary values for all the impacts originate from various studies and contexts but in the end are all assumptions based on willingness to pay (WTP) or choices and preferences of people somewhere. Complex calculations could be created using these values, estimated probabilities, and flood and population characteristics to arrive at a value for each impact. However, this would only obfuscate the origin of the data and the assumptions it contains. The end result would have questionable meaning or relation to stakeholders.

Furthermore, the attempt yielded values that were insignificant relative to the direct damages. In the simplest example, applying the recommended statistical value of life (in Canada is approximately eight million in 2015 dollars[59]) directly to the 2013 flood, in which one person died within the city, equates to approximately 0.45% of the 1:100 year flood damage estimate from the 2014 study. Similarly low values were found for more complex attempts to quantify injuries, disease, infection, and exposure. This is not to suggest that these factors are not important, but the physical risks in Calgary are actually rather low.

The overall total impact on affected households, however, is significant. There have been two WTP studies related to flooding conducted recently in the UK. The main objective of the previously discussed DEFRA study on intangible effects was to determine a value to be used nationally for assessments. There was also a research paper with a similar methodology published in 2015.

In addition to the health assessment, the 2002 DEFRA study included a survey of flooded households WTP to avoid all the intangible impacts. The overall mean WTP values for flooded respondents was about £200 per household per year, or approximately $615 CAD in current dollars. The 2015 study found a mean WTP value of £653 per household per year, or approximately $1,300 CAD. The more recent study results are significantly higher as the research was conducted after more severe flooding during 2007 and focused on a wider range of intangible impacts.

Because these studies elicit responses on a wide range of stress factors affecting the households, this value can be considered a single quality of life intangible value. The combination of physical and mental well-being would cover all the impacts, including but not limited to illness, worry, loss of services, community relations, loss of enjoyment of the environment or historical assets, etc.

To use a value from the UK is clearly a transfer in space and not Calgary specific. However, unlike the other available data/methods which would be a transfer in at least space, scale, time, etc., this value/method is directly from flood affected households in a relatively comparable urban setting.

A major advantage of this model is that it is relatively easy to understand, verify, and adjust. Ideally, the values would be tested and adjusted in a public engagement process. Do so is beyond the scope of this study phase, but the amounts can be adjusted for each at-risk community in Calgary based on the available demographic data. The WTP studies include demographic profiles which, along with the evidence from the literature, will be used to make the initial judgements.

The value will also be adjusted according to the specific flood impact of the community. For example, if the same number of households flooded in two demographically similar communities, the impact may not be equal if one also lost its school, community centre, and grocer.

At this time, an average value of $1,000 CAD per household per year will be assumed. This amount can be adjusted based on the community profiles according to a risk scale of low ($700), average ($1,000), and high ($1,300).

4.2.5.2 Environment

As discussed, there is no evidence of lasting environmental effects due to water contamination from flooding in Calgary. The cost of fish habitat offsetting measures is assumed to represent the monetized damage due to river bank stabilization projects. These costs are available for the 2005 and 2013 floods. The total values will be correlated to flow rates for those events and applied to the new flood data for each return period.

59. Treasury Board of Canada, 2007. Canadian Cost-Benefit Analysis Guide, Regulatory Proposals

4.3 Business Disruption

Businesses in buildings impacted by a flood will experience disruption of their normal operations. This may occur due to damage to the business's structure, equipment, and inventory; or because they have no access due to evacuations, road closures, or loss of utility services.

4.3.1 Literature Review

Previous studies have utilized a percentage of direct damages to estimate the resultant business losses. The ratio was chosen based on a review of the literature, empirical evidence, and expert opinion. It has been argued a percentage approach is appropriate for many businesses because of the high correlation between output and the facilities[60]. However, it will vary greatly between sectors and even events at the same location.

Other methods that include monetary business disruption losses are modeled as loss of economic flows for a certain duration. Lost sales, revenues, or profits can be the most relatable indicator of impact and it is common to see reference to such figures. However, downtime reduces expenses as well. Sales, profits, and expenses are components of value added, which is a better measure for the net of flows in a company[61].

A key principle of damage evaluation is to avoid summing stock and flow values. Doing so could be double counting because the value of a capital good is the present value of the income flow it generates over the rest of its useful life. However, in the case of a temporary business interruption, the loss of stocks (equipment, inventory), and the loss of flows (productivity during the interruption) can be summed because they each represent different components of damages[62].

Labour productivity is the ratio between an industry's value added and hours worked. It thus allows loss to be measured by duration. Few methods of determining the length of disruption have been suggested in the literature. A German study utilized telephone surveys among businesses in the Elbe and Danube catchments in 2003, 2004, and 2006 to determine mean interruption times. It was found that a water level of 20 cm (8 in) led to an disruption of 16 days, and a depth of 150 cm (5 ft) led to an disruption of 59 days62. However, the specific type of industries surveyed in that study is unknown.

In the United States, FEMA's Hazus model contains tables for flood restoration time by occupancy. These are provided for ranges of flood depths. **Exhibit 4.4** illustrates two examples.

Exhibit 4.4 - Sample from Hazus Flood Restoration Time by Occupancy

Occupancy	Depth	Physical Restoration Time (months)	Add-ons (months)				Max Total Time
			Dry-out & Clean Up	Inspection, Permits, etc.	Contractor Availability	Hazmat Delay	
Single Family Dwelling	(-8')- (-4')	3 - 6	1	2	3		12
	(-4') - 0'	6 - 9	1	2	3		15
	0' - 6'	9 - 12	1	2	3		18
	6'+	12	1	2	3		24
Retail Trade	0' - 4'	7 - 13	1	2	3		19
	4' - 8'	13 - 19	1	2	3		25
	8'+	25	1	2	3		31

Source: Hazus-MH Flood Technical Manual

60. Bubeck, P., and H. Kreibich. "Natural Hazards: direct costs and losses due to the disruption of production processes." GFZ, Helmholtz Centre PotsdamWP12 (2011): 68.

61. HAZUS-MH, F. E. M. A. "Flood Model: Technical Manual." Federal Emergency Management Agency (2003).

62. Messner, Frank. Evaluating flood damages: guidance and recommendations on principles and methods. Helmholz Unweltforschungszentrum (UFZ), 2007.

As evidenced, the Hazus recommendations are rather vague. For retail trade, the depths of zero to four feet of floodwater indicate restoration times between seven and 13 months. Four feet is a large range to begin with and it is assumed that a flood level of one or two inches could be recovered from in much less time. The reported time disruptions from Germany are far less than indicated in this table. Furthermore, this table indicates total reconstruction times. If a building required 25 months to rebuild, it is expected that most businesses would be able to relocate and return to operations sooner. In another FEMA document, the business disruption days are provided in a table for each foot of flood depth[63]. It is a simple linear function, equating to 45 days per foot (30cm) of water. This appears to be a more reasonable estimate that could be used for lower levels of flooding, such as a four-day disruption for one inch of floodwater.

4.3.2 2014 Calgary Study

Following the June 2013 flooding in Southern Alberta, Statistics Canada conducted a special Labour Force Survey that included questions about the impact of the flood on hours worked. They found that a total of 5.1 million hours were lost in Alberta. This survey collected data for only the last two weeks of June. Many additional hours were spent as a result of the flood, however all industries except utilities and public administration experienced a net loss during those two weeks.

In September 2013, the Government of Alberta issued an 'Economic Commentary' using this information as a basis for estimating business losses that were experienced. An estimate of GDP lost by the private sector was made using each industry's 2012 labour productivity amount multiplied by the industry's lost hours. The resultant loss estimate amounted to $485 million in 2007 dollars.[64]

Accordingly, this figure was adopted for the 2014 City of Calgary: Assessment of Flood Damages report. An estimated share of the hours within the City was multiplied by 2013 productivity values for each industry and converted to 2014 dollars. This equated to $359 million. It is possible that this amount greatly overstates the losses for a number of reasons. Downtown Calgary does not operate as a factory and the temporary closure of offices would not cause shutdown of related production. Using the hours from the survey does not consider time made up or work otherwise caught up after the flood. For these reasons, an alternative damage scenario was also provided using the high end of the typical commercial indirect damage range. A value of 45% of direct commercial damages was chosen, amounting to $50 million.

4.3.3 New Damage Calculations

For the purposes of this study, Alberta labour productivity was converted into a daily value per square meter of floor space and disruption periods were estimated for both main and upper levels of buildings. The productivity and disruption periods were then adjusted to account for partial recoveries. Damage curves were created for each building class and the building inventory was expanded to account for both main and upper floors of non-residential buildings.

4.3.3.1 Productivity Values

Statistics Canada provides hourly labour productivity per worker for various industry classifications at the provincial level. Daily productivity per square metre of floor area can be determined by dividing the employee productivity amount by the typical floor area per employee and then multiplying by the daily operating hours, as detailed in **Exhibit 4.5** below.

Exhibit 4.5 - Productivity per Square Metre

Classification		m^2 per Employee	Productivity $/hour,[65]	Operating Hours/Week	Productivity/ Day/m^2
A1	General Office	23	88.25	45	24.67
C7	Retail	33	38.99	65	10.97
I1	Restaurant	30	24.68	80	8.55
L1	Warehouse/Industrial	70	68.52	65	9.09

Productivity is not a measure applied to the public sector. Damages associated with buildings identified as public (schools, government offices, etc.) are included in the intangible household impacts as outlined in Section 4.2.5.

63. FEMA Benefit Cost Analysis Tool (v 4.5.5). 2009.

64. Statistics Canada publishes the productivity figures in a chained Fisher index, with 2007 as the base year.

65. Statistics Canada publishes productivity in chained 2007 dollars. To express these in 2015 dollars, the latest (Q2 2015) implicit price deflator was used. The general office amount was derived from the industry specific employment numbers for the Calgary CMA. Sources: Statistics Canada: CANSIM Table 383-0029 Labour productivity; Table 282-0131 Labour force survey; Table 380-0066 Price indexes, gross domestic product.

4.3.3.2 Disruption Period

The City has been tracking building permit activity as a measure of recovery for flood impacted properties. The initial methodology considered using this recovery data in conjunction with flood depth estimates from the 2013 event to create an accurate function. However, examination of this dataset revealed that tracking permits captures a great deal of construction activity not related to flood recovery. Time spend on post-flood improvements or changes to buildings is not considered in damage estimates.

Disruption times were estimated for repairing a building to a pre-flood level of utility. The maximum average building recovery period is 240 days (approximately 8 months).

The impact on a retail business at ground level would be different than on a 10th floor office. The retail business may suffer a disruption time of several months, while workers in an upper office may be able to return to the office in a matter of days if the utilities are restored and the lobby area deemed safe.

Therefore, disruption times were also estimated for building space not directly flooded (upper floors, evacuated buildings with no damage, and parkade damage only). The average disruption times are indicated in **Exhibit 4.5**

4.3.3.3 Business Loss Adjustments

If a business's space takes seven months to fully restore, its component resources, including staff, are unlikely to be completely lost to the economy for the entire period. A flood event is a disruption of operations, after which complex adjustments and alternate activities take place during recovery. The building disruption time variable was modified to produce a value for total business loss during the recovery process. The following assumptions were used:

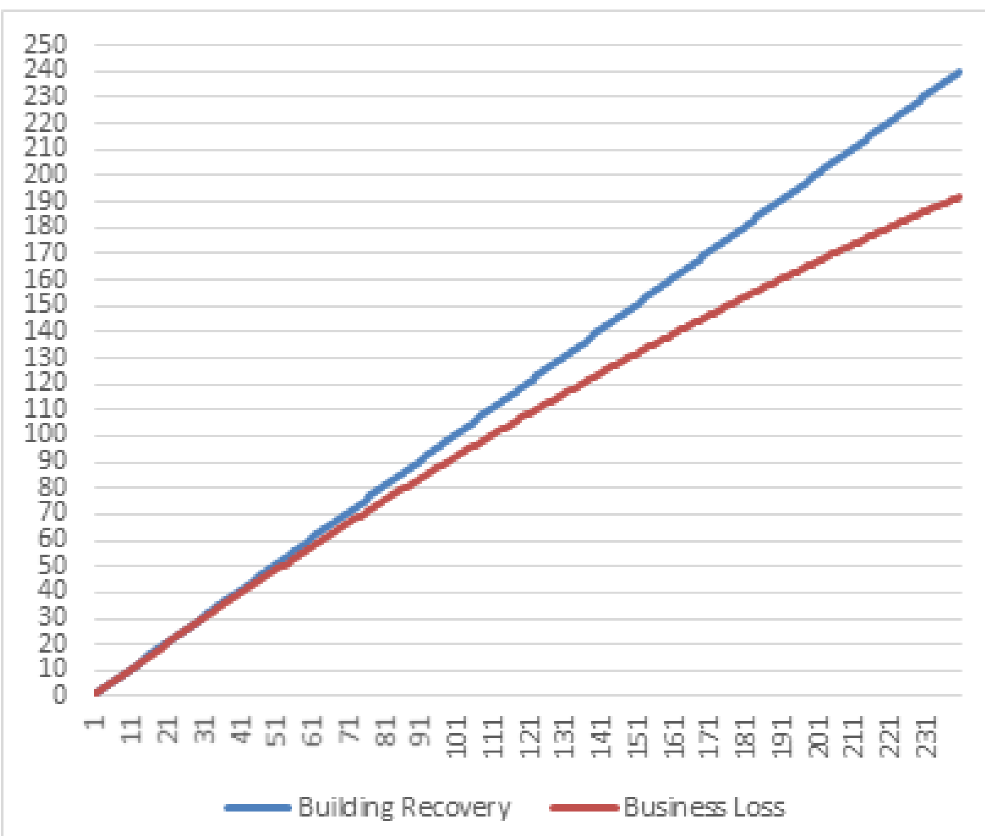
- The loss of productivity decreases as the disruption time increases, to a minimum of 80% at 240 days.
- Productivity lost days for a building recovery period of n days is calculated as:

  $$n * (1 - n / (d / p))$$

  Where d is the maximum number of disruption days and p is the percentage of the maximum recovered productivity.

The effect of this adjustment is that a building recovery time of 90 days equates to an effective 83.25 day period of 100% business loss, or an overall loss of 93% productivity during the entire time. The relationship between building recovery time and effective business loss is illustrated in **Exhibit 4.6.**

Exhibit 4.6 - Effective Business Loss Days



Office work is not as dependent on the physical space as a retail or manufacturing establishment. The work conducted in an office may be related to production outside the flood affected area. It is also possible for many types of office work to be completed at another location. For example, IBI Group's Calgary office was closed and without power for one week during and after the 2013 flood. The computer server was relocated to allow some staff to continue working remotely, while others made up the time in other ways. To account for this, the overall productivity loss for an office closure is reduced by 20%. Additionally, the current office vacancy rate is approximately 11% in Calgary and the general office productivity has been further reduced accordingly.

4.3.3.4 Incorporation in Damage Model

A depth damage curve was created by combining the disruption days per depth of flooding with the daily loss per square metre. To allow for varying disruption times within a building, a second building record was created for the damage model. This record contains the floor area of the upper floors from the property tax assessment. It is not feasible to classify every use within a building on the upper floors. Instead, all commercial space above the first floor is classified as general office using the Calgary productivity estimate. The resultant inventories and damage curves are used as inputs into the damage model.

4.4 Residential Displacement

Structural damage from floodwaters, loss of critical services, or lack of access due to evacuation and road closures can all lead to residential displacement. During and after a flood event, affected residents will have to find alternative accommodations and incur extra personal expenses. Expenses may include restaurant meals, daily essentials, hotel costs, and extra fuel. Residents of buildings that require substantial repairs will require alternative accommodation for a longer period and incur costs for moving and rent.

4.4.1 Literature Review

Residential displacement costs are not often explicitly estimated in flood damage assessments. The required assumptions are relatively straightforward so there are few studies of this topic and the available information is typically found in technical manuals, such as those produced by FEMA in the U.S.

The Hazus flood model determines the number of individuals likely to use government-provided short-term shelters. The proportion of displaced individuals requiring shelter is based on income and age of the population. The assumption is that households with lower incomes and younger, less established families and elderly families are who do not have family and friends nearby will be more likely to require shelter. Income weighting is 0.8 and age is 0.2. The model considers displacement due to flooded homes, restricted access (roads), and loss of utilities.

As with the business disruption times, FEMA benefit-cost documentation refers to a displacement time of 45 days per foot of floodwater[66]. The FEMA guidance is to consider the depth from the first finished floor. Therefore, a foot of water in a finished basement equates to the same displacement period as a home on slab with one foot of water on the main floor.

The FEMA guide contains monthly default displacement costs of $1.44 (2009 dollars) per square foot of living space. These values represent costs incurred for the event period and a monthly rent for longer restoration periods.

4.4.2 2013 Flood

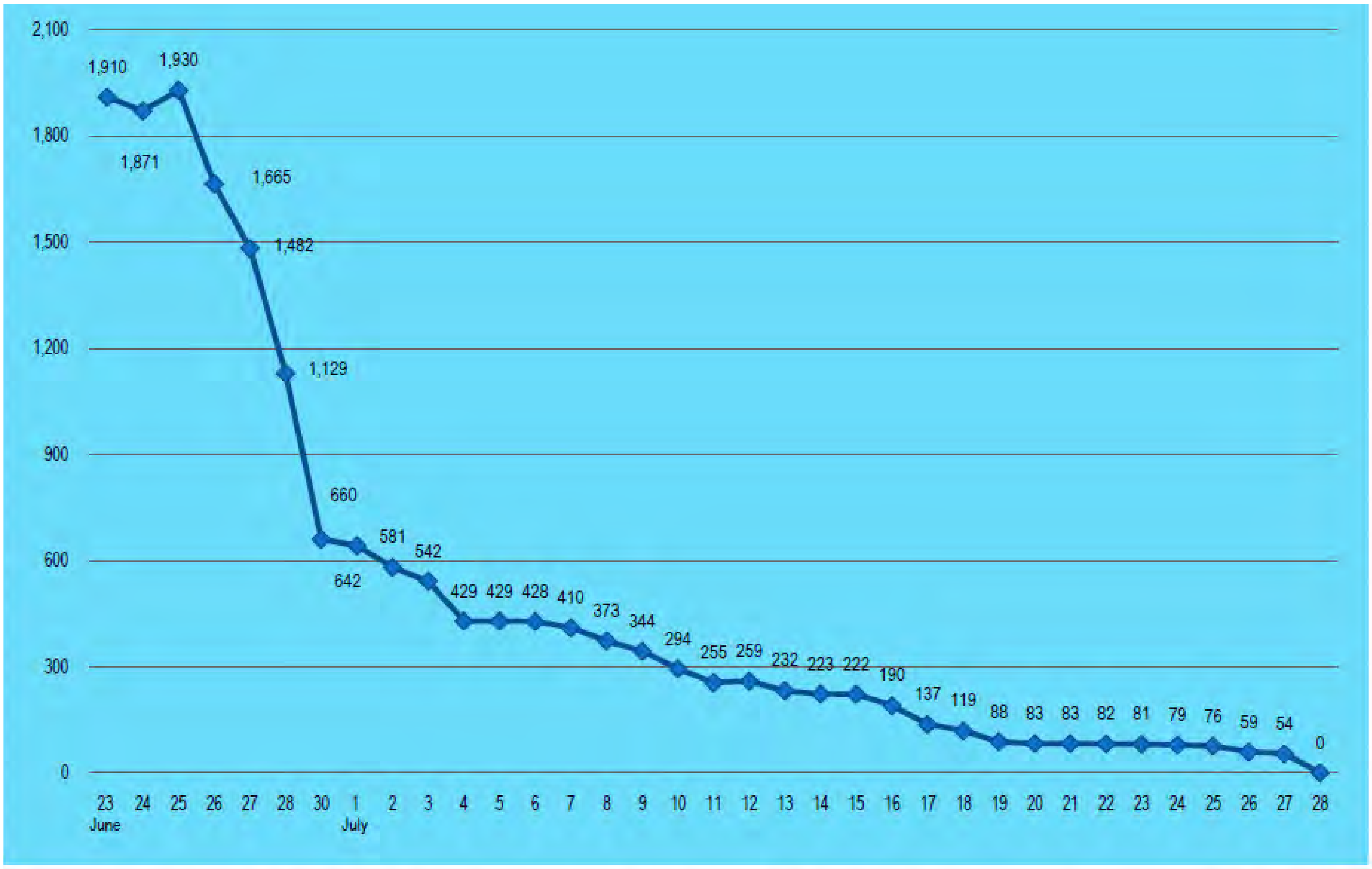
As the water flow estimates on June 20, 2013 increased, CEMA used the available inundation maps to identify communities throughout the city that could be impacted. Evacuation notices were spread via press releases, website and social media, and through the Alberta Emergency Alert System. City staff also conducted door-to-door evacuations in many areas. Within 15 hours, 32 communities were evacuated, amounting to approximately 80,000 people[67]. This compares to 1,500 during the 2005 flood.

The City opened a total of nine reception centres for evacuees. Approximately 3,800 were registered, 2,800 were provided shelter and 68,000 meals served. Neighbourhoods that were deemed safe were reopened and had power restored by the following afternoon. By July 28, all people housed in shelters were able to either return home, find alternate long-term accommodations, or be transitioned into temporary housing with Calgary Housing Company. The number of people housed in reception centres between June 23 and July 28, 2013 is illustrated in **Exhibit 4.7**.

66. FEMA. Supplement to the Benefit-Cost Analysis Reference Guide, June 2011.

67. City of Calgary. Summary of June 2013 Flood Emergency Response and Initial Recovery Efforts (EM2013-0822 Attachment).

Exhibit 4.7 - Number of People Housed in Reception Centres Between June 23 and July 28, 2013 (Calgary)



4.4.3 2014 Calgary Study

In the 2014 Provincial Flood Damage Assessment, displacement costs were covered by the residential indirect damage amount of 15% of direct damages. Of that, temporary accommodation costs were estimated to be approximately $10 million for the previous 1:100 year flood event. This estimate was based on expected average durations for buildings with either basement or main floor flooding. It amounted to around 10% of the indirect portion of damages or about 1.5% of the direct residential damages.

4.4.4 New Damage Calculations

For the purposes of this study, revised displacement times and daily costs are used to create damage curves. As with business disruption, separate values and inventory records are used for upper-level units. Additional damages were added for households evacuated or without utilities but not flooded.

4.4.4.1 Displacement Period

Available information about recovery after the 2013 floods indicates that the displacement times vary greatly between buildings with similar inundation levels. As discussed above in regards to business interruption, the reconstruction process generally involves much more than restoring a building to its previous state.

Unfortunately, we do not have accurate information on basement suites in Calgary but it is assumed that most finished basements do not contain essential living spaces, such as kitchens, and a home with minor basement flooding will be largely inhabitable during the restoration. Basement flooding above 50 cm may affect electrical and mechanical equipment and having an inspection completed can take longer than the actual repairs.

For multifamily units not directly damaged, restoration of electricity and life-safety systems determine the displacement duration. However, availability of specific mechanical equipment and a number of building-specific issues are highly variable. After the 2013 floods, re-entry of residents into multifamily buildings with only flooded underground parking levels ranged from a couple of days to several weeks.

It is recognized that as the number of buildings flooded increases, there may be issues with availability of contractors, inspectors, and equipment. The estimated displacement duration considers the time to complete repairs plus a general average expected delays including contractors, materials and equipment, and inspections for all return periods. These average displacement times are illustrated in **Exhibit 4.8.**

4.4.4.2 Evacuation

Following the 2013 flood and the 2015 update to the flood inundation mapping, the City created new flood evacuation areas for future events. The evacuation areas correspond to each return period, up to the 1:100 year flood. The evacuation areas represent parts of the city that pose a safety risk from floodwaters or loss of services at each flood level.

The City's new evacuation areas are used to determine the number of households displaced due to evacuation. For floods greater than the 1:100 return period, IBI Group has estimated evacuation areas based on the updated inundation mapping.

The average time of displacement due to evacuation only is assumed to be one day.

4.4.4.3 Daily Costs

Residential displacement costs are those that would not normally be incurred and are associated with the inability to return home for a period during and after a flood. Individual circumstances will have a great effect on the nature and amount of these costs. However, general assumptions about the population are made in order to estimate total costs. Daily costs per household were calculated with the following assumptions:

- Half of displaced households will find accommodation with friends, family, or a shelter.
- The costs associated with public shelters is included in the emergency operations calculation.
- The remainder of households will spend up to 14 days in a hotel at $166 per day.[68]
- During the first 14 days, each individual will spend an extra $50 per day.
- The number of people per household is 3 for single or semi attached units and 1.7 for multifamily units.[69]
- Households requiring alternate accommodation beyond 14 days will rent another unit of the same type. The average apartment rent is $1,220 per month ($40.67 per day) and the average house rent is $1,695 per month ($56.50 per day).[70]
- A one-time moving expense of $500 per household is included for households requiring accommodation beyond 14 days.

68. Alberta Accommodation Outlook 2015
69. Average of flood-affected communities, City of Calgary 2014 Census
70. CMHC Rental Market Report, Calgary, Spring 2015

Exhibit 4.8 - Estimated Average Residential Displacement Periods[71]

Unit Type/Location	Depth (m)										
	0.1	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3
all apartments u/g parking	0	2	4	7	7	7	10	10	14	14	14
upper level low-rise	35	35	90	90	120	120	180	180	180	180	180
upper level high-rise	21	35	42	60	90	90	90	90	90	90	90
main floor units	60	90	120	180	180	180	210	240	270	300	300
single/semi/row main floor	90	120	180	210	240	270	300	300	300	300	300
Single/semi/row basement	0	0	14	21	30	30	45	45	60	75	90

4.4.4.4 Rental Units

Several simple assumptions are required to account for the rent-related loss incurred when a unit is uninhabitable for a period greater than 14 days. If a rental unit is uninhabitable, the tenant will find other accommodation and continue being a renter. Therefore, rent is not an additional flood damage to that household. However, the landlord of the flooded unit will lose the rental income. The loss of income will be for a duration equal to the estimated displacement times so the full displacement costs for all households regardless of tenure can be used. For homeowners, it is extra cost to the household. For renters, it is the loss of income for the landlords.

4.4.4.5 Incorporation in Damage Model

The depth to displacement days estimates are combined with the daily costs per household to create damage curves for each housing type. To account for potentially different disruption times within apartment buildings, a second inventory record is created for each building with upper level units.

The damages are calculated on a per unit basis, rather than floor area. The total number of units in a multifamily building is not recorded in many of the assessment records. For condominium buildings, the unit count is assumed to be equal to the number of individual residential assessment records on the same parcel. For rental buildings with only one assessment record, the total finished living space in that record is divided by 75 square meters (800 ft2) for an estimated number of units. Where possible, the number of units is confirmed with block-face municipal census data.

Costs associated with residential buildings that are only evacuated are not computed in the damage model. Instead, the number and type of units within the evacuation zones that were not flooded is determined when the model has been run for each return period. That number is then multiplied by the first-day displacement costs.

4.5 Traffic Disruption

Floods can cause major traffic disruptions due to water on roadways or closures and evacuations of entire areas. Traffic delays have financial and social costs.

4.5.1 Literature Review

There is a body of research on the economic impacts of traffic congestion and methods of estimating costs, but very little on flood-specific impacts. Congestion can either be recurrent or non-recurrent. Recurrent congestion refers to daily high traffic volumes while non-recurrent congestion is the result of random incidences such as accidents, stalls, construction, and floods.[72]

Estimates are commonly comprised of the additional operating costs of vehicles and the opportunity cost (time) of the occupants. Traffic delays also have many broader economic and social implications including supply chain effects, air pollution, crashes, labour market pooling[73], and land use decisions but many of these are only relevant for persistent conditions.

Transportation modelling of both optimum and congested or disrupted conditions provides a means to estimate a total cost. There have been several studies on the cost of traffic congestions or disruptions in Canada, including two by Transport Canada in 2006 upon which many others are based. A recent study was prepared for TransLink in 2015 and estimated the current and projected costs of congestion in Metro Vancouver. The operating costs and value of occupant time used in the Vancouver study were $0.21 per kilometer and $16.69 per hour in 2011 dollars.[74]

While traffic disruption is occasionally mentioned in the literature on flood impacts, it is rarely included in flood damage assessments. There are some studies of the economic impact of particular highway closures due to flooding or landslides but very few on urban flooding.

71. Days due to underground parking and basement flooding are not added when main floor flooding occurs

72. iTrans. Costs of Non-Recurrent Congestion in Canada Final Report. Transport Canada Economic Analysis. TP 14664E.

73. Dachis, Benjamin. “Tackling Traffic: The Economic Cost of Congestion in Metro Vancouver.” CD Howe Institute eBrief 206 (2015).

74. HDR. Current and Projected Costs of Congestion in Metro Vancouver. Final Report. Translink (2015).

Several studies on predicting future climate change impacts included analysis of flooding on transportation networks. A study of Boston found a doubling of delays and lost trips but that the impact was probably not large enough to justify a major effort for adapting the physical infrastructure to expected climatic conditions, except for some key links.[75]

A case study of future climate change scenarios in Portland Oregon modelled the effects of bridge and road closures due to higher levels of flooding. It was found that the availability of alternate routes limited increases in travel miles but the resultant congestion was more significant. The authors state, however, that while their findings may be conservative (assuming perfect choices by drivers), the traffic disruptions in Portland will be small compared to the damage to property and infrastructure. This finding is similar to another case study in Japan.[76]

4.5.2 2013 Flood

Over 800 kilometres of roadways were closed during the 2013 flood, including 20 bridges. 300 metres of Macleod Trail required rebuilding. LRT services were disrupted as stations lost power, a portion of track was damaged, and tunnels were inundated with water and debris. Bus routes were detoured or cancelled.

Within six days, 85% of flood-affected roads were open and all downtown roads were cleaned. All bridges were inspected and open within two-weeks. The LRT tunnels were pumped out and repaired and 100 metres of new track laid near the Erlton station within 13 days.

4.5.3 2014 Calgary Study

Traffic detours, congestion, and cancelled trips were included in the discussion of indirect damages and considered as part of the 15% of direct residential damages value used.

4.5.4 New Damage Calculation

Detailed traffic modelling of flood impacts is beyond the scope of this study and not warranted due to the expected value in relation to other damages. However, an estimate of the number of vehicles affected is required. Daily traffic counts are available for major roads but flooding affects large areas of the City and not just individual transportation links.

The City of Calgary Transportation Forecasting division provided an analysis of trips within the evacuated areas for the 35, 50, and 100 year return periods. The analysis included a daily count of vehicle trips passing through, originating, or terminating in the affected area, as illustrated in **Exhibit 4.9.**

The following assumptions are made to determine the disruption of vehicle trips due to flooding:

- Trips beginning or ending in the flood area are assumed to be cancelled trips.
- The cost of a cancelled trip is included in other estimates relating to the structure associated with the trip (business disruption, household displacement, and intangibles).
- The remaining trips within the flood area are detoured.
- An average detour distance and time was estimated for each return period beyond 10 based on alternative routes available.
- Additional time was considered for the effect a detoured vehicle has on the other vehicles normally traveling the route.
- The operating costs and value of occupant time is $0.22 per kilometer and $0.29 per minute.[77]
- The effective average duration of the impact increases with flood severity, ranging from two to 14 days.

Impacted trips were only calculated for three return periods. At the 1:100 year flood, most of the major vulnerable linkages would already be closed. The impact of flooding beyond the 1:100 would primarily be an increase of cancelled trips. Therefore, the same number of detours are assumed to occur but for a longer period due to increased damages. The number detoured at the remaining return periods was estimated based on the evacuation areas in relation to the three return periods with trip counts provided.

Exhibit 4.9 - Flood Impacted Trips per Day

Return Period	Vehicle Trips in Flood Area *	Vehicle Trips Beginning in the Flood Area	Vehicle Trips Ending in the Flood Area
100	935,100	223,400	236,800
50	709,900	93,800	97,500
35	338,600	15,100	14,900

source: City of Calgary Traffic Forecasting

*includes trips beginning or ending in flood area

75. Suarez, Pablo, et al. "Impacts of flooding and climate change on urban transportation: A systemwide performance assessment of the Boston Metro Area." Transportation Research Part D: transport and environment 10.3 (2005): 231-244.

76. Dutta, Dushmanta, Srikantha Herath, and Katumi Musiake. "A mathematical model for flood loss estimation." Journal of hydrology 277.1 (2003): 24-49.

77. These values were taken from the 2015 HDR/Translink study of Metro Vancouver, in 2015 dollars.

4.6 Waste Disposal

The majority of flood-damaged property is disposed of in landfills. During a large-scale emergency clean-up operation, proper sorting of recyclable material or hazardous waste is not often performed. Additionally, current practice is to dispose of many items that would have been repaired in the past. This amounts to a great deal of waste from each flooded building.

Waste disposal has costs associated with collection, operation of the facilities, land usage, and environmental impacts.

4.6.1 2013 Flood

After the floodwaters receded, a major cleanup was initiated involving City staff, homeowners, businesses, and thousands of volunteers. Damaged contents and structural materials were removed from buildings. School sites and other community facilities became designated drop-off points for debris. Waste and Recycling services and local businesses mobilized to remove the waste from the flooded neighbourhoods. Blue cart recycling services were suspended for two weeks as staff and equipment was reallocated. The City's landfills were open for extended hours and all tipping fees were waived for disposal of flood-related waste.

In total, it is estimated that 102,500 tonnes of flood-related waste was received by Calgary landfills.[78]

4.6.2 2014 Calgary Study

Flood cleanup was considered as part of the total 15% indirect damages. No specific estimate for waste disposal was made.

4.6.3 New Damage Calculation

The amount of post-flood waste created is assumed to be related to the total direct damages to buildings and contents. City of Calgary landfills normally charge $110 per tonne for basic waste and $165 for construction and demolition materials when part of a mixed load. The average of these rates is $138 and is assumed to represent the landfill cost for the flood-related waste. An additional $50 per tonne is added to account for the time of private operators to bring the waste to the landfills, for a total cost of $188 per tonne.

At this rate, the 102,500 tonnes of waste from the 2013 flood would cost over $19 million. 2013 was a 1:75 year event with estimated direct damages of approximately $1.15 billion. This equates to approximately 1.7% of estimated direct building and content damages. This ratio will be applied to calculations for each return period.

4.7 Flood Fighting and Emergency Response and Recovery

Flood fighting and emergency response requires significant effort by Municipal Administrations and volunteers and it is often unaccounted for in damage estimates, or alternatively, included under indirect damages computed as a percentage of direct damage. For the 2005 and 2013 flood events, the City of Calgary estimated costs related to these efforts. Emergency operations for various City departments as a result of the 2005 flood event equated to some ±$2 million and for the 2013 flood, flood emergency response and initial recovery efforts equated to ±$60 million. A summary of the activities associated with the latter event is contained in **Appendix A.**

4.8 Infrastructure Damages

For the City of Calgary Assessment of Flood Damages Study of 2014, total infrastructure damage was estimated at $299.1 million based on costs estimated by various City departments. This included $258 million in infrastructure damage for the City of Calgary, $24.5 million in infrastructure damage at Stampede Park and damages to other franchise utilities including Enmax and Telus of $16.6 million. The City of Calgary estimates have been updated and are contained in the Deputy City Manager's Report to Priorities and Finance Committee, dated July 14, 2015. The total budget, excluding resiliency, is $409,647,000. However, excluding buildings which have been estimated under direct commercial damages, these equate to $310.9 million. This represents an increase of some 17.1% from the previous estimate. Assuming the previous infrastructure damages for Stampede, Enmax and Telus hold their values, total infrastructure damages for the 2013 flood equate to $352 million.

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INSURABLE FLOOD DAMAGES

5

5 Insurable Flood Damages

5.1 Introduction

The following section provides an overview of flood insurance coverage for Alberta and Calgary and considers total and average insurance payouts for the 2005 and 2013 flood events, along with calibration of the depth-damage curves to account for insurable losses.

5.2 Flood Insurance Coverage

Flood coverage is one of the most complicated aspects of home insurance in Canada. Thus, it is generally not possible to provide an objective, reliable assessment of the proportion of flood-related losses that would be insured following any type of flooding event (including losses associated with infiltration flooding, groundwater, stormwater, riverine and sewer backup flooding) for any specific location of Canada. Important factors that complicate the assessment of flood insurance for homeowners include the following:

- There are approximately 300 property insurance companies in Canada, and specifics of coverage differ between companies. Each of these companies develops their own approach with respect to insurance premiums, deductibles, sub-limits and availability of coverage for policyholders and they types of coverage they offer.
- Segmentation of perils (i.e., separating and pricing risks independently), and application of sub-limits (i.e., capping payouts for high-risk insureds) to manage risk associated with costly insured flood loss events complicates the home insurance landscape for flood-related perils, including sewer backup.
- Competition in the insurance industry results in difficulty in assessing the overall proportion of home insurance policyholders that may have certain types of coverage, especially in the case of segmented perils for which coverage is offered using an add-on or optional endorsement, such as flood, overland water and sewer backup. In some cases homeowners considered high risk by one company, and thus offered reduced sewer backup coverage or no coverage at all, may be able to find coverage from a different company.
- Insurers typically underwrite homeowner insurance coverage based on municipal boundary, postal code or forward sortation area (first three digits of postal codes) (Friedland et al. 2014). In some circumstances, insurers may choose to limit coverage in geographical areas considered to be high risk of insurance losses based on frequency of historical claims, but due to the competitive nature of the insurance industry, homeowners in these areas may be able to purchase coverage from other insurers.

  These factors are not applied universally to all home insurance policyholders insured by a specific company. For example, sub-limits may be increased if individual homeowners undertake flood mitigation measures within their homes, such as the installation of backwater valves. These same factors may affect deductibles, premiums, etc. Further, Insurers that have chosen not to offer coverage to high-risk homeowners in particular locations my offer coverage if individual homeowner undertakes mitigation activities.

- Lack of clarity in policy wordings in the past have led to situations where insurers have provided payouts for losses that were not technically insured. This situation was apparent in parts of southern Alberta following the June 2013 flood event. For example, in a paper commissioned by the Canadian Institute of Actuaries on the topic of improving the management of risk associated with insured water perils, Friedland et al (2014: 2) stated

  "many losses arising from the [June 2013] Alberta floods…were covered by insurers as a goodwill measure and to enhance the long-term relationship with customers and not because the peril of water damage was covered in the insureds' policies."

  These "goodwill" payouts complicate the flood insurance landscape, as it is difficult to predict how insurers will react to widespread uninsured losses following major loss events. As discussed later, following the 2013 Alberta floods, the insurance industry has attempted to clarify policy wordings (for example, through the introduction of a "limited" sewer backup model wording, developed by the Insurance Bureau of Canada). However, clarified wordings presented by IBC are not required to be adopted by insurers providing home insurance coverage in Alberta.

- An important change in the flood insurance landscape within the last few months has been the introduction of homeowners' flood insurance coverage by two major insurance companies. These insurers represent roughly 15% of the Alberta personal property insurance market. Previously homeowners in Alberta were unable to purchase coverage for overland flood losses (associated, for example, with stormwater or river flood hazards) from any insurer, except in rare circumstances. As outlined in this report, the specifics of coverage are different between these two companies.

- While it is likely that other insurance companies will also choose to provide limited coverage for overland flooding, it is not possible to generate a reliable estimate of the proportion of the market that will have access to these types of coverage. Further, as these offerings are likely to be made in the form of optional, additional endorsements, it is also not possible to assess the number of policyholders who will choose to purchase coverage.

Despite the abovementioned challenges, there are some sources of data that shed light on claims associated with regional flooding events, notably those that result in significant payouts associated with sewer backup. This report first reviews the available insurance loss data for flood disaster events in Alberta and across Canada. Proprietary sources of insurance data, not accessible for the purposes of this report, are also identified. Next, a review of industry practices related to the insuring of overland flood is provided. This report also reviews findings from a survey of insurance brokers servicing clients in Alberta and Calgary.

5.3 Review of Insurance Data for Disaster Losses

Insurers treat claims data as proprietary and are only willing to share under very specific circumstances and when proper agreements have been put in place. Thus, detailed accounts of insurance claims that occurred as a result of the June 2013 flood event in Calgary were not accessible under the terms of the this project. There is only one publicly accessible source of P&C insurance industry-wide data, contained in the IBC Facts Books. The Facts Books contain tables that provide occasionally published total disaster loss figures.

5.3.1 IBC Facts Book Data

The Insurance Bureau of Canada has been collecting natural catastrophe loss totals since 1983. This information was based on insurance member surveys following significant disaster events. All major loss events in the Facts Books recorded for Alberta are provided in **Exhibit 5.1**.

Exhibit 5.1 - Natural Disasters - Major Multiple Payout Events in Alberta, 1983-2014

Date	Location or region	Event type	Total (000s) including adjustment expenses	Total (adjusted to 2014)
Aug. 3, 1983	Edmonton	Storm	22,060	47,537
Jul. 31, 1987	Edmonton	Tornado	148,377	271,194
Jun. 7, 1988	Medicine Hat	Tornado	50,027	87,969
Jul. 6, 1988	Slave Lake	Flooding	21,500	37,806
Jul. 9, 1990	Calgary	Hail	16,279	25,997
Jul. 3, 1991	Red Deer	Storm	28,202	42,644
Sep. 7, 1991	Calgary	Hail	342,745	518,257
Jul. 31, 1992	Calgary	Hail	22,087	32,907
Aug. 28, 1992	Alberta	Hail	5,263	7,844
Sep. 1, 1992	Alberta	Hail	7,421	11,061
Jul. 29-30, 1993	Alberta	Hail	8,116	11,871
Jun. 18, 1994	S. Alberta	Hail	8,263	12,072
Jun. 6-9, 1995	Calgary	Flooding	20,764	29,676
Jul. 4, 1995	Edmonton	Hail	14,698	21,007
Jul. 10, 1995	S. Alberta	Hail	26,389	37,716
Jul. 17, 1995	Calgary	Hail	52,304	74,754
Jul. 16-18, 1996	Calgary	Hail	119,091	167,719
Jul. 24-25, 1996	Calgary	Hail	85,222	120,020
Jul. 4-9, 1998	Calgary	Hail	69,742	95,637
Jul. 14, 2000	Pine Lake	Tornado	17,916	23,512
Aug. 9, 2000	Calgary	Storm	28,058	36,822
Jul. 13, 2001	Alberta	Storm	25,513	32,661
Jun. 8, 2002	S. Alberta	Flooding	42,828	53,621
Aug. 11-12, 20023	Alberta	Wind/hail	33,565	40,879
Jul. 2-11, 2004	Edmonton	Hail	166,000	198,502
Jul. 15, 2004	Calgary	Hail	21,500	25,710
Jun. 6-8 & Jun. 17-19, 2005	Alberta	Flooding	300,000	351,028
Aug. 10, 2006	Alberta	Hail	13,593	15,599
Jun. 5, 2007	Alberta	Storm	44,621	50,104
Jul. 7, 2007	Alberta	Wildfire	7,376	8,282
Jul. 28-29, 2007	Alberta	Hail	16,581	18,618
Jul. 2008	Lethbridge	Wind/hail	20,500	22,494
Aug. 1-3, 2009	Alberta	Wind/thunderstorm	376,300	411,825
Jul. 12-13, 2010	Calgary/S. Alberta	Wind/thunderstorm	530,000	569,579
May 14-17, 2011	Slave Lake	Wildfire	742,000	774,799
Nov. 27, 2011	Alberta	Wind/thunderstorm	238,500	249,043
Jul. 11-12, 2012	Edmonton	Wind/thunderstorm	N/A	N/A
Jul. 26, 2012	S. Alberta	Wind/thunderstorm	N/A	N/A
Aug. 12, 2012	Region around Calgary	Wind/thunderstorm	562,000	578,163
Jun. 19-24, 2013	S. Alberta	Wind/thunderstorm	1,827,000	1,862,707
Aug. 7-8, 2014	S. Alberta/Calgary	Wind/thunderstorm	568,900	568,900

Exhibit 5.2 - Major Payout Events associated with Storm and Flooding in Alberta, 1983-2014

Date	Location	Event type	Commercial, Personal Property			Auto°			Total # of claims	Total (000s) (including adjustment expenses)	Total (adjusted to 2014)
			# of claims	$°	Average payout°	# of claims	$°	Average payout°			
Aug. 3, 1983	Edmonton	Storm	4,793	17,191	3,587	6,229	4,869	782	11,022	22,060	47,537
Jul. 6, 1988	Slave Lake	Flooding	2,700	19,000	7,037	600	2,500	4,167	3,300	21,500	37,806
Jul. 3, 1991	Red Deer	Storm	7,212	17,275	2,395	7,812	10,927	1,399	15,024	28,202	42,644
Jun. 6-9, 1995	Calgary	Flooding	1,596	20,292	12,714	298	472	1,584	1,894	20,764	29,676
Aug. 9, 2000	Calgary	Storm	4,624	21,229	4,591	2,681	6,829	2,547	7,305	28,058	36,822
Jul. 13, 2001	Alberta	Storm	5,000	16,964	3,393	2,582	8,549	3,311	7,582	25,513	32,661
Jun. 8, 2002	S. Alberta	Flooding	3,502	42,828	12,229	N/A*	N/A*	-	-	42,828	53,621
July 2-11, 2004	Edmonton	Hailstorm (and flooding)**	12,955	166,000	12,814	N/A*	N/A*	-	-	166,000	198,502
Jun. 6-8 & Jun. 17-19, 2005	Alberta	Flooding	N/A*	300,000	-	N/A*	N/A*	-	-	300,000	351,028
Jun. 5, 2007	Alberta	Storm	N/A*	N/A*	-	N/A*	N/A*	-	-	44,621	50,104
Aug. 1-3, 2009	Alberta	Wind/ thunderstorm	N/A*	N/A*	-	N/A*	N/A*	-	-	376,300	411,825
Jul. 12-13, 2010	Calgary/S. Alberta	Wind/ thunderstorm	N/A*	N/A*	-	N/A*	N/A*	-	-	530,000	569,579
Nov. 27, 2011	Alberta	Wind/ thunderstorm	N/A*	N/A*	-	N/A*	N/A*	-	-	238,500	249,043
Jul. 11-12, 2012	Edmonton	Wind/ thunderstorm	N/A*	N/A*	-	N/A*	N/A*	-	-	N/A*	N/A*
Jul. 26, 2012	S. Alberta	Wind/ thunderstorm	N/A*	N/A*	-	N/A*	N/A*	-	-	N/A*	N/A*
Aug. 12, 2012	Region around Calgary	Wind/ thunderstorm	N/A*	N/A*	-	N/A*	N/A*	-	-	562,000	578,163
Jun. 19-24, 2013	S. Alberta	Wind/ thunderstorm	N/A*	N/A*	-	N/A*	N/A*	-	-	1,827,000	1,862,707
Aug. 7-8, 2014	S. Alberta/Calgary	Wind/ thunderstorm	N/A*	N/A*	-	N/A*	N/A*	-	-	568,900	568,900

°Not adjusted
*Not available or disclosed
**The July 2004 disaster event that occurred in Edmonton is also included in the table, as personal communications with insurance indust representatives revealed that a significant portion of the losses that occurred during this event were flood related (Sandink 2007).

Exhibit 5.2 provides detail on large loss events that were associated with storms, floods and thunderstorms, which are likely to have had significant property losses related to flooding and sewer backup. Historically, the figures were broken out to reflect the proportion of overall losses from personal property (i.e., home), auto and commercial, however, for disasters that occurred after the year 2006, only total losses have been published. Thus, average individual claims can only be calculated for events that occurred between 1983 and 2005. These statistics are provided in Exhibit 5.2. This information represents all Alberta large loss events for which data was collected between 1983 and 2015. It is important to note that loss figures presented in Table 2 may include payouts for non-physical damage to buildings, including living expenses of insured homeowners while they wait for their homes to be restored.

5.3.2 Average Individual Claim Amounts

Between 2000 and 2014, Aviva reported that the average water damage claim varied, with an increasing trend, starting at approximately $5,423 in 2000 and reaching over $16,000 by 2014 (**Exhibits 5.3 and 5.4**). It should be noted that the figures provided by Aviva Canada are for water damage losses generally, and include insurable flood losses (i.e., sewer backup) as well as other insured water damages (e.g., burst pipes, water heater failure, etc.).

Exhibit 5.3 - Aviva Canada, Historical Water Damage Claim Averages

Year	Average Water Damage Claim Value
2000	$5,423
2001	-
2002	$7,192
2003	$8,944
2004	$11,709

Sources: Aviva Canada; Friedland et al., 2014

Exhibit 5.4 - Aviva Canada, Estimated Average Water Damage Claim Values, 2010-20014

Year	Average Water Damage Claim Value
2010	>$14,000
2011	$15,309
2012	$15,500
2013	$20,537
2014	$16,070

Sources: Aviva Canada; Friedland et al., 2014; Pers. Comm., Aviva Canada, Aug. 2015 (2011 figure)

With the exception of Aviva Canada, home insurance companies do not publish information on specific losses associated with water damage. However, additional information can be gleaned from historical editions of IBC's Facts Books. Average payouts for property claims following "flooding" and "rainstorm" events, as reported in IBC Facts Books are presented in **Exhibit 5.5**. When adjusted to 2015 values, the mean individual payout over this period was $13,817, or $12,100 if the Saguenay flood is removed from the calculation. Major recent urban flood events, specifically those that occurred in Edmonton and Peterborough in 2004 and Calgary and the Greater Toronto Area, in 2005, resulted in average property claims of $18,511 (2015 CAD).

Exhibit 5.5 - Average Payout for Property Claims associated with Flooding and Rainstorm Events, 1983-2006

Event	# of property claims	Flood-related property losses ($000s)	Average payout ($)	Average payout ($), adjusted to 2015
Slave Lake, Jul. 1988	2,700	19,000	7,037	12,572
Harrow, July 1989	1,930	13,326	6,905	11,727
Toronto, Jul. 1992	993	4,596	4,628	7,008
S. Ontario, Aug. 1992	1,137	4,292	3,776	5,717
Saskatchewan, July 1993	2741	5,383	1,964	2,925
Quebec, July 1993	1,366	7,624	5,581	8,313
Winnipeg, Aug. 1993	21,264	184,837	8,692	12,946
Calgary, Jun. 1995	1,596	20,292	12,714	18,440
S. Ontario, Jan. 1994	3,289	11,759	3,576	5,326
Saguenay, Jul. 1996	5,289	203,579	38,491**	55,012**
Ottawa, Aug. 1996	2,341	19,705	8,417	12,030
Outaouais, QC, Aug 1996	1,459	7,729	5,297	7,571
Montreal and Quebec City, Nov. 1996	9,813	75,684	7,713	11,024
Sudbury, April 1997	2,553	20,426	8,000	11,244
Chambly, July 1997	3,118	29,865	9,578	13,426
Atlantic Provinces, July 1999	1,661	15,251	9,181	12,570
Atlantic Provinces, Sept. 1999	1,912	14,391	7,527	10,306
Sydney, Oct. 2000	346	3,909	11,303	15,055
Atlantic Provinces, Sept. 2001	701	6,201	8,848	11,402
Southern AB, June 2002	3,502	42,828	12,229	15,571
Atlantic Provinces, March 2003	2,727	24,591	9,018	11,191
Edmonton, July 2004	9,500*	143,000*	15,053	18,218
Peterborough, July 2004	5,154	87,000	16,939	20,501
Calgary, June 2005	13,500*	144,500*	10,704	12,737
Toronto, August 2005	13,011*	247,000*	18,984	22,589

**Large commercial losses skewed the average payout for this event
*Sewer backup only
Sources: IBC 2008; IBC 2000; *Sandink 2007 and Pers. Comm., Insurance Bureau of Canada; Bank of Canada 2015

5.3.3 Proprietary Sources

Aside from information published by IBC and Aviva Canada, three proprietary sources of personal property insurance loss data exist in Canada. These include Verisk Analytics Property Claims Service (PCS) Canada, Catastrophe Indices and Quantification, and the CGI Habitational Information Tracking System (HITS) database. Pre-arranged agreements between ICLR and these groups prohibit the publication of their data under the terms of this project. The information is provided should the team wish to pursue these sources in the future.

Property Claims Service Canada and CatIQ both rely on surveys of insurance industry partners to generate overall assessments of losses following major disaster events. Both of these services consider catastrophes to events that are likely to exceed $25 M in losses. CatIQ also publishes information associated with "notable events," which include loss events that exceed $10 M. The CGI HITS database includes detailed claim information (including address, date of claim, claim type and loss amount). This information is considered highly sensitive and is only released to agencies if special data sharing agreements are established between the interested agency and each contributing insurance company.

5.3.4 Property Claims Service (PCS) Canada

This is the information used by IBC to populate the Facts Book table starting in 2009. While IBC publishes only overall loss estimates produced by PCS, entities that subscribe to PCS are able to access commercial, auto and personal property claim counts as well as loss estimates broken out into the categories of commercial, auto and personal property. PCS includes an entry for the 2013 Alberta Flood disaster. The entry provides information on number of personal property, auto and commercial claims as well as total loss amounts for these respective categories.

http://www.verisk.com/property-claim-services/the-pcs-canada-service-verisk-insurance-solutions.html

5.3.5 Catastrophe Indices and Quantification (CatIQ)

CatIQ is a service that provides payout and claims information following large insurance loss events. The service is somewhat similar to that provided by PCS Canada, with some additional information. For example, CatIQ has tailored surveys to break out sewer backup losses. To date an estimate for the June 2013 Alberta flood has not been developed by CatIQ. CatIQ is currently developing an estimate for this event and will be releasing it to subscribers in the near-term.

https://www.catiq.com/

5.3.6 CGI Habitational Tracking System (HITS) Database

The CGI HITS database contains the most comprehensive collection of home insurance claim data for the Canadian P&C insurance industry. Agencies outside of CGI are unable to access the raw data unless special agreements with contributing insurance companies are secured. In 2014 CGI reported the HITS database stored 9.5 million records (Sandink et al. 2014). Records include specifics of individual claim occurrence, including date that the claim was made, type of claim, amount paid, and address of home insurance policyholder. With respect to water damages, data contained in the HITS database is coded using the categories displayed in **Exhibit 5.6**.

Exhibit 5.6 - Water Loss Codes Used in CGI HITS Database

Category	Sub-Category	Code
Water Damage	Standard, buildings	30
	Standard, contents	31
	Special, sewer backing, flood, etc.	39

http://www.cgi.com/en/insurance/property-risk-services

5.3.7 Considerations for Insurance Data

There are several issues with insurance data that reduce its reliability with respect to developing accurate estimates of loss potential for individual structures. These limitations should be kept in mind if this data is to be used to assess potential and historical losses. These limitations include:

- Inclusion of non-physical losses in payout estimates, including losses associated with living expenses;
- Lack of specificity in claims data. For example, claims information does not differentiate between different types of flooding, as they may be defined by those involved in the management of flood risk. It is notable that even in cases where overland flood losses were covered by insurers during the 2013 Alberta flood, they would not necessarily have been identified with a distinct "loss code" and were likely coded as sewer backup losses (Friedland et al. 2014; Sandink et al. 2014);
- "Water damage" loss estimates, including those provide by Aviva Canada and discussed above, cover the range of insured water perils, including failure of internal plumbing, along with flood perils (e.g., sewer backup);
- The potential impact of sub-limits on loss data, and;
- Lack of representation of uninsured losses (notably overland and infiltration flooding) in insurance loss data.

5.4 Review of Offerings and Limitations in Calgary

There are a number of different flood types that affect ground-related homes. These include floodwaters that enter homes via the surface of the ground (overland flooding), through foundation walls and basement floors (seepage or infiltration flooding) and through underground wastewater or stormwater management systems (sewer backup) (Sandink 2015). Insurers in different parts of the country treat each of these types of flooding in specific ways.

Though there is no standard with respect to policy wordings and types of coverage that may be provided to individual insureds, the model wordings published by the Insurance Bureau of Canada are considered the best example of an industry standard related to water damage coverage. **Exhibit 5.7** provides a summary of the IBC model wordings as they relate to water damage coverage in Canada.

Exhibit 5.7 - IBC Model Wording Summary, Water Damage

Region	Insured	Not Insured
Canada, excluding Quebec	• Sewer backup.	• Flood.* • Sewer backup within 72 hour of flood waters reaching or leaving premises. • Groundwater, rising water table. • Surface water.
Quebec	• Sewer backup. • Accidental entrance or seepage of surface or groundwater. • Rising of the water table.	• Flood.* • Surface or groundwater if occasioned by flood* or if caused directly or indirectly by flood.* • Repeated, continuous flow.

* Including but not limited to waves, tides, tidal waves, tsunami, overflowing of any watercourse, natural or man-made.

Source: Sandink et al. 2015

Based largely on the above wordings as well as previous literature (Sandink et al. 2015; Thistlethwaite and Feltmate 2013), widely insurable water damages are further summarized here:

- Flooding associated with plumbing failures (including burst pipes, watermain failure, failed water heaters, appliance failures and sprinkler system failure);
- Basement sump pump failures;
- Other "non-natural" sources of flooding;
- Damage caused by water entering homes through "…an opening which has been created suddenly and accidentally…" by an insured peril, such as wind (IBC 2003: 9);
- Coverage for sewer backup, frequently attributed to excess water entering municipal wastewater systems during extreme rainfall events, is typically available as an optional endorsement or add-on to standard homeowner insurance policies.

Coverage that is not widely available in Alberta includes:

- Losses associated with overland flooding. Flooding, as defined by the IBC model wordings, includes "…waves, tides, tidal waves or the rising of, the breaking out or the overflow of, any body of water, whether natural or man-made" (IBC 2003: 6). With respect to major causes of flood-related losses in Canada and Alberta, this definition excludes coverage for:
  - Losses associated with the accumulation or flow of stormwater (i.e., extreme rainfall stormwater flows outside of riverine flood hazard areas), and;
  - Losses associated with riverine flooding.
- Seepage (or infiltration) flooding, including water that seeps or flows into the home through cracks in basement floors, foundation walls or between the joint between basement floors and walls. This type of flooding may be caused by:
  - Overland water seeping into the backfill area directly beside foundation walls
  - Rising of the groundwater table (or other sources of groundwater)

Aside from the above exclusions, the 2014 IBC Limited Sewer Backup endorsement wording would exclude coverage for sewer backup if it occurs within 72 hrs of overland flood waters arriving at or leaving the premises (IBC 2014).

ICLR has been notified of many instances (as yet un-quantified) where sewer backup flooding may appear to be infiltration flooding. These include:

- Instances where stormwater backs up into foundation drainage, via private stormwater connections. In this case, the foundation drainage system that surrounds the foundation footing becomes pressurized, forcing water into the basement through leaky foundation walls and basement floors. This water may enter via media (e.g., gravel) beneath basement floor slabs.
- Instances where backwater valves have been improperly installed in a home where foundation drainage is connected to the home's private sanitary sewer lateral. In instances where the valve is placed in the lateral upstream of the foundation drain connection to the lateral, when the valve closes under sanitary surcharge conditions, sewage may be forced into foundation drainage, causing what may appear to be infiltration flooding.

While it is unclear how frequently this type of flooding occurs, it serves to complicate insurance coverage for flooding, as policy wordings may not reflect nuances of many flood cases.

It is important to note that some providers may deny payouts for residential sewer backup losses if uninsured overland flooding is found to be the underlying cause of the sewer backup event (IBC 2014c).

Further, as described above, insurers have provided "goodwill" payouts for uninsured losses in the past, particularly during the 2013 Alberta flooding event. With respect to home insurance coverage, condominium corporations and commercial entities that own apartment buildings may be offered commercial flood insurance that covers damage to building structures and other common elements; however, flood coverage for contents and unit upgrades is typically not offered to apartment tenants or individual condominium unit owners.

Further adding to the complicated nature of water damage insurance coverage, the details of specific home insurance policies are affected by the risk of loss for individual policyholders, resulting in different premiums, deductibles and coverage conditions for individual households (**Exhibit 5.8**). The nature of a specific insurance policy may be affected by claims history and location of the household. In some circumstances, homeowners may not be offered optional sewer backup endorsements if they are considered to be at high risk of loss – a determination likely made based on the claims history of the policyholder and frequency of sewer backup claims in a policyholder's neighbourhood (typically defined by Forward Sortation Area or Postal Code) or municipality (Applied Systems 2013; Friedland et al. 2014), although the high level competition in the industry means that high-risk households denied sewer backup coverage by one insurance provider may be able to find coverage from another provider.

5.4.1 Overland Flood Coverage Offerings Made in Alberta by Two Major Canadian Insurers

As discussed above, overland flood damages are considered widely uninsured in Canada and Alberta. However, there are cases where limited access to insurance for flooding has been provided in Calgary. For example, some Calgary insureds have been able to access flood coverage through a special arrangement organized by a Calgary broker (Beynon 2014). Further, Cooperator's has offered flood coverage in Alberta since May 25, 2015, Aviva has made overland water coverage available since June 2, 2015 and RSA has recently announced coverage (as of November 2015). Exhibit 5.9 outlines primary characteristics of these new flood coverage offerings.

RSA has defined flood in the following way: "Flood…means the breaking out or the overflow of a body of water or a watercourse, whether natural or man-made, provided the break out or overflow is caused solely by rainfall or rainwater, but flood does not include a break out or overflow of water from a watercourse or body of water containing salt water." Further, RSA states that the endorsement "…covers sudden and direct physical loss or damage caused by the backing up or escape of water, from a sewer, sump, septic tank, eaves trough, downspout or drain…." and coverage is "…extended for direct physical loss or damage to insured property which is caused directly by flood" (RSA, 2015b).

As part of the roll out of the new "overland water" endorsement, Aviva clarified sewer backup endorsements to ensure that overland flood would not be covered under their sewer backup wordings. Specifically, the sewer backup endorsement has been clarified to ensure that it covers only water from sewer, septic systems or sump pumps, and not overland floodwater. Aviva indicates that if a policyholder only has sewer backup coverage, they will not be covered for damages if overland water enters the home concurrently with sewer backup.

Exhibit 5.8 - Factors Affecting Potential Losses Borne by Homeowners in the Event of Flood Losses (Insured and Uninsured)

Factor	Description
Sub-limits	• Adjust payout limits to reflect risk for specific perils, such that higher risk insureds would receive a lower payout in the event of a claim. • Specific risk factors for individual insureds may affect sub-limits.
Deductibles	• Adjust deductibles to reflect risk such that higher risk insureds would be responsible for higher deductibles. • Specific risk factors for individual insureds may affect deductibles.
Availability	• Limit the availability of water damage or sewer backup coverage for high risk households. • Specific risk factors for individual insureds may affect availability.

Adapted from Sandink 2015

Exhibit 5.9 - Overview of Current Flood Insurance Offerings in Alberta

	Co-operators	Aviva
Initial offering date	May 25, 2015	June 2, 2015
Availability	Everyone in the province, regardless of risk level	Most properties, excluding very high risk properties • 94% of Aviva customers would be eligible for coverage • Not available for homes with reverse-slope driveways
Prerequisites	Must have sewer backup endorsement	Must have sewer backup coverage in place
Perils covered	• Flooding caused by overflow of a body of water • Sewer/water backup • Accumulation of surface water caused by heavy rain	• Sudden accumulation of water from heavy rains, spring run-off, overflow from lakes and rivers • Infiltration flooding caused by overland water (from any single occurrence) • Sewer backup from overland water (only if evidence that home experienced overland water entrance as well) • "If there is no evidence of overland flooding, sewer backup is not covered under the endorsement, even if sewer backup was caused directly or indirectly by overland water
Notes on covered perils	• Coverage added to existing sewer backup endorsements	• Sewer backup available as separate endorsement • Sump failure coverage provided under other endorsements
Exclusions	• -	• Damage caused by intentional breaches of man-made structures (e.g., dams, dikes, levees) • Any salt-water related flooding (N/A in AB) • Infiltration flooding not covered, unless caused by overland flooding
Coverage, deductible details	• Flexible coverage • Variable deductibles (available as percentage of claim amount – 2% to 35%, minimum $1,000) • Discounts provided for loss mitigation items (e.g., secondary sump pump)	Variable deductibles (policyholder can choose): • $1,000; $2,500; $5,000; $10,000; $25,000; $50,000 • Deductible selection affects premiums (i.e., policy holders may select a higher deductible to lower their premium) • May also opt to have a lower home contents/personal property limit, or have no personal property coverage, such that home contents would not be insured, to lower premiums

Sources: Aviva Canada 2015a,b; Co-operators 2015a,b

5.5 Summary: Flood Insurable Damages in Calgary

In summary, with respect to extreme rainfall and flood hazards, widely insurable damages in Alberta and Calgary include the following:

- Basement sump pump failures;
- Damage caused by water entering homes through "… an opening which has been created suddenly and accidentally…" by an insured peril, such as wind (IBC 2003: 9);
- Coverage for sewer backup, frequently attributed to excess water entering municipal wastewater systems during extreme rainfall events.
- Coverage that is not widely available in Alberta includes:
- Flooding, including damages associated with "…waves, tides, tidal waves or the rising of, the breaking out or the overflow of, any body of water, whether natural or man-made" (IBC 2003: 6). With respect to major causes of flood-related losses in Canada and Alberta, this definition excludes coverage for:
    - Losses associated with the accumulation or flow of stormwater (i.e., extreme rainfall stormwater flows outside of riverine flood hazard areas), and;
    - Losses associated with riverine flooding.
- Seepage (or infiltration) flooding, including water that seeps or flows into the home through cracks in basement floors, foundation walls or between the joint between basement floors and walls. This type of flooding may be caused by:
    - Overland water seeping into the backfill area directly beside foundation walls, and;
    - Rising of the groundwater table (or other sources of groundwater).
    - As reflected in the IBC model wordings, there has also been movement toward clarifying sewer backup wordings as a result of experience with recent severe flooding events (for example, that sewer backup would not be covered if it occurs within 72 hours of floodwaters reaching or leaving a premises).

To date, three insurers have offered overland flood coverage as optional endorsements. Experience in other parts of the world suggests that uptake of optional flood endorsements may be low. For example, in Germany, where natural disaster coverage (including flood cover) is offered by the private insurance industry as an option and is available in 99% of areas of the country, penetration is approximately 33% (OECD 2015).

Some characteristics of insurance offerings made by companies in Alberta to date suggest that a relatively high proportion of homeowners may choose to purchase coverage. For example, by limiting coverage in very high-risk areas, some of the product offerings will likely remain affordable. An example provided by RSA indicated that, for a low risk household in Alberta insured for $300,000 or less, "Waterproof Coverage" premiums would be $147. A similar home insured for $600,001-$1,000,000 would be charged $247 for coverage. Further, insurers that have offered coverage to date have reported to industry groups that policyholder interest in, and uptake of overland water/flood coverage is high. Indeed, one company has recently reported that the vast majority of their home insurance clients have expressed interest in, or have purchased overland flood endorsements. Nevertheless, the market share of companies currently offering overland flood coverage in Alberta is relatively low. As a result most homeowners are unlikely to be covered for overland flood at present.

5.6 Analysis of Flood Insurable Damages in Calgary

The available flood insurance data does not lend itself to any type of uniform recalibration of depth-damage curves or flood damage modelling for a variety of reasons:

- Payment information is not depth specific.
- It does not separate content and structural damage.
- Indirect damages and direct damages are blended.
- Coverage is extremely variable by insurance company and options selected by individual homeowners.
- Most homeowners are unlikely to be covered for overland flooding at present.

Notwithstanding, there is a concerted movement by the industry and government to move toward a national and comprehensive flood insurance program for floodplain residents.

5.7 References

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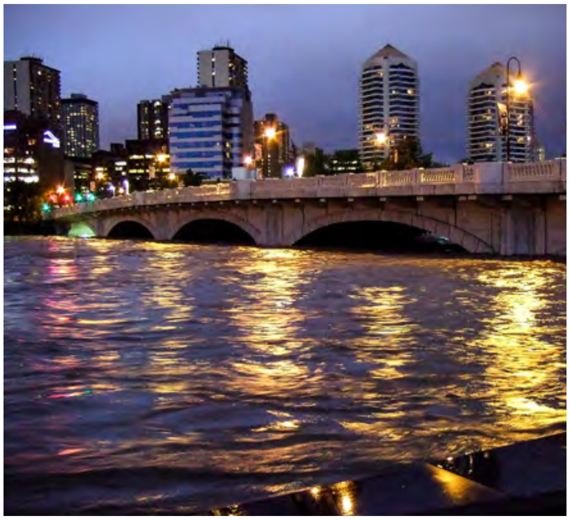

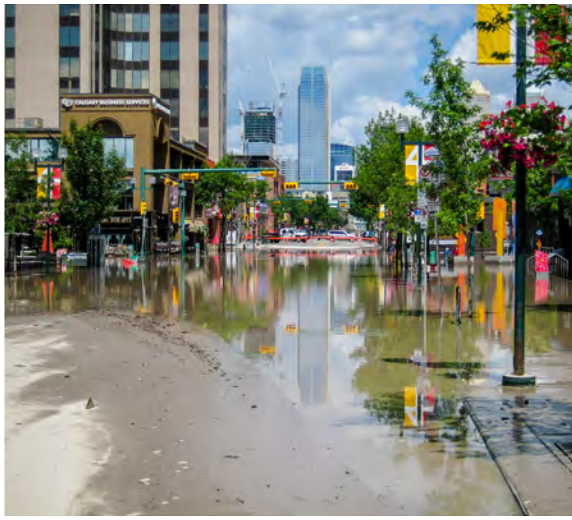

Phase 2

REPORT

Flood Mitigation Options Assessment - Phase 2

Prepared for the City of Calgary
by IBI Group and Golder Associates Ltd.

38737 | November 2016

CALGARY FLOOD, 2013

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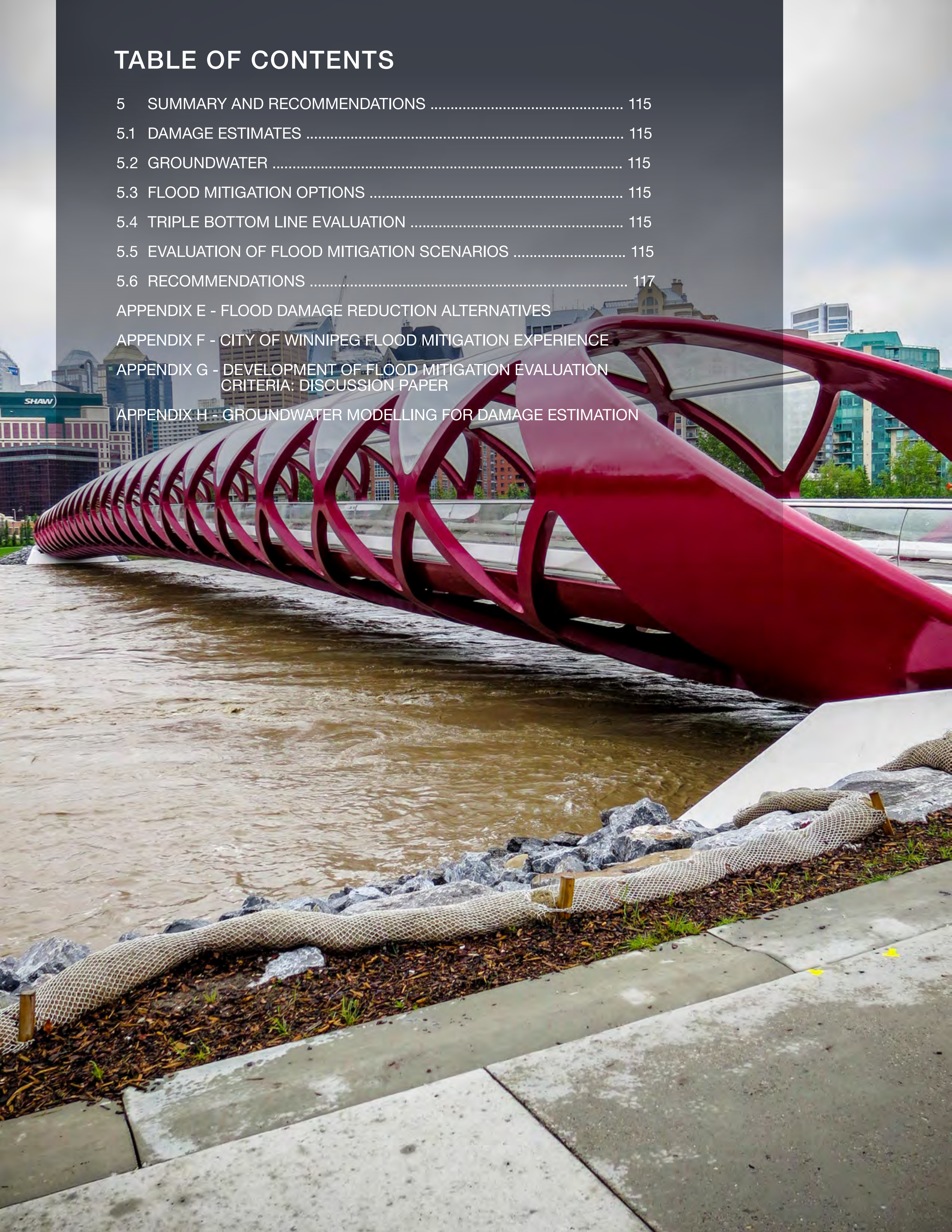


INTRODUCTION

1

1 Introduction

1.1 Background

The flood of June 2013 was the largest flood in Calgary since 1932, causing estimated damage of $409 million to City of Calgary infrastructure as well as extensive damage to private property in the city. This event also caused a significant amount of social, environmental and economic damage and disruption and put the safety of Calgarians at risk. Global climate change models predict extreme rain events are likely to become more frequent and severe in the future, potentially leading to higher flood risks; therefore it is imperative that there be proactive approaches to increasing flood resiliency.

Since the 2013 flood, The City and The Government of Alberta (The Province) have been reviewing several flood mitigation options. The City has been directing its focus on solutions within city limits including:

1. Bank stabilization and erosion protection works at various locations throughout the city.
2. The Glenmore Reservoir diversion tunnel;
3. The design of permanent flood barriers throughout the city;
4. Replacing gates on the Glenmore Dam to increase storage capacity;
5. How changes in land use policy could limit the damage during a flood event; and
6. Updating the emergency response plan for temporary barriers.

The Glenmore diversion tunnel was analyzed in considerable detail; however, is no longer under consideration as a more economically-efficient alternative is being developed for the Elbow River (the Springbank Off-Stream Reservoir). Several new barriers have been designed and constructed within the City limits in addition to the installation of outfall gates on the Bow and Elbow Rivers to prevent backup into communities. In a number of areas river channel constrictions (debris and select gravel bars) have been removed and improvements to storm and sanitary lift stations implemented.

The Province has been reviewing flood mitigation options outside of the city including:

1. Changes to reservoir management on the Bow River system;
2. The Springbank off stream storage reservoir;
3. The McLean Creek dry dam, and
4. The Room for the River initiative.

In October 2014 the Province announced that the Springbank off-stream storage project would be constructed. In addition, The City and The Province have been working together to update the hydrology and flood inundation mapping for the Bow and Elbow rivers considering the changes that have occurred since the 2013 flood. The estimated flows for the 1:100 year (or 1% annual probability) flood and flows for other return periods have higher values due to the inclusion of the 2013 flood into statistical analyses. This has resulted in increased flood extents and depths which should be accounted for in any analysis of flood mitigation options.

In February 2015, The Province released a draft final report by IBI Group that detailed estimates of flood damage derived from a calculation model and depth versus damage curves for various types of building or development in Calgary. The report was intended in part to provide a basis for evaluating the cost effectiveness of flood mitigation projects. *The Provincial Flood Damage Assessment Study City of Calgary: Assessment of Flood Damages* draft report examines damage across Calgary for a range of flood return frequencies. These estimates were subsequently employed to evaluate large-scale mitigation options for the Elbow River.

In light of the changing dynamics of the floodplain and the City's desire to better understand flood risk costs and benefits and to continue evaluating a range of structural and non-structural mitigation options, IBI Group and Golder Associates were retained in July of 2015 to undertake the Flood Mitigation Options Assessment study.

1.2 Purpose

This analysis is critical to making informed decisions on prioritizing and implementing flood risk reduction strategies. This will include determining which structural options are the most appropriate and providing direction for land use policy changes or other non-structural mitigation approaches in flood prone areas. The main objectives of the project are to:

1. Develop and apply a reliable, transparent and repeatable calculation process to understand and quantify flood risk costs and benefits across Calgary including aspects related to public safety, community planning and function, damage to buildings and infrastructure, service disruption, direct and indirect economic impacts, and the environment.
2. Provide guidance on what levels of protection are appropriate (i.e., what return period to protect to) for various flood affected communities based on the cost benefit ratios.
3. Analyse and compare which individual or combined flood mitigation options are the most cost beneficial at specified levels of service (e.g., 50, 100, 200 or 350 year return period).
4. Provide a triple bottom line prioritization of key structural and non-structural investments and actions to increase flood resiliency.
5. Provide guidance in prioritizing structural and non-structural flood mitigation investments and actions.

1.3 Scope

The project has been subdivided into two phases:

1. Phase 1 provides an update of the existing flood damage model created by IBI Group Inc. on contract for the Province, including groundwater modelling and use of the updated hydrologic and hydraulic information already generated by Golder for The City and the Province, and groundwater modelling.
2. Phase 2 involves an assessment of flood mitigation options within Calgary through a triple bottom line analysis that includes community consultation considerations and the creation of a prioritized list of investments and actions.

Both phases of the assessment have been performed in the context of current flood resiliency conditions, such as protection provided by the Glenmore Dam, permanent flood barriers in the city and 2014 changes to the Municipal Development Plan and the City of Calgary Land Use Bylaw 1P2007.

BASELINE FLOOD RISK PROFILES

2

2 Baseline Flood Risk

2.1 Introduction

The following section details damage estimates for the flood study area, including direct and indirect damages, along with the monetization of intangibles. Damages have been calculated separately for the Bow and Elbow in accordance with the flow distribution assumptions as presented in Section 2.5 "Allocation of Flood Inundation Areas for Damage Estimation" of the Phase 1 report. A comparison with previous damage estimates is also provided along with an explanation of the differences. And finally, damage estimates are presented for the existing conditions with consideration for mitigation measures that are in place or being constructed as well as for specific social impacts in various communities.

2.2 City-Wide Unmitigated Baseline

The unmitigated estimates reflect total potential damages. These values reflect a "worst case" scenario as they do not consider any existing mitigations. This is equivalent to failure of existing structures and lack of any non-structural measures. The unmitigated baseline allows for the evaluation, including benefit/cost analyses, of both current and proposed mitigation options.

2.2.1 Adjustment of Damage Model Results

For the Phase 1 analysis, considerable effort was devoted to groundwater flood damage modelling, resulting in a predicted flood groundwater elevation by return period which was subsequently employed to calculate basement damage in the flood hazard zone as well as the "adjacent-to" areas. A review of the unadjusted values employing this relationship resulted in unrealistically high damage values for the higher frequency events (1:10 year flood and below) when very little overbank flooding actually occurs.

The unadjusted values have a significant effect on the average annual damage, adding over $20 million on an annual basis and thereby overstating damage for benefit/cost purposes (see **Exhibit 2.1**). The high estimated direct damages have a hyperbolic effect on the myriad other calculations tied to these values.

Properties affected by the more frequent floods are likely to have implemented protective or adaptive measures. A recent survey (April, 2016) commissioned by the City found that 50% of flood prone households had sump pumps, 27% had a backup generator, and 29% had some form of private flood mitigation measure. The frequent flood events are not associated with issues such as widespread power loss that exacerbate groundwater damages due to pump failures, particularly in the commercial core.

In reviewing basement seepage complaints and damage data from the June 2005 flood (a 1:8 year event) it should be noted that a large percentage of basement flooding was related to soil saturation due to successive and intensive rainfall events, along with storm sewer backup, rather than riverine or overland flooding. In addition, research undertaken by the University of Calgary in the neighbourhoods of Rideau and Roxboro indicated a significant decrease in average basement damages as one moved away from the area of inundation (see **Exhibit 2.2**).

Accordingly, it was considered prudent to adjust the damages for the 5, 8, and 10 year return floods to reflect more reasonable anticipated damage values.

2.2.2 Direct Damage Estimates

As outlined in the Phase I report, direct damages for this study are limited to damage to physical property as a result of floodwaters.

2.2.2.1 Residential Damages

Residential damages for the entire study area by return period are detailed in **Exhibit 2.3**. As evidenced, these damages equate to approximately $1.1 billion for the 1:100 year flood, increasing to $1.6 billion for the 1:200 year flood, $2.1 billion for the 1:500 year flood, and $2.5 billion for the 1:1000 year flood event.

2.2.2.2 Non-Residential Damages

Non-residential property is comprised of commercial uses, such as retail, office, and industrial, as well as institutional uses, such as schools, government, or recreational facilities. Stampede Park, and in particular the associated annual Calgary Exhibition and Stampede, represents a unique circumstance as it relates to flood damage estimates. The reported 2013 damages were employed to adjust the combined Stampede Park stage-damage curves and indirect damages to current values.

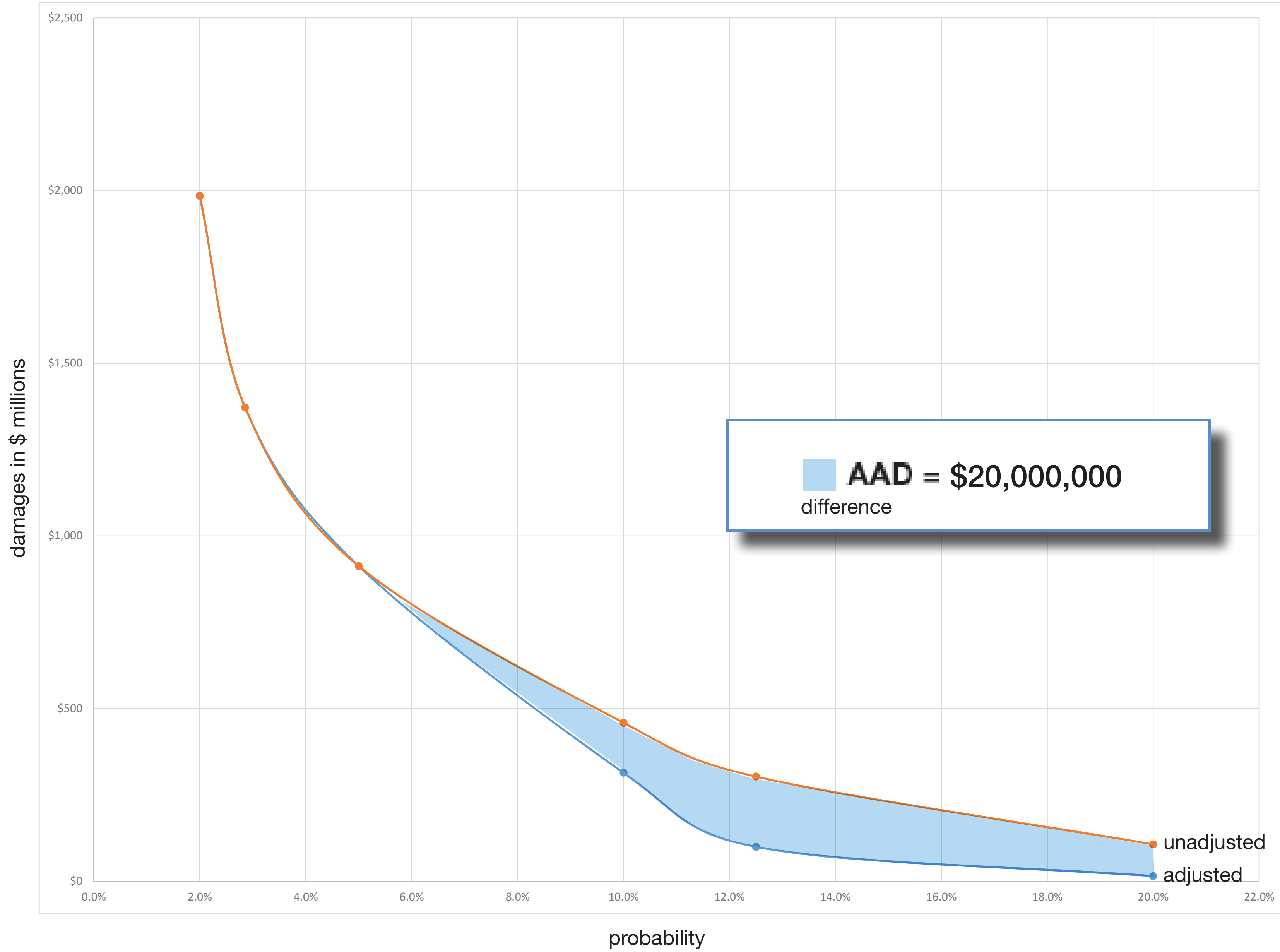
Total direct non-residential damages for the entire study area for the 1:100 year flood are estimated at $399 million, increasing to $1.7 billion for the 1:500 year event.

2.2.2.3 Infrastructure Damages

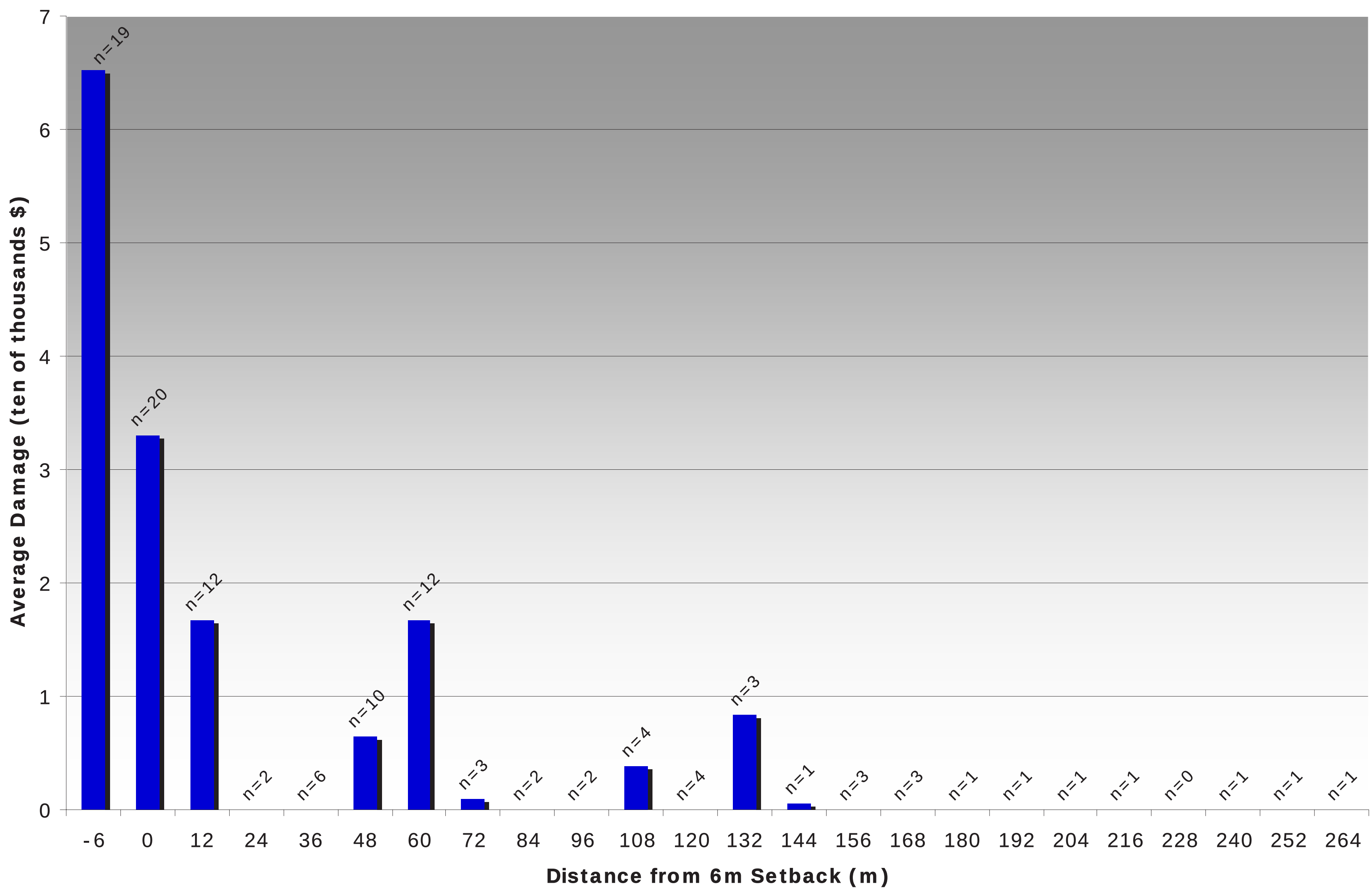
Flood damages to City infrastructure were estimated by various City Departments based on the 2013 flood and have been extrapolated across return periods to reflect the revised flow regime and areal extent of flooding with no adjustments for structural or non-structural measures currently in place.

For the 1:100 year event, infrastructure damages equate to some $549 million.

Effect of Groundwater Damage Adjustment on AAD



Average Damage vs. Distance from 6m Setback, Rideau and Roxboro June 2005



Source: University of Calgary Environmental Science 2006

2.2.3 Indirect Damage Estimates

Indirect damages include other costs incurred due to flood damaged property and infrastructure such as residential displacement, business disruption, traffic delays, habitat restoration, emergency response, and waste disposal. For the purposes of this study, these damages were developed from first principles as outlined in Section 4 "Triple Bottom Line Model Enhancements" of the Phase 1 report. Environmental damages are largely considered intangible. However, the monetization of environmental damages has been achieved by utilizing the tangible costs of habitat enhancement or compensation required for erosion control projects. Therefore, the amount is considered an indirect tangible cost and included in this total. The values are expressed in **Exhibit 2.3.** As with infrastructure, the amounts for traffic disruption, habitat restoration and emergency response were extrapolated across return periods based on inundation areas relative to events with available data.

Total indirect damages for the 1:100 year return are estimated at approximately $1 billion, or some 48% of the direct damage estimate.

2.2.4 Intangibles

The methodology for assigning a monetary value to intangible damages such as public health is detailed in Section 4 of the Phase I report. For the city-wide worst-case baseline, standard values per household were utilized as follows:

- $24,505 per affected single-family or townhouse household ($1,000 per year);
- $17,153 per affected main-floor apartment household ($700 per year); and
- $6,126 per affected upper-level apartment in a building with main-floor flooding ($250 per year).

These amounts represent the present value of annual payments for 100 years derived from secondary research on household willingness-to-pay to avoid the intangible effects of flooding. Further adjustments to these amounts based on community amenities and demographics is included in the community-specific risk profiles.

The total intangible value for each return period is included in **Exhibit 2.3.** As indicated, intangibles amount to $211 million at the 1:100 year event.

2.2.5 Groundwater Damage Estimates

Groundwater accounts for a large portion of flood damages in Calgary, particularly for higher frequency events where there is limited overland inundation. The amount of damage caused by groundwater alone decreases as larger floods inundate more of the floodplain surface. At the more frequent events, groundwater is responsible for nearly all the residential damage. Total direct groundwater damage peaks at $334 million for the 1:50 year flood and ranges from 72% of direct damages at the 1:10 year flood down to 4% at the 1:1000 year flood. The groundwater damage amounts for each category and return period are detailed in **Exhibit 2.4.**

2.2.6 Bow and Elbow Rivers

Exhibit 2.5 details damages by the Bow and Elbow Rivers respectively for the specified return periods. The Bow constitutes a majority of the direct damages, ranging from 74% to 51% of the total and generally decreasing with probability. As well, the Bow River experiences much greater non-residential damages. This is most evident at the higher frequencies but diminishes at the lower frequency events as water spills from the Elbow River through the Beltline district, in addition to covering several hundred acres in the Manchester, Alyth, Bonnybrook, Highfield and Inglewood industrial areas at the 1:500 year return period. The Bow River accounts for approximately 68% of Annual Average Damages (AAD).

2.2.7 Total Damage Estimates

Total damage estimates by return period are illustrated in **Exhibit 2.3.**

As detailed for the 1:100 year flood event, damages are estimated at $3.26 billion, increasing to $9.74 billion for the 1:500 year and $12.8 billion for the 1:1000 year event.

2.2.8 Average Annual Damages

Average annual damages are the cumulative damages occurring from various flood events over an extended period of time, averaged for the same timeframe. The average annual damages are obtained by integrating the area under the damage-probability curve, which depicts total damage versus probability of occurrence and is illustrated for the entire study area in **Exhibit 2.6**. The average annual damage for the flood study area is estimated at $168 million.

Flood Study Area Total Damages

Damage Category		Return Period 5	8	10	20	35	50
Residential	Direct	$7,126,000	$42,535,000	$121,203,000	$359,928,000	$523,486,000	$704,926,000
	Displacement	$294,000	$2,631,000	$6,781,000	$21,113,000	$31,308,000	$41,075,000
	Subtotal	$7,420,000	$45,166,000	$127,984,000	$381,041,000	$554,794,000	$746,001,000
Commercial	Direct	$2,869,000	$10,803,000	$29,968,000	$71,417,000	$122,418,000	$218,168,000
	Disruption	$2,216,000	$8,407,000	$38,198,000	$91,097,000	$167,741,000	$361,219,000
	Subtotal	$5,085,000	$19,210,000	$36,415,000	$116,002,000	$232,484,000	$386,955,000
Infrastructure		$0	$13,800,000	$63,870,000	$213,580,000	$314,696,000	$391,614,000
Traffic Disruption		$0	$652,000	$1,029,000	$3,259,000	$7,468,000	$13,691,000
Habitat Restoration		$0	$4,047,000	$4,514,000	$5,837,000	$7,237,000	$8,366,000
Emergency Response		$0	$3,400,000	$10,887,000	$36,406,000	$53,641,000	$66,752,000
Waste Disposal		$168,000	$894,000	$2,347,000	$6,957,000	$10,488,000	$14,341,000
Tangibles	Direct	$9,995,000	$67,139,000	$215,041,000	$644,925,000	$960,600,000	$1,314,707,000
	Indirect	$2,677,000	$20,030,000	$63,756,000	$164,668,000	$277,884,000	$505,444,000
	Subtotal	$12,672,000	$87,169,000	$278,797,000	$809,593,000	$1,238,483,000	$1,820,152,000
Intangibles		$2,345,000	$12,613,000	$35,361,000	$102,881,000	$133,214,000	$164,206,000
Grand Total		**$15,017,000**	**$99,782,000**	**$314,158,000**	**$912,474,000**	**$1,371,698,000**	**$1,984,357,000**

Damage Category		Return Period 75	100	200	350	500	1000
Residential	Direct	$934,557,000	$1,109,205,000	$1,615,144,000	$1,929,321,000	$2,153,960,000	$2,554,062,000
	Displacement	$54,703,000	$68,387,000	$113,922,000	$153,039,000	$181,498,000	$225,110,000
	Subtotal	$989,261,000	$1,177,591,000	$1,729,066,000	$2,082,360,000	$2,335,458,000	$2,779,172,000
Commercial	Direct	$295,762,000	$398,755,000	$732,732,000	$1,320,176,000	$1,676,316,000	$2,127,897,000
	Disruption	$517,934,000	$739,583,000	$1,535,202,000	$2,985,234,000	$3,987,784,000	$5,879,685,000
	Subtotal	$583,672,000	$824,154,000	$1,848,870,000	$3,810,152,000	$4,903,251,000	$7,125,350,000
Infrastructure		$486,377,000	$548,842,000	$705,730,000	$866,399,000	$934,836,000	$1,074,926,000
Traffic Disruption		$26,228,000	$53,284,000	$71,195,000	$88,993,000	$131,919,000	$153,906,000
Habitat Restoration		$10,000,000	$10,973,000	$13,696,000	$16,187,000	$17,938,000	$21,829,000
Emergency Response		$82,905,000	$93,553,000	$120,295,000	$147,682,000	$159,347,000	$183,226,000
Waste Disposal		$19,270,000	$23,429,000	$36,891,000	$51,556,000	$59,729,000	$73,291,000
Tangibles	Direct	$1,716,697,000	$2,056,801,000	$3,053,605,000	$4,115,896,000	$4,765,112,000	$5,756,885,000
	Indirect	$711,041,000	$989,208,000	$1,891,201,000	$3,442,690,000	$4,538,215,000	$6,537,047,000
	Subtotal	$2,427,737,000	$3,046,009,000	$4,944,806,000	$7,558,586,000	$9,303,327,000	$12,293,932,000
Intangibles		$187,123,000	$211,108,000	$310,334,000	$382,559,000	$436,802,000	$508,616,000
Grand Total		**$2,614,861,000**	**$3,257,117,000**	**$5,255,140,000**	**$7,941,145,000**	**$9,740,129,000**	**$12,802,548,000**

Average Annual Damages (AAD)	**$168,000,000**

Damages Attributed to Groundwater

Return Period												
Damage Category	**5**	**8**	**10**	**20**	**35**	**50**	**75**	**100**	**200**	**350**	**500**	**1000**
GW Direct Damages	$6,872,092	$33,003,140	$100,237,624	$265,863,764	$296,120,819	$334,204,898	$223,624,020	$202,856,096	$271,765,967	$242,990,021	$226,081,449	$182,349,320
GW % of Total	69%	62%	72%	64%	47%	39%	19%	15%	12%	8%	6%	4%
GW Residential Direct Damages	$6,139,719	$30,704,113	$92,682,600	$239,094,795	$241,022,845	$255,485,872	$155,033,844	$139,772,301	$198,660,918	$198,110,438	$186,785,246	$158,902,597
GW % of Total	86%	72%	76%	66%	46%	36%	17%	13%	12%	10%	9%	6%
GW Non-residential Direct Damages	$732,373	$2,299,028	$7,555,024	$26,768,969	$55,097,974	$78,719,027	$68,590,176	$63,083,795	$73,105,049	$44,879,583	$39,296,202	$23,446,723
GW % of Total	26%	21%	40%	49%	54%	52%	32%	22%	12%	4%	3%	1%
Waste Disposal	$115,191	$553,206	$1,680,205	$4,456,466	$4,963,641	$5,602,015	$3,748,434	$3,400,318	$4,555,400	$4,073,051	$3,789,626	$3,056,579
GW % of Total	69%	62%	72%	64%	47%	39%	19%	15%	12%	8%	6%	4%
GW Residentail Displacement	$248,667	$1,780,831	$5,041,779	$13,970,926	$13,233,304	$13,629,616	$9,340,764	$8,623,733	$13,896,043	$14,072,179	$12,900,413	$10,088,076
GW % of Total	85%	68%	74%	66%	42%	33%	17%	13%	12%	9%	7%	4%
GW Residential Intangible	$2,075,203	$9,187,103	$27,959,435	$75,107,463	$73,333,498	$75,164,046	$46,259,200	$41,381,505	$61,029,358	$63,312,048	$61,285,546	$59,422,051
GW % of Total	89%	73%	79%	73%	55%	46%	25%	20%	20%	17%	14%	12%
GW Non-residential Disruption	$895,026	$2,849,681	$9,974,205	$35,613,974	$89,263,850	$154,226,893	$160,262,156	$156,006,218	$191,856,819	$133,795,596	$101,328,758	$60,959,897
GW % of Total	40%	34%	57%	58%	69%	65%	43%	29%	15%	5%	3%	1%
Number of GW Affected Households	2,479	5,235	6,556	8,709	11,943	13,515	10,458	9,475	13,082	10,475	8,577	6,251
GW % of Total	100%	96%	93%	82%	73%	66%	48%	39%	36%	26%	20%	13%
Groundwater Subtotal	$10,090,988	$46,820,755	$143,213,042	$390,556,126	$471,951,472	$577,225,453	$439,486,140	$408,867,552	$538,548,187	$454,169,844	$401,596,166	$312,819,344
GW % of Total	68%	61%	72%	65%	51%	44%	25%	18%	14%	7%	5%	3%
AAD due to GW	$40,700,000											
GW % of Total	24%											

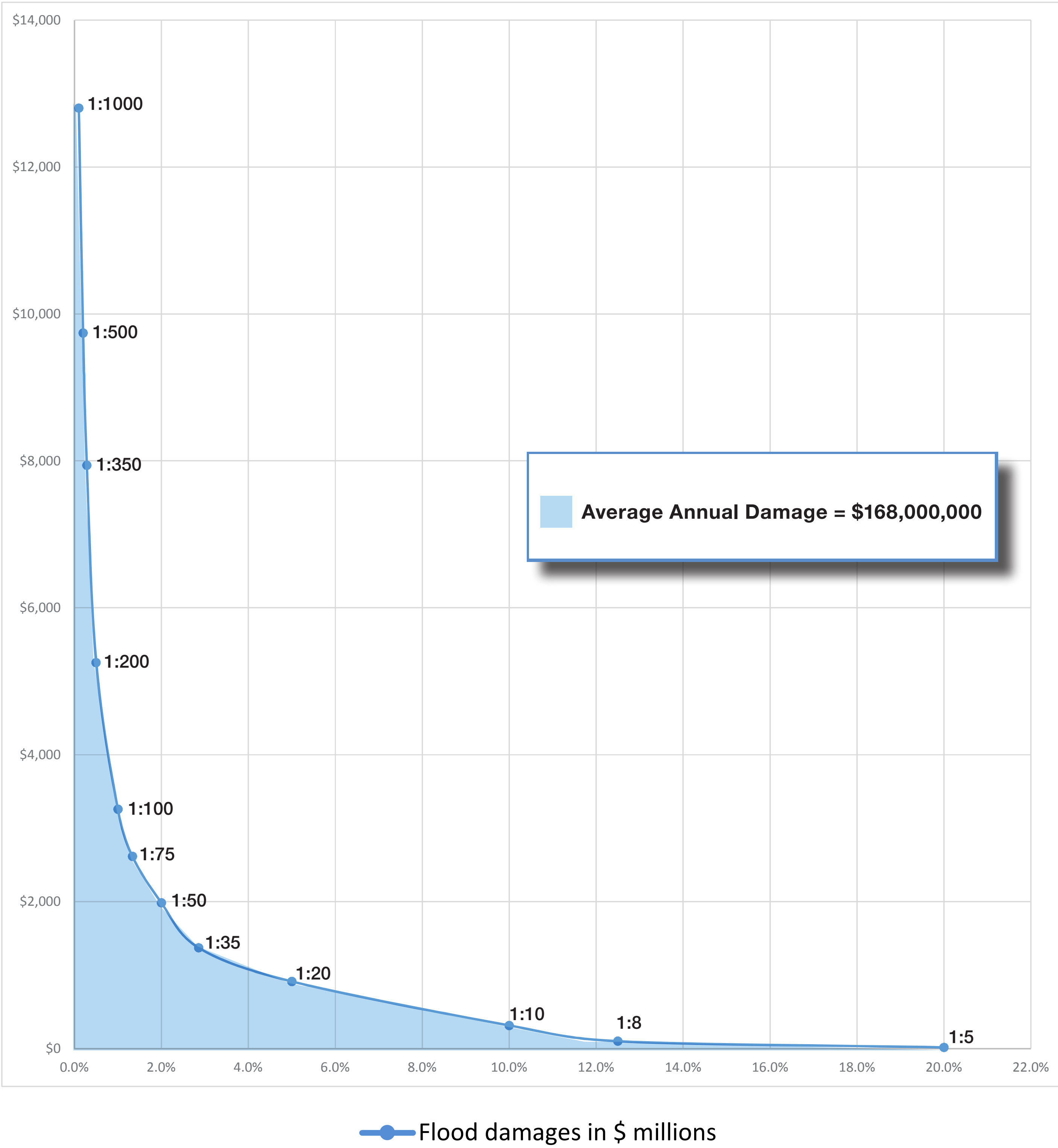
* Damages due to flooding of buildings (does not include infrastructure, traffic, habitat, or emergency response)

Damages Attributed to Bow and Elbow Rivers

Return Period													
Damage Category		5	8	10	20	35	50	75	100	200	350	500	1000
Direct Damages	Elbow	$2,664,514	$16,034,588	$43,700,407	$108,047,275	$163,134,601	$289,005,175	$435,606,040	$565,259,546	$959,693,806	$1,494,483,672	$1,704,046,268	$2,005,647,880
	%	27%	30%	31%	26%	26%	34%	38%	40%	44%	49%	48%	46%
	Bow	$7,330,798	$37,304,016	$96,329,957	$306,978,203	$462,532,317	$566,568,307	$714,003,335	$832,459,884	$1,241,141,763	$1,581,238,702	$1,859,264,874	$2,366,756,162
	%	73%	70%	69%	74%	74%	66%	62%	60%	56%	51%	52%	54%
Residential Direct Damages	Elbow	$1,912,704	$15,016,316	$41,518,165	$101,823,198	$147,363,963	$254,765,153	$384,280,931	$477,062,529	$763,328,417	$898,764,799	$990,756,153	$1,108,284,177
	%	27%	35%	34%	28%	28%	36%	41%	43%	47%	47%	46%	43%
	Bow	$5,213,707	$27,519,078	$79,685,298	$258,104,888	$376,121,891	$450,160,784	$550,276,507	$632,142,142	$851,815,437	$1,030,556,352	$1,163,203,800	$1,445,778,087
	%	73%	65%	66%	72%	72%	64%	59%	57%	53%	53%	54%	57%
Non-residential Direct Damages	Elbow	$751,810	$1,018,272	$2,182,242	$6,224,078	$15,770,639	$34,240,023	$51,325,109	$88,197,016	$196,365,389	$595,718,873	$713,290,115	$897,363,704
	%	26%	9%	12%	11%	15%	23%	24%	31%	34%	52%	51%	49%
	Bow	$2,117,091	$9,784,937	$16,644,659	$48,873,315	$86,410,426	$116,407,523	$163,726,828	$200,317,742	$389,326,326	$550,682,350	$696,061,074	$920,978,074
	%	74%	91%	88%	89%	85%	77%	76%	69%	66%	48%	49%	51%
Residentail Displacement	Elbow	$72,404	$856,677	$2,061,360	$4,713,657	$6,567,981	$12,400,633	$20,393,620	$28,245,392	$57,589,142	$78,485,005	$93,389,936	$112,370,663
	%	25%	33%	30%	22%	21%	30%	37%	41%	51%	51%	51%	50%
	Bow	$221,415	$1,773,928	$4,719,519	$16,399,576	$24,740,093	$28,674,340	$34,309,738	$40,141,433	$56,333,115	$74,553,705	$88,107,629	$112,739,293
	%	75%	67%	70%	78%	79%	70%	63%	59%	49%	49%	49%	50%
Residential Intangible	Elbow	$293,079	$2,972,904	$8,063,302	$20,635,519	$28,394,987	$47,187,694	$62,322,743	$74,611,593	$133,267,671	$164,320,628	$186,692,952	$209,746,528
	%	12%	24%	23%	20%	21%	29%	33%	35%	43%	43%	43%	41%
	Bow	$2,051,679	$9,639,975	$27,297,830	$82,245,629	$104,819,472	$117,017,981	$124,800,661	$136,496,726	$177,066,657	$218,237,938	$250,108,585	$298,869,214
	%	88%	76%	77%	80%	79%	71%	67%	65%	57%	57%	57%	59%
Non-residential Disruption	Elbow	$585,387	$788,737	$1,769,950	$9,071,940	$22,218,001	$47,607,102	$80,712,836	$160,975,415	$354,208,912	$1,071,851,452	$1,333,616,441	$1,797,486,350
	%	26%	9%	10%	15%	17%	20%	22%	30%	28%	40%	38%	34%
	Bow	$1,630,338	$7,618,348	$15,817,799	$51,832,859	$108,085,007	$188,699,881	$287,907,317	$374,663,596	$908,969,004	$1,591,899,613	$2,160,282,963	$3,509,521,454
	%	74%	91%	90%	85%	83%	80%	78%	70%	72%	60%	62%	66%
Number of Affected Households	Elbow	658	2,032	2,882	3,578	5,794	9,456	10,173	11,398	18,788	20,700	21,879	23,512
	%	26%	37%	41%	34%	35%	46%	46%	47%	52%	51%	50%	50%
	Bow	1,832	3,438	4,154	7,084	10,599	11,133	11,728	12,976	17,229	20,152	21,922	23,878
	%	74%	63%	59%	66%	65%	54%	54%	53%	48%	49%	50%	50%
Totals	Elbow	$3,615,384	$20,652,906	$55,595,018	$142,468,391	$220,315,570	$396,200,604	$599,035,238	$829,091,945	$1,504,759,530	$2,809,140,757	$3,317,745,597	$4,125,251,422
	%	24%	27%	28%	24%	24%	31%	34%	37%	39%	45%	43%	40%
	Bow	$11,234,231	$56,336,267	$144,165,105	$457,456,267	$700,176,889	$900,960,509	$1,161,021,051	$1,383,761,639	$2,383,510,540	$3,465,929,957	$4,357,764,051	$6,287,886,122
	%	76%	73%	72%	76%	76%	69%	66%	63%	61%	55%	57%	60%
AAD	Elbow	$62,400,000											
	%	37%											
	Bow	$105,600,000											
	%	63%											

* Damages due to flooding of buildings (does not include infrastructure, traffic, habitat, or emergency response)

Flood Damages Probability Distribution Bow and Elbow Rivers



2.2.9 Comparison with Previous Damage Estimates

A variety of factors have contributed to an increase in the estimated damages for the City of Calgary. These are briefly summarized hereinafter.

2.2.9.1 Increase in Peak Discharge and Flood Level

As discussed in the Phase 1 report, the previous City of Calgary damage estimates undertaken in 2014 were based on the 2011 hydrology study and 2012 hydraulic model undertaken by Golder Associates. The most recent damage estimates are based on revised updated hydrology and hydraulics by Golder Associates in 2015. Hydraulic modelling has resulted in simulated water levels that are on average 0.27 m higher for the Bow River and 0.38 m higher for the Elbow River than those using the 2012 model.

2.2.9.2 Expanded Flood Hazard Area

The areal extent of inundation has increased substantially and particularly within the downtown area for the lower frequency events, greater than 1:200 year. For the 1:100 year event, the largest increases occur in Hillhurst and the Beltline, with lesser increases evident in the area just north of the Deerfoot Meadows commercial development in southeast Calgary. The other area of note is related to a large area of spill at the 1:500 year return period, which covers several hundred acres in the Manchester, Alyth, Bonnybrook, Highfield and Inglewood industrial areas.

The expanded flood hazard area includes more than double the amount of buildings as the 2014 inventory. The estimated total number of residential units in the hazard area is 52,883 along with 1,970 non-residential buildings.

2.2.9.3 Reallocation of Flood Inundation Areas for Damage Estimation

Along some of the river reaches the source of overland floodwater can be a mixture of Bow and Elbow River water, particularly during extreme flood events (e.g., 1,000 year flood). Consequently, judgement and approximation was employed to define the boundary lines separating the flood inundation areas attributed to the Bow River or Elbow River for those areas where mixing of the river floodwaters may occur. These boundary lines were used to attribute the flood inundation areas to either one of the rivers for the purpose of flood damage modelling.

2.2.9.4 Residential Displacement and Commercial Disruption

Indirect damages include other costs incurred due to flood damaged property and infrastructure such as residential displacement, business disruption, traffic delays, habitat restoration, emergency response and waste disposal. For the purposes of this study, these damages were developed from first principles as outlined in Section 4 of the Phase 1 report.

2.2.9.5 Monetization of Intangibles

A methodology was developed for assigning a monetary value to intangible damages such as public health, as detailed in Section 4 of the Phase 1 report. These amounts represent the net present value of annual payments for 100 years derived from secondary research on household willingness to pay to avoid the intangible effects of flooding.

2.2.9.6 Groundwater Damage Estimates

Groundwater accounts for a large portion of flood damages in Calgary, particularly for higher frequency events where there is limited overland inundation. In consideration of the overall characteristics of the alluvial aquifer a simplified relation of maximum groundwater level versus distance from the edge of surface inundation relationship was developed for application throughout the study domain. This relationship was used to estimate or approximate the maximum groundwater table rise within the alluvial aquifer for the various flood return periods.

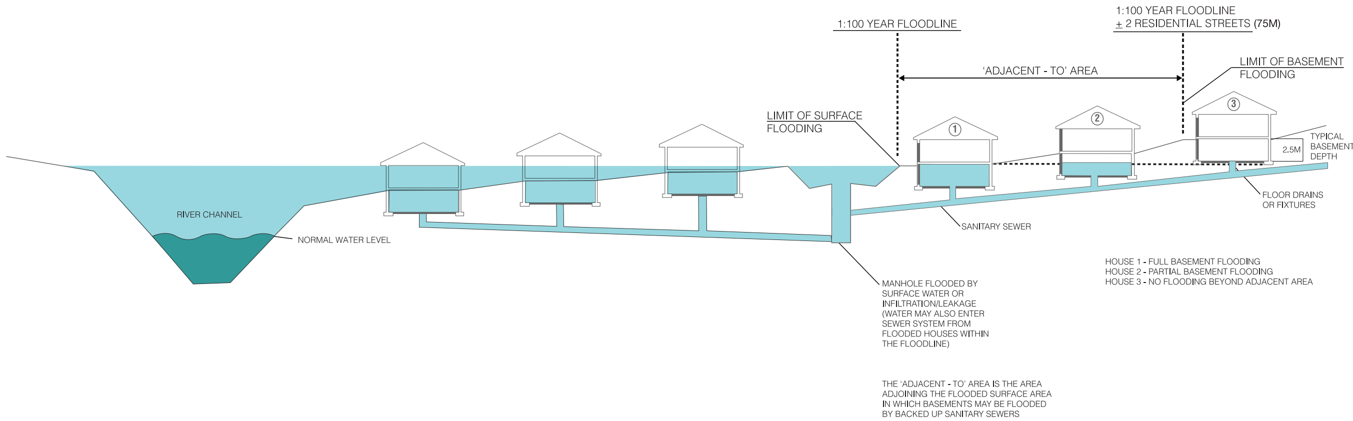
As it relates to the “adjacent-to” area, the area adjoining the flooded surface area in which basements may be flooded by backed up sanitary sewers, the modelled groundwater profiles were employed to determine basement damages from groundwater beyond the area of surface inundation. A further groundwater profile was modelled for areas with flood barriers in place to account for damages to basements due to groundwater flooding. These relationships are depicted in Exhibit 2.7. Additional relationships were developed to model the effects on maximum groundwater levels by the Springbank Road and potential Bow River reservoir(s). The detailed methodology and results of the groundwater flood modelling conducted in the Phase 2 study are presented in Appendix H.

2.2.9.7 Discussion of Results

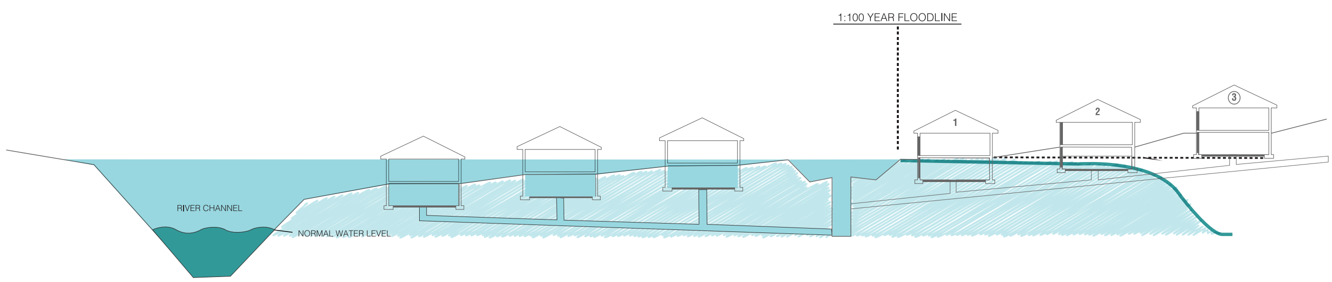
The impact of these factors resulted in an essential doubling of the average annual damage from $84 million to $168 million with the largest impact (62%) attributable to the increase in peak discharge.

Groundwater Flooding Assumptions

1) CONVENTIONAL 'ADJACENT-TO AREA' ASSUMPTIONS
- ALL BASEMENTS BELOW HYDRAULIC GRADELINE FLOODED WITHIN DEFINED AREA (75m)

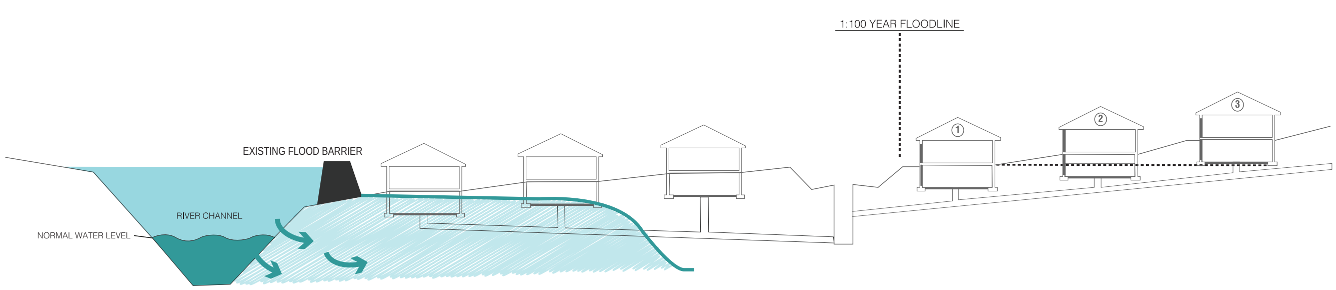


2) GROUNDWATER/LIMIT OF SURFACE FLOODING FUNCTION
- ALL BASEMENTS FLOODED BELOW MODELLED GROUNDWATER PROFILE



3) EXISTING BARRIER IN PLACE - NO SURFACE FLOODING

BASEMENT FLOODING BASED ON GROUNDWATER FLOODING FUNCTION



2.3 Existing Mitigation

Many parts of the city are currently protected to various levels by existing barriers. The City is also currently constructing several new barriers and drainage improvements. To conduct benefit/cost analyses on the proposed scenarios, only the additional benefit they provide should be considered. Therefore, a second damages baseline, or 'Scenario 0', was calculated.

Existing baseline mitigation measures include:

- TransAlta's hydro facilities and reservoirs in the Bow River basin - historical operations
- Glenmore reservoir on the Elbow River, including gates improvements
- Existing barriers (existing conditions without raising dykes)
- Discovery Ridge barrier (not in study area)
- Stampede barrier
- Zoo barrier (100-year flood level)
- Eau Claire West barrier (200-year flood level)
- Heritage Dr./Glendeer Circle barrier (100-year flood level)
- Centre Street bridge lower deck - gates (50-year flood level)
- Bonnybrook improvements (100-year flood level)
- Deane House barrier (100-year flood level)
- Stormwater outfall gates (downtown, Mission, Eau Claire, Bowness)
- Gates and Pump Stations at planned permanent barriers
- Temporary flood barriers at various locations per the City's flood emergency response plan

This scenario represents damages that would be incurred at the current level of protection. The difference in the AAD of the unmitigated and current scenarios is the benefit of existing measures. The benefit of proposed mitigation scenarios is the amount of damages they reduce from the current scenario.

2.3.1 Adjustment of Damage Model Results

For the reasons outlined in Section 2.2.1, and to provide consistent comparison of scenarios the modeled damages at the 5, 8, and 10 year return floods were adjusted in the same manner for all scenarios.

2.3.2 Isolated Flooding

The flood modelling for each scenario identified overland flooding areas as either being inundated or isolated. An inundated area is flooded by water from the river channel. An isolated area has surface water that is disconnected from the water in the river channel. Isolated flooding occurs due to elevation lower than the river level and poor drainage of stormwater, groundwater, or sewer backup. A separate flood surface was created for the isolated areas.

The isolated areas are further identified as having no mitigation, stormwater outfall gates, or gates and pumps. For the purposes of assigning damages, the following assumptions were used:

- Isolated without protection: a 100% probability of overland accumulation was assumed. The isolated area flood surface was applied to all structures.
- Isolated with gates: a 50% probability of overland accumulation was assumed. The isolated area flood surface was applied to 50% of structures, and the river plus groundwater surface applied to the remaining 50%.
- Isolated with gates and pumps: a 0% probability of overland accumulation was assumed. The river plus groundwater surface was applied to all structures.

2.3.3 Application of Intangible Damage Values

The Phase I report details the research conducted to assess and monetize the intangible impacts of flooding on households. Based on the methodology and results of studies that determined a household's willingness-to-pay to avoid the effects of flooding, a standard value per affected household was adopted and utilized for the city-wide damages as indicated in Section 2.2.4. This value represents the impact on a household's quality of life including but not limited to illness, worry, loss of services, community relations, loss of enjoyment of the environment or historical assets, etc.

Phase I research also sought to identify variables that contribute to this impact. Many of the key variables such as personality, previous experience, pre-existing conditions, trust in authorities, and preparedness cannot be measured. Others, such as age, gender, income, and household type can be assessed with census data. It was found that household type and income would be the most reliable indicators. The impact of flooding is generally greater for families with children and for households with lower incomes.

The intangible damage amount per household was adjusted according to the tract level data from the 2011 federal census and national household survey. Flooding affects a total of 15 tracts within the city. The percentile rank for each census tract was calculated based on a combination of median household income and percentage of households with children. This determined the top, middle, and bottom thirds in terms of relative impact, or high, medium, and lower groups.

The high impact was associated with an increase of 30% annually per household, no change for the medium impact, and a decrease of 30% for the lower impact. These values were then assigned to each affected household according to the census tract it is located in.

2.3.4 Infrastructure, Traffic Disruption, Habitat Restoration, and Emergency Operations

Several of the categories included in this study are not object-based and therefore not determined by a depth of flooding in a specific location. This includes infrastructure, traffic disruption, habitat restoration, and emergency operations. For the unmitigated scenario, damages associated with these categories were estimated for select return periods, primarily using data from past events (2005 and 2013 floods). These costs were then extrapolated to other return periods based on the relative extent of inundation. In order to apply these categories of damages to the existing and all other scenarios to be analysed, a relationship between the unmitigated estimate and the overland direct damage amount across all return periods was determined for each category. These equations were subsequently applied to the overland direct damage of all remaining scenarios.

2.3.5 Total Damage Estimates

Total damage estimates by category and return period are illustrated in **Exhibit 2.8.**

As detailed for the 1:100 year flood event, damages are estimated at $2.68 billion, increasing to $9.08 billion for the 1:500 year and $12 billion for the 1:1000 year event.

2.3.6 Average Annual Damages

The average annual damage for the flood study area is estimated at $116.6 million. The Bow River accounts for approximately $75 million, or 64%, of the total AAD.

2.3.7 Comparison with Unmitigated Damage Estimates and Community Groups

A comparison of the unmitigated and existing scenario (0) is provided in **Exhibit 2.9.** The exhibit indicates damages associated with the flooding of buildings (direct damages, business interruption, residential displacement, and household intangibles). Damages are further broken down by community group. The community groups reflect areas that would likely be protected together by mitigation along a common reach of the river.

When comparing the AAD from the unmitigated direct damages to buildings to the existing mitigations in place, the largest change can be seen along the Bow River in the City Centre for communities such Sunnyside and Hillhurst, on the north side as well as Downtown on the south. Bowness and communities along the Elbow River benefit less from existing mitigation.

2.4 Summary and Conclusions

The updated hydrology and hydraulics have greatly increased the baseline damage amounts. In addition, application of the groundwater modeling over the expanded hazard area results in large estimated damages due to groundwater flooding.

Existing mitigation measures are providing considerable benefit. The difference in AAD between the unmitigated and existing scenarios amounts to an annual benefit of over $50 million.

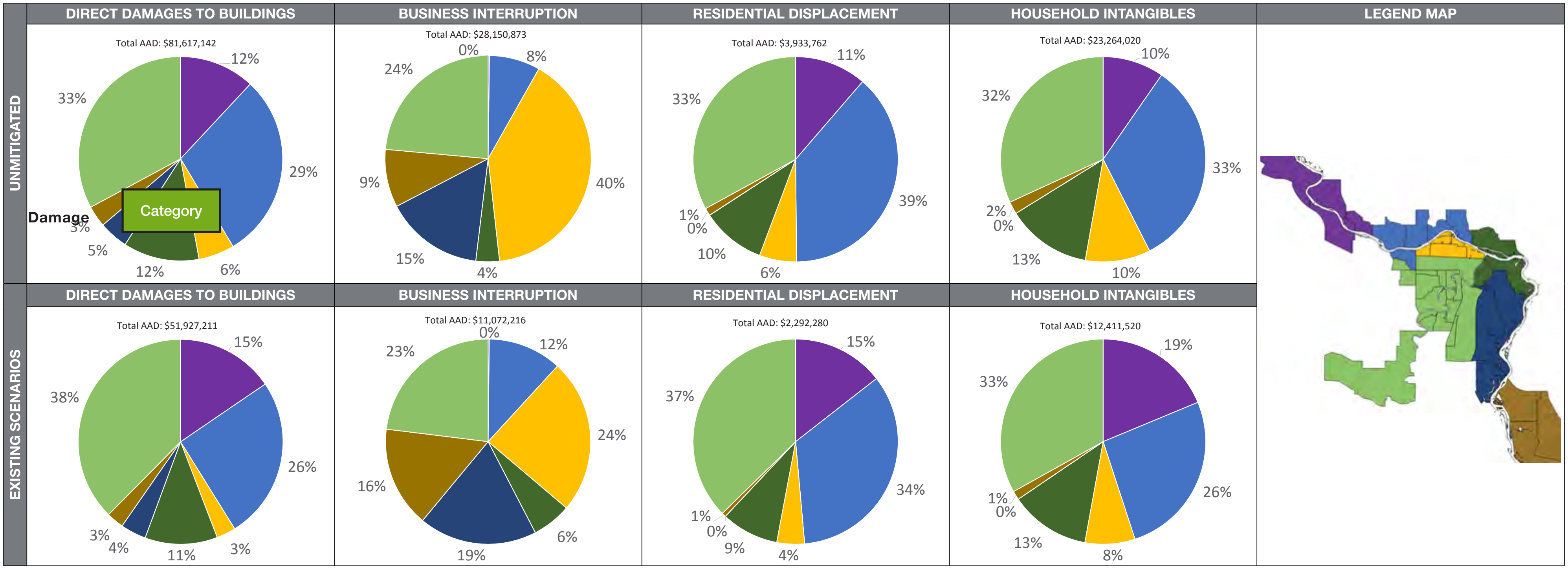
The majority of existing mitigations are effective for floods of higher frequency (below 100 year return period). Therefore, the damage estimates differ greater for these events and are essentially equal above the 1:200 year event. However, the benefits at the frequent events are substantial. For instance, at the 1:20 year event the mitigated total is estimated at $571 million which is roughly 60% of the unmitigated total of $912 million.

For the purposes of this study, the benefits provided by all scenarios will be derived from the existing scenario, referred to as Scenario 0 or simply “the baseline”. The benefits will be calculated as the reduction in AAD from the $116.6 million baseline.

Scenario 0 - Existing Baseline

Damage	Category	Return Period (yrs)										
		5	8	10	20	35	50	75	100	200	350	500	1000
Residential	Direct	$3,868,000	$22,484,000	$47,726,000	$241,227,000	$383,460,000	$586,502,000	$852,257,000	$1,042,714,000	$1,557,819,000	$1,928,469,000	$2,152,833,000	$2,552,599,000
	Displacement	$122,000	$1,071,000	$2,557,000	$11,542,000	$20,427,000	$32,127,000	$49,141,000	$64,922,000	$108,839,000	$152,646,000	$181,067,000	$224,804,000
	Total	$3,991,000	$23,554,000	$50,283,000	$252,768,000	$403,887,000	$618,629,000	$901,398,000	$1,107,635,000	$1,666,658,000	$2,081,115,000	$2,333,900,000	$2,777,403,000
Commercial	Direct	$296,000	$8,688,000	$11,439,000	$34,570,000	$58,718,000	$90,605,000	$150,218,000	$223,210,000	$555,751,000	$1,146,401,000	$1,409,351,000	$1,818,342,000
	Disruption	$202,000	$6,510,000	$8,703,000	$28,812,000	$49,645,000	$107,577,000	$224,685,000	$450,315,000	$1,219,213,000	$2,694,879,000	$3,541,697,000	$5,381,885,000
	Total	$497,000	$15,199,000	$20,142,000	$63,382,000	$108,364,000	$198,182,000	$374,903,000	$673,524,000	$1,774,964,000	$3,841,280,000	$4,951,048,000	$7,200,227,000
Infrastructure		$0	$8,807,000	$37,523,000	$144,695,000	$222,186,000	$325,388,000	$441,362,000	$511,923,000	$700,893,000	$866,399,000	$934,836,000	$1,074,926,000
Traffic		$0	$416,000	$573,000	$2,208,000	$5,273,000	$11,376,000	$23,801,000	$49,700,000	$70,707,000	$88,993,000	$131,919,000	$153,906,000
Habitat Restoration		$0	$2,582,000	$1,025,000	$3,954,000	$5,110,000	$6,951,000	$9,074,000	$10,235,000	$13,603,000	$16,187,000	$17,938,000	$21,829,000
Emergency Operations		$0	$2,170,000	$6,396,000	$24,664,000	$37,873,000	$55,464,000	$75,232,000	$87,260,000	$119,470,000	$147,682,000	$159,347,000	$183,226,000
Waste Disp.		$71,000	$530,000	$1,006,000	$4,689,000	$7,517,000	$11,511,000	$17,042,000	$21,521,000	$35,931,000	$52,287,000	$60,576,000	$74,331,000
Subtotals	Direct	$4,164,000	$39,979,000	$96,688,000	$420,492,000	$664,365,000	$1,002,496,000	$1,443,837,000	$1,777,847,000	$2,814,463,000	$3,941,269,000	$4,497,020,000	$5,445,866,000
	Indirect	$394,000	$13,279,000	$20,260,000	$75,868,000	$125,845,000	$225,005,000	$398,976,000	$683,951,000	$1,567,762,000	$3,152,674,000	$4,092,544,000	$6,039,981,000
	Subtotal	$4,559,000	$53,258,000	$116,948,000	$496,360,000	$790,209,000	$1,227,501,000	$1,842,813,000	$2,461,797,000	$4,382,225,000	$7,093,943,000	$8,589,564,000	$11,485,847,000
Intangibles		$1,526,000	$7,109,000	$14,429,000	$74,619,000	$111,605,000	$159,389,000	$187,038,000	$219,771,000	$328,969,000	$455,326,000	$491,979,000	$542,804,000
Total		$6,085,000	$60,367,000	$131,377,000	$570,979,000	$901,815,000	$1,386,890,000	$2,029,851,000	$2,681,569,000	$4,711,194,000	$7,549,268,000	$9,081,543,000	$12,028,651,000
AAD		$116,578,000											

Comparison of Unmitigated and Existing Scenarios by Community Group



GROUP	1	2	3	4	5	6	7	
COMMUNITY	BOWNESS PARKDALE MONTGOMERY	HILLHURST SUNNYSIDE WEST HILLHURST CRESENT HEIGHTS SUNALTA	DOWNTOWN COMMERCIAL CORE CHINATOWN EAU CLAIRE DOWNTOWN EAST VILLAGE DOWNTOWN WEST END	INGLEWOOD BRIDGELAND/RIVERSIDE RAMSAY	BURNS INDUSTRIAL EAST FAIRVIEW INDUSTRIAL ALYTH/BONNYBROOK GLENDEER BUSINESS PARK HIGHFIELD	RIVERBEND DOUGLASDALE/GLEN SHEPARD INDUSTRIAL	BELTLINE ELBOW PARK ELBOYA RIDEAU PARK MISSION ROXBORO ERLTON	CLIFF BUNGALO LOWER MOUNT ROYAL MANCHESTER INDUSTRIAL PARKHILL GLENMORE PARK

IDENTIFICATION AND QUALITATIVE ASSESSMENT OF FLOOD MITIGATION OPTIONS

3

3 Identification and Qualitative Assessment of Flood Mitigation Options

3.1 Introduction

The following section is devoted to an examination of flood mitigation options, commencing with a general assessment of typical structural and non-structural approaches. Provincial and City-initiated flood studies are summarized, and along with an examination of the myriad options that have been assessed and implemented in Winnipeg, one of the major cities in Canada where flooding occurs periodically, a long list of potential approaches has been screened, resulting in a shortlist of preferred options for consideration in the flood mitigation scenarios.

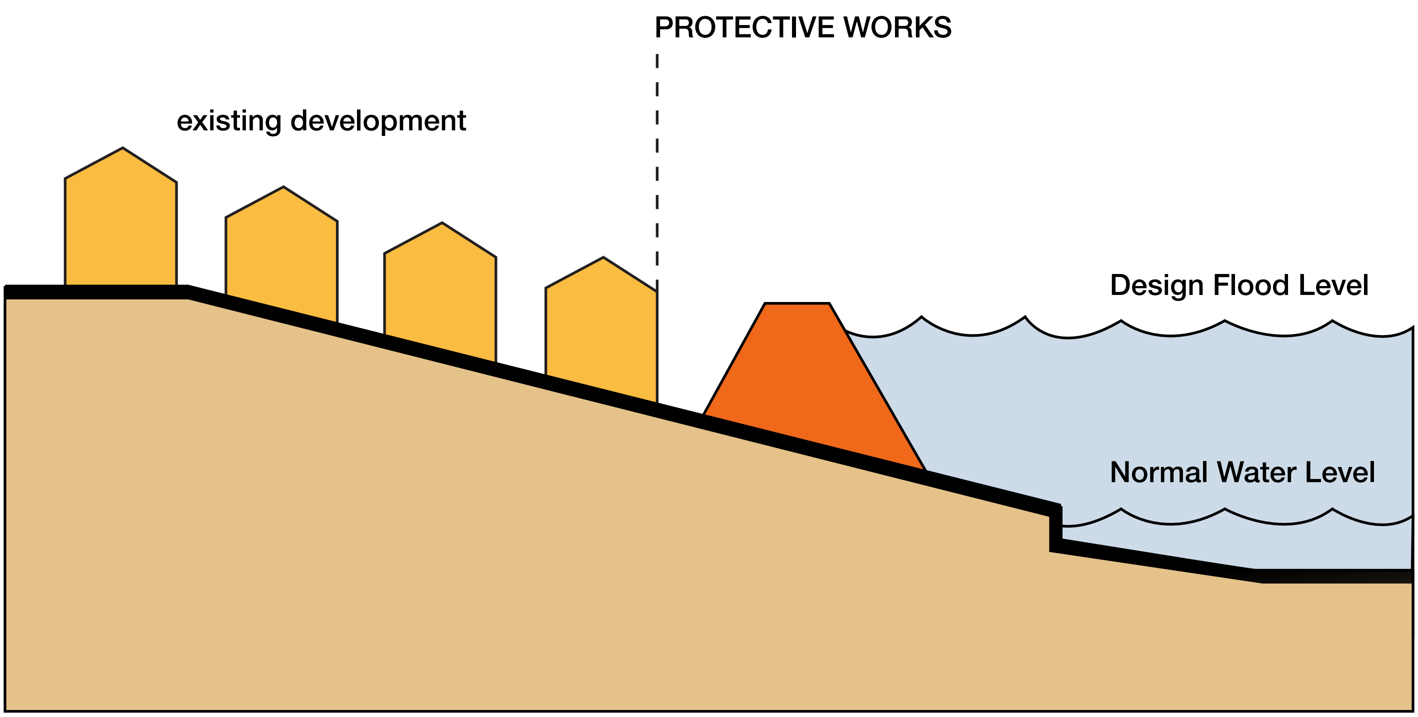
3.2 General

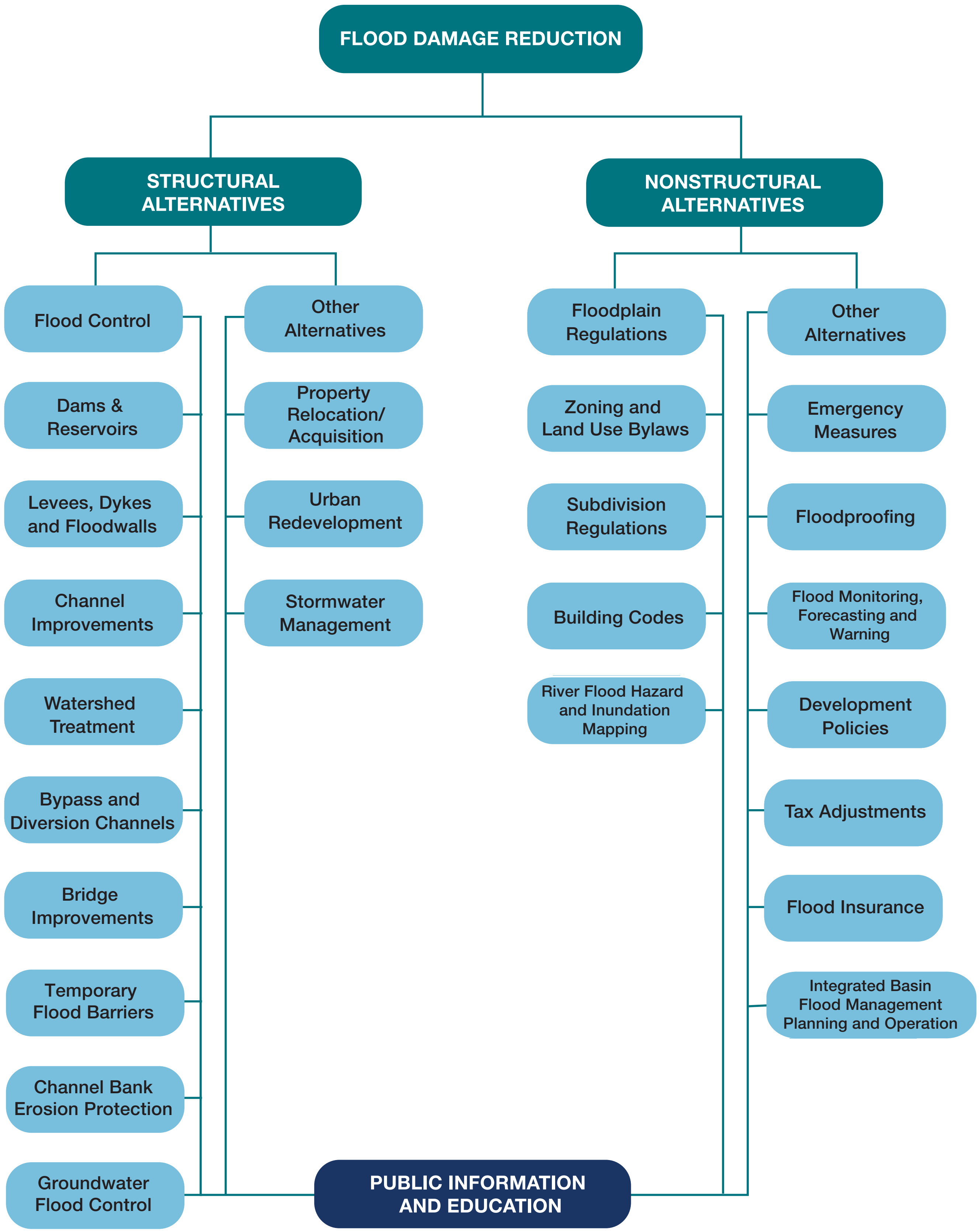
There are two basic approaches to the problem of reducing flood damages. The first, structural alternatives, consists of methods to control the extent of flooding by construction of dams, reservoirs, dykes or other protective works. The second approach which limits the susceptibility of the developments to flood damages, is effected through a variety of non-structural alternatives, especially land use controls. **Exhibit 3.1** details the various types of flood damage reduction alternatives.

3.3 Structural Alternatives

Structural alternatives consist of physical works located on or immediately adjacent-to the stream channel for the purpose of confining the floodwaters or reducing the flood stages. Physical structures have been the principal means of flood control in the past. The primary reason for this is that structural solutions can be easily implemented to protect existing development. While these works are effective to the magnitude of the selected design flood, when such floods are exceeded, substantial damages can result. Environmental aspects of structural flood control measures can oftentimes reduce the functional and economic aspects.

Exhibit 3.2: Structural Alternatives




FLOOD DAMAGE REDUCTION
STRUCTURAL ALTERNATIVES
NONSTRUCTURAL ALTERNATIVES
Flood Control
Dams & Reservoirs
Levees, Dykes and Floodwalls
Channel Improvements
Watershed Treatment
Bypass and Diversion Channels
Bridge Improvements
Temporary Flood Barriers
Channel Bank Erosion Protection
Groundwater Flood Control
Other Alternatives
Property Relocation/ Acquisition
Urban Redevelopment
Stormwater Management
Floodplain Regulations
Zoning and Land Use Bylaws
Subdivision Regulations
Building Codes
River Flood Hazard and Inundation Mapping
Other Alternatives
Emergency Measures
Floodproofing
Flood Monitoring, Forecasting and Warning
Development Policies
Tax Adjustments
Flood Insurance
Integrated Basin Flood Management Planning and Operation
PUBLIC INFORMATION AND EDUCATION

3.4 Non-Structural Alternatives

Non-structural alternatives to reduce the damages from floods include: floodplain regulations in the form of land use bylaws, subdivision regulations and building codes, floodproofing, flood forecasting, development policies, evacuation and contingency measures, tax adjustments and flood insurance. For the most part, non-structural alternatives are classified as preventive rather than corrective, in that they seek to reduce flood damage by restricting via some form of land use control, development in the floodplain rather than providing protection for existing development.

3.5 General Description of Alternatives

The alternatives are described in general terms with the various advantages and disadvantages of each presented for consideration. In addition, their applicability in the context of the City of Calgary flood risk situation is assessed and a recommendation put forth as to whether they represent viable alternatives and should be pursued further or discarded at this juncture (see **Appendix E**).

3.6 Review of City and Provincial Design Reports

3.6.1 Studies for the Province of Alberta

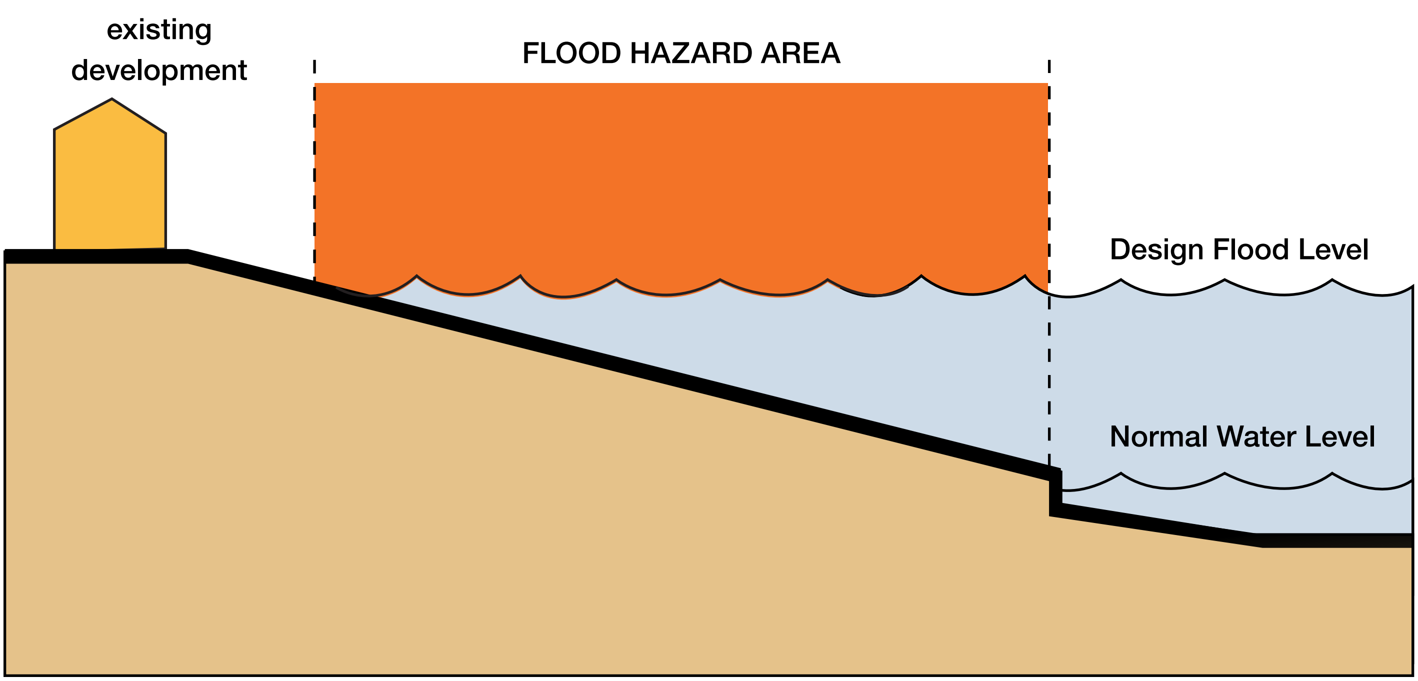
3.6.1.1 Study for the Southern Alberta Flood Recovery Task Force (2014) [1]

This study commissioned by the Province for evaluating alternative flood mitigation measures in the Bow and Elbow River Basins, was prepared by AMEC (June 2014). Exhibit 3.4 summarizes the alternative flood mitigation measures evaluated in that study that are relevant to flood mitigation for Calgary, although no specific measures were identified within the city.

3.6.1.2 Bow River Working Group

In 2015, the Province initiated the Bow River Working Group and the Bow River Advisory Committee. This process takes a watershed management approach to examine the feasibility of upstream reservoirs and operational changes to manage flooding and drought on the Bow River. The Working Group is comprised of stakeholders from the watershed including municipalities, regional partners, First Nations, Bow River Basin Council, TransAlta, and irrigation districts. A report from the Working Group is expected by summer 2017.

Exhibit 3.3: Non-Structural Alternatives



[1] AMEC Environmental & Infrastructure, June 2014, Flood Mitigation Measures for the Bow River, Elbow River and Oldman River Basins, Prepared for Southern Alberta Flood Recovery Task Force.

Exhibit 3.4: Summary of Major Flood Mitigation Measures (AMEC 2014)

Category	Type	Bow River Basin	Elbow River Basin
Structural Measures	Major Infrastructure	• Ghost River Dam	• Off-stream storage site at SR1 • Elbow River dam site at MC1 • Elbow River dam site at FC1
	River Diversion		• Priddis Creek • Calgary Tunnel
	Barriers	• Permanent dykes • Temporary barriers	
	Erosion Protection	• For pathways and related facilities along river banks	
	Storm Water System	• Amendment to existing outlets • Adequate storm water control during floods • Improvement of storm and sanitary lift stations	
	Groundwater Control	• Select control measures	
Non-Structural Measures	Flood Warning	• Monitoring improvement • Forecasting improvement • Improved flood warning service by the Province	
	Flood Management	• Development of basin flood management plans • Plan implementation by a single authority	
	Flood Mapping	• Flood inundation maps to be updated by the Province	

3.6.2 Studies and Projects for the City of Calgary

3.6.2.1 Glenmore Reservoir Tunnel Diversion (2014)[3]

This feasibility study commissioned by the City of Calgary was prepared by Hatch (2014) for evaluating the Glenmore Reservoir tunnel diversion as a potential flood mitigation measure for some of the communities in Calgary. Three diversion alignment options (i.e., 58th Avenue to Bow River, Heritage Drive to Bow River, to Fish Creek) were considered or evaluated. The Heritage Drive was identified as the preferred route for the tunnel alignment. The diversion tunnel is no longer being considered in preference to other options.

3.6.2.2 Temporary Flood Barriers (2013)[4]

The flood response plan support study commissioned by the City of Calgary was prepared by Golder (2013) for creating a total of 135 information reference sheets for the temporary flood barriers. The temporary barriers are for protection against the 20- to 100-year flood events on the Bow River, and the 9- to 100-year flood events on the Elbow River. The City of Calgary deploys three types of temporary barriers (i.e., sandbag, earth fill, and water tubes).

3.6.2.3 Permanent Flood Barriers (2017)[5]

The River Flood Protection Conceptual Design Study, commissioned by The City of Calgary, was prepared by Associated Engineering (expected 2017). Conceptual design and benefit-cost analysis were conducted for 33 permanent barriers along the Bow and Elbow Rivers, for a range of return periods from 20-year to 1000-year.

3.6.2.4 Bank Stabilization and Erosion Protection Projects

The City of Calgary has commissioned a number of bank stabilization and erosion protection projects post the June 2013 flood. All critical sites and almost all of the high priority sites have been completed to date. **Exhibit 3.5** summarizes the project sites based on the information provided by the City.

[3] Hatch Mott MacDonald, July 2014, Glenmore Reservoir Diversion Feasibility Study, Prepared for the City of Calgary.

[4] Golder Associates Ltd., 2013, City of Calgary Flood Response Plan Support, Prepared for the City of Calgary.

[5] Associated Engineering, 2017, River Flood Protection Conceptual Design Study, Prepared for the City of Calgary.

Summary of Riverbank Erosion Stabilization Projects

No.	Length of Erosion (m)	Site Description: Short Name	Site Description: Location of Site	Date (Substantially) Completed or projected completion date
1	1040	Inglewood	Inglewood PRIORITY SITE D/S of Blackfoot Trail where groins were placed during event. Remedial measures for entire section from 17 Ave to Inglewood bird sanctuary should be considered together. Fill required to maintain previous bank lines.	Spring 2014
2	600	Home Road	Home Road PRIORITY SITE. Pathway adjacent to slope at BLB60024.	Spring 2014
3	250	Sunnyside	Memorial Drive and Sunnyside PRIORITY Sites. Severe ongoing erosion. Continued erosion will threaten the pathway and Memorial Drive.	Fall 2014
4	350	Enmax	Enmax PRIORITY SITE, Pathway and utility station in close proximity to river. Relatively narrow channel width. Inside of moderate meander. Recreational access point. Ongoing bank erosion. Site was severely damaged during the 2005 flood.	Spring 2014
5	175	Memorial/19th Street	Memorial Drive and 19 Street PRIORITY SITE.	Fall 2014
6	350	Diamond Cove	Diamond Cove PRIORITY SITE, slope erosion	Spring 2014
7	40	Elbow WSC Gauge	WSC Canada gauging station located on steep eroding bank downstream of pedestrian bridge. Hotspot in 2010.	Fall 2014
	143		WSC Canada gauging station located on steep eroding bank downstream of pedestrian bridge. Hotspot in 2010.	
8	119	Lindsay Park	Outside of meander bend upstream of Lindsay Park along high traffic area. Pathway has been rerouted following 2013 event. Hotspot in 2010.	Summer 2014
9	98	Langevin Bridge	Outside of mild meander. Bridge pathway underpass; paved trail close to bank; riprap.	Summer 2014
	142		Outside of mild meander upstream of 4th Avenue flyover. Thin band of native and non-native trees and shrubs. Steep bank with active erosion and bare ground in the tree understory. Ongoing erosion threatens pathway.	Summer 2014
	50		Riprap bank protection under and around bridges lost. Sections of erosion but stable overall. Disturbed, steeply bermed bank with sparse tree cover and non-native grass understory and bare-ground patches. Straight stretch. St. Patrick's Island begins just D/S of reach.	Summer 2014
10	331	Stampede Severe Meander	Outside of severe meander at Stampede grounds. Various types of bank protection installed in the past: vegetated gabions at U/S of reach, riprap, and retaining wall at D/S of reach (under bridge).	Fall 2014 (completed by Transportation Infrastructure)
11	150		Along right bank between Stampede Barns Bridge and Agriculture Trail.	Fall 2014 (completed by Transportation Infrastructure)
12	150	Alyth Yard Bridge	Transition to inside of bend at Bonnybrook Train Bridge.	No work was required at this site
13	45	St. Mary's High School	U/S of wooden retaining wall at St. Mary's School and D/S of Pedestrian Bridge over Elbow River.	Fall 2014

Summary of Riverbank Erosion Stabilization Projects

14	182	South Highfield Project: Bonnybrook (BB) Landfill, BB at Calf Robe, U/S of Lafarge & South Highfield Remainder	Downstream of Bonnybrook Wastewater Treatment Plant and Calf Robe Bridge.	Spring 2016
15	52		Bank upstream and under Calf Robe Bridge	Spring 2016
16	355		Outside of moderate meander. Bank under flow attack and being undercut.	Spring 2016
17	285		Downstream of Calf Robe Bridge and upstream of landfill site BRB39008_A	Spring 2016
18	312	Parkdale Blvd	Adjacent Parkdale Boulevard pathway at 30/31 St NW. Relatively straight reach. Poor to fair rootmass protection. Dry, steep bermed bank.	Spring 2016
	268		Adjacent Parkdale Boulevard pathway at approximately 34th Avenue. Outside of moderate meander around mid-channel island. Poor to fair root mass protection.	Spring 2016
19	950	Pine Creek WWTP	Bank adjacent to Pine Creek WWTP.	Spring 2015
20	50	Under 85th Street	Under 85th Street Bridge. Bank height and slope varies.	Spring 2015
21	95	16 Avenue Outlet	Outside of moderate meander just D/S of 16 Avenue Bridge, high (5-6 m) steep sloping bank. Concrete outfall structure with riprap protection. D/S half of reach slope is protected with natural cobbles and riprap washed away in 2013 event. U/S bank is undercut and wasting. Scour occurring behind U/S wing-wall and under bridge.	Spring 2016
22	300	Pathway at Calf robe	Inside of mild meander upstream at Calf Robe bridge. Adjacent to Refinery Park.	Spring 2015
23	77	Elbow Retaining Wall	Wooden retaining wall (approx 2 m high) on outside of mild meander along Elbow Drive (at approximately 33 Ave). Adjacent pathway partially eroded. Hotspot in 2010.	Spring 2015
24	50	Deane House	Downstream of 9th Avenue Bridge, along steep slope.	Spring 2015
25	143	D/S of Stanley Park	Downstream of Stanley Park concrete slab armouring (See ERB06380, which is being repaired as part of ongoing works) at outside of severe meander. Subject to attack along high valley wall.	Summer 2015
26	94	Bowness Rail Bridge	Outside of moderate meander at Bowness Park rail and pedestrian bridge. Steep cutbank erosion with some woody vegetation; sediment delivery source. Riprap protection under rail bridge partially damaged.	Spring 2015
27	206	U/S of Glenmore	U/S of Glenmore Trail. Outside of moderate meander. Immediately D/S of hardened riprap bank.	Fall 2015
28	60	U/S of Glenmore Phase 2	U/S of Glenmore Trail Phase 2. Immediately D/S of Phase 1.	Scheduled for 2017
29	800	Shepard Outfall	Shepard Ditch Outfall. Outside of mild meander. Point bar at D/S end of reach and on opposite bank. Reach prone to frequent ice jams.	Summer 2014
30	60	Douglasbank	Upstream of Pedestrian Bridge. Relatively straight reach confined by west valley wall. Minor cutbank erosion. Disturbed bank. Riparian habitat lacking. Potential for some bank stabilization and riparian enhancement. Some erosion U/S B118 outfall	Spring 2015
31	30	Elbow Rail Bridge	Steep bank with pathway between abutment and river under rail bridge. Unstable bank giving way and endangering pathway. Poor vegetation coverage.	Fall 2015

Summary of Riverbank Erosion Stabilization Projects

32	100	Discovery Ridge	Outside of meander bend at Discovery Ridge on north/left bank of Elbow River.	Spring 2016
33	50	Upstream of 9th Avenue	Downstream of Macdonald Bridge and Upstream of 9th Avenue. Steep High Bank.	Fall 2015
34	180	Inglewood Golf Course	Downstream of Blackfoot Trail Bridge. Inside of moderate meander. Bridge at U/S end. Large point bar starts at D/S end. Inglewood Golf Course.	Spring 2016
35	126.9		Outside of moderate meander adjacent Inglewood Golf Course. Moderate rootmass protection.	Spring 2016
36	94.4	Montgomery/ 16 Avenue	Outside of mild meander around mid-channel bar. Adjacent to paved pathways, private residential.	Scheduled for 2017
37	525	Douglasdale	Outside of mild meander. Ongoing bank erosion and minor slumping. New bank appears to be vegetated and stable (to be confirmed)	To be completed by Parks
38	126.9	Centre Street Bridge	Inside of moderate meander. Good riparian habitat except at U/S end near Center Street Bridge. Will include u/s gravel bar work.	Scheduled for 2017
39	50	Memorial Off-Ramp	Outside of moderate meander adjacent memorial drive turnoff to Crowchild Trail southbound and pathway. Channel widens over reach with several mid-channel islands, channel begins to narrow again at D/S end of reach.	Scheduled for 2017
40	150	Shouldice Park	Inside of mild meander adjacent to Shouldice Park, paved and unpaved pathways, Outfall B95A.	Scheduled for 2017
41	332.5	U/S of Alyth	Straight stretch upstream of railway bridge, previously placed broken concrete slabs have some minor damage. New riprap looks in good condition.	No work planned.
42	77.7	Bowmont Natural Area	Bowmont Natural Environment Park. Paved pathway. Outside mild meander steep, naturally eroding cutbank.	Pathway to be moved further back from riverbank as part of East Bowmont SWQR Work
43	229.1		Bowmont Natural Environment Park. Paved and non-paved recreational pathways. Outside of mild meander (around island). Ongoing bank erosion and recreational access erosion.	

3.7 Assessment of Non-Structural Mitigation Measures

3.7.1 Introduction

Structural flood damage reduction measures are those that focus on altering the characteristics of the flood, leaving the structures in the floodplain that could be damaged by floods unaltered. Non-structural flood damage reduction projects are those that focus on altering the characteristics of the structures that could sustain flood damages, leaving the characteristics of the flood unaltered (Buss, 2010).

Researchers have noted that the strong emphasis on structural mitigations may be a result of a combination of factors including:

- A decision-making context that includes formal and informal institutions, disciplinary backgrounds of decision makers, organizational structure, funding sources, etc.
- The difficulty accounting for transactional costs of non-structural measures. For example, transactional costs would be associated with design and implementation of public policies, including planning and design costs, costs for information, participation processes, negotiations, solving conflicts, and implementation costs such as legal enactment and monitoring (Meyer, Priest, & Kuhlicke, 2012).
- A general lack of methods to evaluate and prioritise non-structural measures compared to structural measures.

For the purposes of this study, non-structural measures examined included contingency measures, regulations, property buyouts, property level mitigations/floodproofing, and insurance. These are highlighted in the following sections, with recommendations summarized in the concluding Section 5.6.1.

3.7.2 Contingency Measures

The objective of this section is to identify and assess the effectiveness of existing flood mitigation techniques for The City of Calgary with regards to:

- Flood forecasting and monitoring;
- Emergency measures;
- Public education; and
- Evacuation procedures

Contingency measures comprise some of the most useful techniques available for reducing flood losses due to their relatively low cost, low environmental impact, and short implementation time (Shawcross, 1987). They also offer a high degree of flexibility when compared with fixed structural solutions, and can therefore be more appropriate to adapt to changing future needs, particularly in the face of environmental uncertainty. Because they are implemented at the local level, they can be very impactful if properly managed, and should therefore be considered an essential component of any flood plain management plan (Shawcross, 1987).

3.7.2.1 Flood Forecasting and Monitoring

Alberta Environment maintains Alberta's River Forecast Centre (RFC), which is highly automated and accesses data from remote river level and weather monitoring stations via satellite, telephone telemetry, a web database, along with various field partners. The RFC makes use of a Geostationary Operational Environmental Satellite (GEOS) system that obtains data from over 100 remote sites (Government of Alberta, 2009). Every three hours the GEOS system is updated with information from its various sources, processing approximately 20,000 pieces of information a day.

3.7.2.1.1 Flood Forecasting

Flood forecasts are produced by the RFC as the need arises and disseminated to a variety of government and media agencies. The RFC also communicates directly with municipalities that may be affected by a flood in order to pass on technical information about potential flooding (Government of Alberta, 2009).

Alberta Environment and Parks collects, processes, and displays most information they gather for all major Alberta River Basins every 15 minutes (where available), accessible in current time on their website (Government of Alberta, 2009). Data and advisories are also available to anyone with a smart phone through the Alberta Rivers mobile application.

3.7.2.1.2 Improvements in Forecasting and Monitoring

After the Southern Alberta Floods in 2013, The City of Calgary took steps to improve its forecasting abilities by streamlining weather and river inputs into its predictive models. In 2014 The City repaired and improved river monitoring stations in Calgary, improving their resilience to flooding in the future. They also installed additional river monitoring cameras along the Elbow River in the Mission area and on the Bow River at Poppy Plaza. Agreements have been reached with private companies that can be used to increase monitoring in the event of a high water event (Water Resources, 2014).

In addition, The City has updated their flood inundation maps using data from the 2013 floods[6], data that is publicly available for planning purposes and that was used to help revise The City's flood response plans. It has also started looking at how climate change and groundwater may affect future flood events (Water Resources, 2014).

[6] Available at http://www.calgary.ca/UEP/Water/Pages/Flood-Info/Calgary-flood-maps/Flood-maps.aspx

3.7.2.1.3 Current Flood Forecasting

Current flood forecasting depends primarily on the characteristics of the approaching flood. In Southern Alberta, precipitation, soil saturation, snowpack and snowmelt, and runoff need to be taken into account. Generally the larger the catchment area, the larger its capacity, and the longer the flood forecasting time authorities can provide.

Emerging technologies coupled with large computing power predict that it may be possible to warn of major rain-bearing weather systems up to a week in advance (Golding, 2009). However, typical riverine flooding in the basins in which it occurs can still only be reliably predicted, and warnings sent out, within 12-48 hours. Luckily, with the ability to foresee snowmelt and test for soil saturation, citizens can be better prepared than ever before for a flood in Calgary, and can be prepared well in advance.

Recommendation 1: As previously recommended by the Expert Management Panel on River Flood Mitigation (2014), The City should work with the River Forecasting Centre and other agencies to further develop its forecasting capabilities to send out faster and more accurate information and alerts about potential flood events.

3.7.2.2 Emergency Measures

3.7.2.2.1 The Calgary Emergency Management Agency (CEMA) Emergency Operations Centre (EOC)

CEMA works together with a number of other administrations and communities in order to better prepare Calgary for emergencies and help in its recovery (The City of Calgary, 2016). CEMA works on a model guided by a hazard identification and risk assessment approach, after which it is able to identify how frequently hazards may occur, how big of a threat they are, their potential impacts on communities, and subsequently which ones to prepare for (Vroegop, 2014).

3.7.2.2.2 Municipal Emergency Plan

The City of Calgary's Peacetime Emergency and Disaster Plan was replaced by the recently revised 2010 Municipal Emergency Plan (MEP). The MEP is intended to provide prompt coordination of Calgary's resources when an emergency, disaster, or catastrophe have been identified, as well as outline legislation indicating where authority lies during such an event (Calgary Emergency Management Agency, 2010). The Flood Emergency Reference Manual is included as a special annex to the MEP, and is specifically designed to address flooding. This material has been classified as confidential and is therefore only available in emergency situations to those parties who require it.

3.7.2.3 Public Education

3.7.2.3.1 Available Information

Public education is an important step in keeping the public safe, and successfully executing any emergency plan. Currently The City of Calgary provides information on its website[7] as well as in a flood readiness brochure.

The brochure and website both provide an abundance of information on flood terminology and types of flooding that Calgarians may be susceptible to, including overland flooding, basement seepage, sewer backup, and storm water backup.

The brochure encourages citizens to make a plan in case of emergencies and practice it with their families. Part of this plan is the creation of a 72-hour emergency kit that will enable citizens to stay healthy and safe in the critical first days after an emergency when first responders are busiest. These kits can also be requested through The City of Calgary by calling 3-1-1.

The City of Calgary advises putting personal documents and important items like insurance papers, passports, photos and family videos in water tight bags or containers and moving them to areas that aren't susceptible to water damage, such as high levels and away from windows. The same recommendations are made for electronic equipment if space permits.

The City has a number of recommendations for businesses, including the removal of business records and dangerous goods from basements or lower floors to upper floors wherever possible. The City of Calgary provides a more detailed publication to help businesses prepare for disasters, including flooding[8].

Other preventative and preparatory measures centre on methods to maintain proper drainage in and around the home that prevent flooding and sewer backup. Such techniques include cleaning out eavestroughs, downspouts and gutters, and making sure not to overwater lawns and garden beds close to the house. By taking a number of preventative measures, basement seepage is less likely to occur (The City of Calgary, 2015).

[7] Available at http://www.calgary.ca/UEP/Water/Pages/Flood-Info/Flood-Information.aspx

[8] Available at http://www.calgary.ca/CSPS/cema/Pages/Businesses/Prepare-your-business-for-an-emergency.aspx

3.7.2.3.2 Emergency Alerts

The City of Calgary has provided a list of flood-related weather alerts based on the Environment and Climate Change Canada vocabulary used to advise citizens of imminent weather conditions. These terms are available on both The City of Calgary website and in the Flood Readiness brochure, and include:

Weather Advisory – Issued when a certain weather or environmental condition is either occurring, imminent, or expected to occur.

Weather Watch – Issued when development of a weather or environmental condition may pose a significant threat to public safety or property. Public should take appropriate precautions and continue to monitor weather conditions.

Weather Warning – Issued when a hazardous weather or environmental condition poses a significant threat to public safety or property. The public should seek appropriate shelter and continue to monitor weather conditions.

High Stream Flow Advisory – Indicates that stream levels are either rising or are expected to rise, but that no major flooding is expected. Minor flooding in low-lying areas may occur. People near affected water bodies should be cautious.

Flood Watch – Indicates that stream levels are rising and may overflow the tops of riverbanks. Flooding may occur in areas close to riverbanks and appropriate precautions should be taken.

Flood Warning – Indicates that high water levels will result in the flooding of some areas. Those people situated close to the affected water bodies should take appropriate measures to avoid flood damage and prepare to evacuate if instructed to do so.

State of Local Emergency – If City of Calgary officials deem that there is danger to life, or widespread risk to public and private property, a State of Local Emergency can be declared. In this occurrence the Director of CEMA may order mandatory evacuations if necessary, or take other precautions to protect life and property.

3.7.2.4 Evacuation

In the event of an evacuation, City of Calgary police will block off a perimeter around the evacuation area and supervise evacuation of the area with help from the Fire Department as needed. Depending on evacuation orders, and if time permits, prior to evacuating the home, The City suggests:

- Turning off gas appliances;
- Turning off electrical appliances and then shutting off the main breaker panel; and
- Locking all windows and doors.

City crews request that if gas and electricity are turned off prior to leaving, a note be left on the front door advising city crews that this has been completed.

While the MEP does not specifically contain any provisions for those people with disabilities, CEMA has recently prepared a guide for persons with disabilities and special needs and for first responders who might be assisting those people in an emergency or disaster (Calgary Emergency Management Agency, 2015). It gives readers a number of ways that they can help reduce the impact of an emergency by being prepared and letting family and neighbours know ahead of time of any special requirements. CEMA provides emergency preparedness suggestions and a self-registry for vulnerable people to make sure that all Calgarians can get the help they need in an emergency.

3.7.2.5 2013 Southern Alberta Flood

3.7.2.5.1 Introduction

In late 2013, The Conference Board of Canada was asked to review The City of Calgary's response to the 2013 Southern Alberta Floods. After a comprehensive evaluation, they returned with some best practices that helped The City respond to the 2013 flood in addition to recommendations for future preparedness.

3.7.2.5.2 2013 Flood Review

Between June 19 and 22, a combination of snowmelt and precipitation in the watersheds surrounding Calgary led to an increase in soil saturation in the area. Heavy rainfall added to the amount of water present and contributed to the melting of the snowpack, resulting in 1 in 100, and 1 in 500 year peak flow rates in the Bow and Elbow Rivers respectively.

Flood warnings were issued by Environment Canada in the early hours of June 20, 2013 and by 10:16am a State of Local Emergency was declared. Within 15 hours, CEMA and its partners managed the evacuation of entire communities, comprising about 80,000 citizens, utilizing the Calgary Fire Department to perform water rescues.

Internal Communications – The new CEMA Emergency Operations Centre was built in partnership with the Calgary Fire Department, in conjunction with a number of other business units that provided funding. The improved building was large enough to house all the stakeholders and a significant media presence, all able to congregate in separate rooms within the same building, and able to communicate a unified message to the public (Vroegop, 2014).

The new EOC enabled CEMA and its partners to utilize a number of improvements in technology to improve communications between first responders and those at the EOC. One such improvement was the use of GIS maps, which allowed the Calgary Police Service and Fire Department to instantly exchange information and display an overview of the crisis.

Despite all of these improvements, communication within the EOC was, at times, criticized because the chain of command was not solidified and properly communicated, and primary points of contact were not always present at the EOC. As such, when new people arrived there was confusion as to who they reported to and who was in charge. When the MEP was enacted, certain people and agencies were not aware of the new responsibility or authority they possessed, as was the case with the Calgary Police Service. The Conference Board of Canada (Vroegop, 2014) therefore recommended that each agency and its mandate be clearly identified, and every person and agency's point of contact be clearly specified for the duration of the event.

Furthermore, some of the technology used as part of CEMA's Incident Management System unfortunately failed during the crisis, and staff were forced to manually document events during this time. This may have led to some missing information, or some information being improperly recorded.

Public Communication – When the Calgary Municipal Emergency Plan is put into place, all crisis-related communications must then automatically be approved by CEMA. Having CEMA as the central coordinating authority for media relations and public messaging helped build a strong and unified message during the 2013 floods (Vroegop, 2014). CEMA was able to do this, in part, by distributing radios to media stakeholders from the Calgary Police Service. Not only did this help with the dissemination of correct information, it also helped stem the flow of any misinformation.

Shortly after flooding began on June 20, the Municipal Building was flooded. As a consequence, 3-1-1 call lines were unavailable to the public for approximately an hour and The City's website, calgary.ca, crashed. Within an hour, the system was back up and running through the use of the EOC, and the amount of on-call IT staff was tripled. These staff members were able to update and direct people to The City of Calgary news blog, and deal with an estimated 100,000 3-1-1 calls in just the first two weeks of the flood (Yablonski, 2013).

CEMA received some criticism from private sector companies that they were left out of the loop in many aspects, and it was suggested the CEMA might provide a better way for important private sector partners to be included without having to be physically present, perhaps through a liaison group (Vroegop, 2014).

Social Media – During the 2013 flood, CEMA and The City of Calgary made use of a number of communication platforms and social media outlets. This has been acknowledged as the first widespread use of social media in the response and recovery phases of an emergency in Canada (Kaminska, Dawe, & Rutten, 2013; Vroegop, 2014). CEMA had been able to establish itself and its social media presence with a few smaller incidents prior to the 2013 flood, enabling staff to gain practical experience. When the 2013 flood occurred, CEMA and other City of Calgary staff were ready and able to respond to citizen comments and promote a two way dialogue using social media.

In order to increase communication with citizens and the community, the city used the hashtag #yycflood, which was used an average of 32 times per minute during the first ten days following the flood, totalling 327,682 tweets (Yablonski, 2013). For users with some form of internet, this meant that information and recent updates were easily accessible (Vroegop, 2014).

One potential downfall of the use of social media during these crisis situations is the inability to provide individualized responses back to all the users, because of the massive influx of responses received. The City was better able to respond to service requests received through their 3-1-1 mobile application, or via 3-1-1 telephone calls, as the sheer volume of social media responses made it virtually impossible to respond to them all personally. Additionally, some people interviewed by the Conference Board of Canada (Vroegop, 2014) argued that social media gave a skewed perception of the conditions that some communities were in and resources may have been allocated unfairly amongst communities. This is something that should be monitored on the ground in future events, instead of relying purely on social media.

Volunteers – Volunteers were integral to all phases of the crisis response and recovery. The first volunteers to show up were municipal employees who helped with the evacuation by knocking on doors. In past emergencies, many authorities have asserted that it is best to maintain control of the situation by discouraging unauthorized personnel from becoming involved in an emergency situation. There are also questions of liability in emergency situations where citizens' health may be put in danger. In Calgary, managing the massive amount of volunteers took a lot of work and coordination from community associations, religious groups, professional organizations, and grassroots organizations like YYCHelps. This allowed first responders and other professionals to focus on their jobs and allowed volunteers to use their skills in a productive manner, and to feel useful in what could be an otherwise hopeless situation.

The 2013 Flood showed how many people and organizations were willing to help others, and how quickly they can organize. With some additional foresight, a better defined volunteer framework could match people's skillsets to the appropriate task. CEMA and the City of Calgary should work to build a relationship with these volunteer organizations that can determine which skillsets are needed in which situations, and which organizations can provide them (Vroegop, 2014). This way, certain volunteers can be called to locations when they are needed most. This may also help prevent volunteer fatigue for those people who continually show up to volunteer or make donations.

3.7.2.5.3 Best Practices Employed by The City of Calgary

The Conference Board of Canada identified the following best practices that were critical in assisting The City of Calgary respond to the 2013 flood:

1. The strong capacity of the Emergency Operations Centre (EOC). This was cited as being crucial for enhancing communication and coordination between stakeholders.
2. Success in communicating a single message from the EOC and The City of Calgary through the media, which effectively enabled them to reassure the public.
3. Beginning recovery efforts as soon as possible using a long-term, outcome-based approach.
4. Trying to get evacuees back into their homes as soon as possible, fostering a positive mindset among citizens, thereby enabling self-recovery and building a sense of civic pride.
5. Encouraging grassroots organizations such as YYCHelps that connected citizens and empowered them to clean up their communities and help their neighbours.
6. Servicing both the public's immediate needs as well as having a long-term goal shared by all stakeholders.
7. CEMA has been continuously committed to training and exercising for emergency response, both before and after the 2013 flood. (Vroegop, 2014)

Additionally, it should be noted that since an earlier review (IBI Group, 1986), recommending emergency provisions for the two hospitals located in the flood zone, the two hospitals have since been relocated[9].

3.7.2.6 Recommendations and Discussion

3.7.2.6.1 Introduction

This section outlines some key deficiencies and areas of improvement for The City of Calgary's past and current flood management practices. Recommendations have been made based on past shortcomings, current best practices in other localities, and literature reviews. Reviews and recommendations have been made in the following areas:

- Warning System
- Organization/Communication
- Volunteerism
- Public Education
- Attention for Emergency Workers
- Lesson Sharing

After their review of the response of The City in 2013, The Conference Board of Canada made a number of recommendations, which have been incorporated into the recommendations below.

3.7.2.6.2 Warning System

The emergency alerts that are currently in place may seem ambiguous if citizens are unfamiliar with them. As recommended by IBI Group (1986), a coloured warning system should be considered based on the earliest available flood forecasting data, and clear actions should be associated with each colour. According to how the conditions progress the alert would either be retracted or another one would be issued and residents in affected areas could take appropriate measures. Citizens should continual monitor media reports and social media for updates.

Yellow – Equivalent to a weather advisory or high stream flow advisory. Citizens should ensure that their 72-hour emergency kit is up to date.

Blue – Equivalent to a weather or flood watch. Citizens should make preparations to evacuate premises if necessary, call family or friends outside of the flood hazard area, and be sure they can access their 72-hour emergency kit and suitcases.

Red – Released in conjunction with a weather warning or flood warning. Citizens in affected zones should be advised to plug basement drains, move possessions to higher elevations and finalize evacuation plans.

In addition to the information above, an effective warning message would contain information about the flood conditions – for instance its expected location, timing, depth and duration – as detailed information like this is more likely to be believed, and encourage prompt action (Drabek, 2000).

> **Recommendation 2:** Implement an easy-to-understand colour-coded warning system that associates concrete actions with each warning level.

Putting a new flood warning system into place may prove to be a valuable tool in helping to reduce flood impacts, however the effectiveness of such a tool depends greatly upon the flood being detected with an acceptable degree of accuracy, reliability and timeliness (Tunstall & Parker, 2007). This warning could be disseminated through a number of outlets including Facebook and Twitter, which was widely used during the 2013 flood, as well as through the mobile phone applications, such as the Alberta Rivers: Data and Advisories application and on municipal and provincial government websites. Users can follow The City of Calgary on Facebook or Twitter and sign up to receive automatic notifications whenever they update their social media pages.

[9] The General Hospital located in Bridgeland/Riverside was demolished in 1996 and the Alberta Children's Hospital was moved to new location at 2888 Shaganappi Trail NW. Additionally, a walk-in clinic on 8th Avenue and 8th Street SW has since been removed, and the new Sheldon M. Chumir Centre located in the Beltline at 1213 4 Street SW is outside of the flood fringe.

Similar information would also be available through traditional media sources such as television and radio, and pre-recorded on 3-1-1 when users call in.

A properly implemented warning systems has the potential to prevent loss of life and injury by evacuating people, animals, and property out of the flood zone prior to the flood. Similarly, warning systems can reduce damages to property by allowing time to strengthen existing flood structures or erecting temporary flood barriers. Businesses and homeowners can also use this time to move property out of reach of floodwaters to minimize direct property damages.

Even the best warning systems can only perform well if they are well-maintained and constantly improved. This includes consistent reviews and updates after each use to diagnose and address insufficiencies. This is something that is particularly important where floods are less frequent, as the impacts of these events can fade if it has been many years since flooding has occurred (Tunstall & Parker, 2007).

It is important that both those forecasting the flood as well as those receiving the flood warning understand the warning system and the potential severity of the flood, so that the response to the warning is appropriate (Tunstall & Parker, 2007). In some cases, people refer back to previous experiences they have had with flood events to inform present decision-making. Subsequent floods may be of a different magnitude, may evolve differently, or may affect the area differently due to a change in environment. Therefore it is critically important to constantly be revising (Tunstall & Parker, 2007).

> **Recommendation 3:** Consistently review and update the warning system with new insights into technology, users, response patterns, the flood area, and weather data.

While there have been a number of advances in communication that would allow for advanced warning for many households, there are still a number of people who may not respond for a number or reasons:

- Being out of touch or not using common forms of media;
- Having a disability, special need, or language barrier;
- Becoming aware, but being too late to respond;
- Becoming aware but unable to respond (being out of town, incapacitated etc.);
- Becoming aware and choosing not to respond (due to past experiences); or
- Receiving the warning but do not trust the source of the information.

It has been shown that in locations where flooding is relatively infrequent, people are more likely to delay their response after receiving a warning, often out of denial, or to seek more information and confirm that the information is coming from an official source (Drabek, 2000). In order to prevent such time-consuming deliberation, constant communication between the public and official sources (such as CEMA, municipal governments, and The Province of Alberta) is paramount. Moreover, if the warning message comes from a single, known source it is proven to be more effective, particularly if the source can be verified (Drabek, 2000).

> **Recommendation 4:** Ensure that communication during an emergency comes from a single, reliable source, and that the source of the information can be confirmed.

In instances where people are unable to receive information from mass media outlets, there should be provisions in the MEP to account for those people: first those in the floodway, followed by those in the flood plain, and finally those adjacent to the flood plain. Those citizens most likely to be without access to cellular phones are young children, the elderly, and the socioeconomically disadvantaged. Alberta has the highest percentage of mobile wireless subscribers in Canada, at 90.1% of households having access to at least one cellular phone in 2013 (Canadian Radio-television and Telecommunications Commission, 2015). Nevertheless, citizens without a cellular phone or internet access may require individualized attention in the event of a flood in order to receive prompt notification, and in some cases may need help evacuating as well.

> **Recommendation 5:** Make provisions in the Municipal Emergency Plan for those people who lack access to the latest technology and ensure that they can be notified in an emergency.

By implementing a clear, up-to-date warning system and ensuring that communication comes from a reliable and authoritative source, citizens will be better informed in the case of a flood, and therefore better able to respond.

3.7.2.6.3 Organization/Communication

Emergency Operations Centre officials should have a strong, pre-existing relationship that goes beyond just a single point of contact. This would involve communicating why certain organizations are brought in, what skills they bring to the table, and what authority they do and do not have. With that in mind, boundaries and responsibilities have to be set regarding municipal and provincial roles in crisis management (Vroegop, 2014).

> **Recommendation 6:** Communicate to partners of CEMA what their roles are, why they have been brought in, and what authority they possess in an emergency.

> **Recommendation 7:** Define municipal and provincial roles in emergency management.

Calgary should continue to develop private sector preparedness by providing businesses with business education and formalizing business continuity plans and emergency response plans. This could potentially be part of an improved information-sharing system within the private sector. Creating a point of contact for comparable companies might also be advantageous.

> **Recommendation 8:** Further develop flood preparedness in the private sector through formalization of business continuity plans and emergency response plans, as well as information-sharing within the private sector.

> **Recommendation 9:** Bring similar businesses together by creating a single point of contact for emergency management.

On a broader level, while social media proved to be extremely effective during the 2013 floods, it relies heavily on actions taken by the user in order to stay informed. In the first crucial hours of an emergency, businesses and communities should have ways to contact and inform their constituents of what is happening and which actions they need to take. A longstanding and effective way of doing this is through the use of telephone trees. These could be implemented for all businesses located in the flood zone, and could potentially be initiated by community associations located in the flood zone.

> **Recommendation 10:** Encourage businesses and community associations to create telephone trees to account for all citizens located in the flood hazard area.

3.7.2.6.4 Volunteerism

The city should look at developing the volunteer network that was established during the 2013 flood in order to make good use of peoples' skills. Calgary has seen an abundance of volunteerism prior to and since the flood in 2013 and by encouraging the growth and organization of volunteer networks, the city can have sets of skilled volunteers permanently in place, ready to work where and when they are needed.

The vast amount of volunteers that came together in the 2013 floods were a large piece of what helped Calgary quickly return to normal. The amount of time that it takes individuals and communities to get back to normal has been shown to affect the long- and short-term health of people displaced by flooding - the sooner they can return to their homes, the less negative health impacts they experience (Department for Environment Food and Rural Affairs, 2004). This large scale study performed across the UK also observed positive correlations between community support and short term health effects [10].

> **Recommendation 11:** Calgary should take an interest in developing and utilizing the volunteer network that was established during the 2013 floods in order to make use of peoples' skillsets.

3.7.2.6.5 Public Education

While The City of Calgary has come a long way in promoting public education about flooding, this is a key element to ensuring the success of any other measures taken, as flood fighting, evacuation, and reducing damages all require a high degree of coordinated public participation.

The City of Calgary already provides citizens with an abundance of information on the calgary.ca website. However, some of the most important information for protecting individual property – such as removing items from basements – is not mentioned until halfway through the lengthy 40-page document.

> Recommendation 12: The City of Calgary should highlight the importance of adjusting basement use, making this information concise and easily accessible to website users.

Since a good deal of information is already available to the general public via the calgary.ca website, an additional part of the public education program should focus on communities in the flood hazard area. This should be done through the generation of a shorter version of the existing flood brochure, and dissemination of the most important information in community newsletters. City Councillors should also be encouraged to circulate important information through their websites or in monthly newsletters.

Because of the transient nature of some communities in the flood hazard area, it would be wise to redistribute such a pamphlet every year, preferably in the late winter or early spring so that citizens can prepare for a flood should one occur.

> **Recommendation 13:** Prepare and distribute a yearly brochure to all communities in the flood hazard area containing flood readiness information.

Such a pamphlet should contain, at minimum, the following information[11]:

- The minimum lead time people would have between a flood warning and being evacuated;
- How the order to evacuate will be given;
- How to prepare yourself and your family in the event of an evacuation;
- How to protect your property and possessions in the event of an evacuation;
- Where to go when an evacuation order is issued;

[10] It should be noted that the sources of support for respondents in this study came primarily from neighbours and family, with the least amount of support from charities, community groups and local businesses.

[11] Adapted from IBI Group (1986).

- Whom to contact for those needing special assistance in an emergency;
- Where to go to get sand, sandbags and other emergency supplies;
- Where school children will be sheltered in the event that they have to be evacuated;
- Ways to connect to the city (telephone numbers, websites, and social media contacts) in order to get more information and stay up-to-date; and
- Items that The Province of Alberta recommends be put in a 72-hour emergency kit.

It would be prudent to have this information be available in a number of Alberta's heritage languages if requested in order to overcome any language barriers that may exist. Mandarin should be of primary focus, as Chinatown is located in the flood hazard area.

> **Recommendation 14**: Have the flood readiness brochure available in Alberta's heritage languages, particularly Mandarin, to overcome any language barriers.

The forms of low-intensity public information programs listed above are far-reaching and cost effective, and would be able to provide information to the majority of Calgarians. Direct mail can be mass produced, does not have to be personalized, and can be delivered within a postal code area, ensuring all houses within a community will receive it.

Public meetings are another possible route to disseminate information and have some benefits over brochures. First, you can ensure that the people in attendance are receiving the information, whereas there is no guarantee that the brochures are being read. Second, open houses facilitate interaction with attendees, allowing for input, feedback, and possible demonstrations. Many people who take part in engagement activities also go on to have educational conversations with friends and family (PytlikZillig & Tomkins, 2011).

On the other hand, some evidence has been found to suggest that open houses can have negative outcomes such as participant dissatisfaction, group conflict and polarization (PytlikZillig & Tomkins, 2011). Additionally, those people who are most likely to attend open houses are people who are already engaged and have some background knowledge of the situation. It has been shown that inexpensive, low-intensity programs, such as the use of brochures, can be just as effective in raising awareness as more expensive, high-intensity programs such as public meetings or open houses (IBI Group, 1986). There for, if open houses are to be used, they should be used in conjunction with pamphlets so that those in attendance may be educated prior to arrival so as to have more productive and useful engagement sessions.

> **Recommendation 15**: Use open houses in conjunction with brochures to educate the public and gain feedback when necessary.

Public awareness is important in floods and emergency responses for a number of reasons. Impacts from floods can be measured in both tangible and intangible forms. Intangible impacts are generally described in terms of loss of irreplaceable or sentimental items, impacts on health, negative psychological effects, or being relocated (Department for Environment Food and Rural Affairs, 2004). As discussed above, if people are properly warned and prepared, property damages and tangible impacts can be reduced. Research has also shown that awareness of flood risks can decrease health risks and trauma resulting from flooding (Department for Environment Food and Rural Affairs, 2004).

Finally, it has been found that if residents have never experienced a flood, or if it has been a significant number of years since flooding has occurred, residents are more likely to become complacent and return to old habits, making them less likely to respond appropriately to flood warnings (Drabek, 2000). By sending out regular information on flood readiness, it may help to remind Calgarians that flooding is always a possibility, and being prepared is the best way to reduce damages and health risks.

3.7.2.6.6 Attention for Emergency Workers

After the floods in Calgary in 2005 and 2013, it was easy to see the toll that long periods of high stress took on emergency personnel (Vroegop, 2014). Numerous reports have recommended the investment of time and funds into the health and wellness of emergency management staff to help them stay healthy during these times of high stress and also to help them recover afterwards. Because most people, particularly emergency workers, do not see themselves as needing mental health services following a disaster, they will not seek out such services themselves (DeWolfe, 2000).

Most people who assist with disaster relief are altruistic, compassionate, and dedicated, and will work long and hard, often not considering themselves until disaster efforts are over. Many also do not think they need mental health services, and are therefore unlikely to request them. Because they are likely to witness human tragedy and physical illnesses in their roles, it is important that they have the opportunity to decompress (DeWolfe, 2000). Furthermore, some of these people may be volunteers and may not have mental and health services normally offered to them through their regular employers, making it that much more important to provide opportunities for rest throughout the emergency recovery process.

> **Recommendation 16**: Provide health and wellness support to emergency personnel, particularly during high-stress times of disaster relief and recovery.

3.7.2.6.7 Lesson Sharing

The City of Calgary has learned a number of lessons through the 2005 and 2013 floods, and has the ability to share these lessons with other municipalities and organizations. It also has the ability to learn from others, and could do so by organizing an ongoing conference or forum on flood relief. As of yet no regular event of this kind exists, providing Calgary with an opportunity to be a leader in Canada, providing research and experiences on flood resiliency (Expert Management Panel on River Flood Mitigation, 2014).

Recommendation 17: Host an ongoing conference and workshop on flood resiliency to share best practices and develop national relationships.

3.7.2.7 Damage Reductions Resulting from Contingency Measures

3.7.2.7.1 Introduction

One of the most beneficial and cost-effective actions that a resident can take to reduce tangible and intangible damages is to relocate moveable items to higher elevations and to avoid storing irreplaceable and sentimental items in basements and first floors if possible. Some items are obviously not easily moveable – such as stoves, freezers, washers, dryers, pianos, etc. – and storage space may be at a premium. However, television sets, stereos and other moveable appliances can be put up on tables or desks. If time permits leading up to a flood, drapes/curtains may be tied up, rugs can be rolled up and relocated, and basement furniture can be moved to higher floors. Similar tactics can also be applied to commercial properties. This information should be outlined in the publicly distributed material mentioned above.

This section will provide a generalized assessment of the potential effectiveness and benefits of actions that can be taken by households and businesses in response to flood warnings to reduce economic damages and social impacts of floods in the 1:100 year flood hazard area.

3.7.2.7.2 Past Studies

For this analysis, flood forecasting, warning, and emergency measures will all be considered collectively under contingency measures. A significant number of studies have indicated that given sufficient advanced warning time, in conjunction with a good public awareness campaign, total flood damages can be significantly reduced by owner-initiated activities.

A study of flood damages has found that contents damages can be largely reduced depending on the warning time and the reaction of occupants. Damage reduction models are optimistic and assume that when notified, property owners will act rationally and efficiently, and also that they will have the opportunity to act (Carsell, Pingel, & Ford, 2004). Unfortunately this is not always the case, as some floodplain occupants will not be notified at all, some may not know what to do, and some may not be capable of taking proper actions. The reliability of this response can be increased by ensuring that the message comes from a respected source (Pappenberger, et al., 2015). The recent flooding in Calgary has made citizens more aware of the chance of flooding in the flood hazard area, thereby increasing the uptake of floodproofing measures and causing people to make adjustments to their basement use.

A number of studies show a range of methods that can be used to show avoided damages as a result of early warnings and other contingency measures. Pappenberger et al. (2015) recently published a review that found up to 36.68% of direct, tangible damages could be avoided due to a number of consecutive actions, summarized in **Exhibit 3.6**. The authors took these actions as cumulative damage avoidance percentages, and applied them to the previous sum of damages that was not previously saved (Pappenberger, et al., 2015). They also performed a cost-benefit analysis for each damage reduction pathway, also included in **Exhibit 3.6.**

Exhibit 3.6: Avoided damages and cost-benefit ratios for various pathways when responding to flood warnings due to consecutive actions, adapted from (Pappenberger, et al., 2015).

Pathway	Description	Damages avoided due to early warnings (%)	Ratio of monetary costs to benefits (after 20 years)
Flood Defence Operations (FDO)	Avoided damages by warning dependent flood defences	32%	1:155
Watercourse Capacity Maintenance (WCM)	Damages avoided by water course maintenance	0.9%	1:4
Community Based Operations (CBO)	Damages avoided by community level defences	0.36%	1:2
Early Warning Measures **Subtotal**	FDO, WCM, CBO	32.85%	1:159
Warning Dependent Resistance (WDR)	Residual damages avoided by warning-dependent (temporary resistance) measures	0.0036%	1:1.02
Contents Moved & Evacuated (CME)	Residual damages avoided by moving and evacuating property contents	5.7%	1:28
Total	FDO, WCM, CBO, WDR, CME	36.68%	1:178

Another study looking at the potential damage-reducing benefits of certain flood warnings in Europe found a range of potential damage reductions (Priest, Parker, & Tapsell, 2011). The authors posit that the difference in reductions can be attributed to both an increase in experience with floods as well as an increase in warning lead time. In addition to many of the previously discussed contingency methods, this study also mentions business continuity planning (BCP) – activities taken to reduce the impact of floods on businesses. These can include actions that aim to directly reduce damages, such as moving items out of the path of the flood; or it could relate to actions taken to reduce disruptions in trading or production, for example, through the establishment of an alternative supply chain (Priest, Parker, & Tapsell, 2011). It was estimated that BCP could help reduce the proportion of flood damage to property and business activities avoided (both direct and indirect flood losses) by up to 5% (Priest, Parker, & Tapsell, 2011). The authors underscore that in the short term, household and community resiliency measures may show the largest potential for reducing damages, particularly when performing a cost-benefit analysis. A summary of values of Expected Annual Damages (EAD) avoided from this study can be found in **Exhibit 3.7**.

Exhibit 3.7: Avoided damages for various pathways when responding to flood warnings, adapted from (Priest, Parker, & Tapsell, 2011).

Pathway	Description	Damages avoided due to given pathway (%)
Flood Defence Operations (FDO)	Proportion of EAD likely to be saved through operation of flood defences that are dependent on a warning being available.	28%
Watercourse Capacity Maintenance (WCM)	Damages avoided by water course maintenance before and during a flood (estimated)	10%
Community Based Operations (CBO)	Damages avoided by community level defences	1%
Business Continuity Planning (BCP)	Damaged avoided by the use of business continuity plans; include direct and indirect losses	5%
Contingent Resilience Measures (CRM)	Damages avoided through small-scale, individual property flood damage reduction measures	2%
Contents Moved & Evacuated (CME)	Residual damages avoided by moving and evacuating property contents	5%

3.7.2.7.3 Residential Damages

Paragon Engineering Ltd. performed a study (Paragon Engineering Limited, 1985) comparing damage reductions possible for various dwelling types in southern Ontario (see **Exhibit 3.8**). This study was based on adjustments of actual damage curves, and reflects the relocation of valuable items that can be easily moved. In one-story structures, only those items that could be readily transported in a car were accounted for. They found damage reductions on the scale of **2.5%** for homes without basements all the way up to **23%** for typical two storey townhouses.

Exhibit 3.8: Comparison of damage reductions due to flood warnings with total damages at 2.4 meters, adapted from (Paragon Engineering Limited, 1985).

Structure Type	Total Damages at 2.4 m (2016 CAD)	Damage Reduction at 2.4m (2016 CAD)	Percent Damage Reduction (%)
One-story with Basement	$43,398	$1,236	2.8%
One-story no Basement	$35,906	$907	2.5%
Two-story with Basement	$37,589	$5,123	13.6%
Two-story no Basement	$28,334	$5,470	19.3%
Split-level	$46,284	$7,170	15.5%
Townhouses	$25,538	$5,916	23.0%
Mobile Homes	$27,068	$1,806	6.6%

More recent studies (Pappenberger, et al., 2015) estimate that residential damages may be reduced by up to 36.68% if all contingency measures are in place, as seen in **Exhibit 3.8**. This is dependent on a high response rate and early warning times. The variance seen among these studies is high, as can be expected since it is dependent on human behaviour and environmental variables. However even the minimum benefit of taking action has a positive benefit/cost ratio.

3.7.2.7.4 Commercial Damages

Priest et al. (2011) report that in England, BCP is slowly beginning to increase, with businesses incorporating weather-related events into their contingency plans. However, only 5% of companies were actually able to implement their BCP, and it is difficult to estimate what damages could actually be reduced from such plans. Commercial flood damages and implementation of a BCP is highly dependent on:

- The overall time and effort needed to remove contents from basements and first floors;
- Sufficient suitable storage space, particularly if upper floors of buildings are occupied by other tenants; and
- Personal attachment to company items by general employees impacting the level of effort expended on salvaging items – time would likely be better spent on their own homes if at risk (IBI Group, 1986).

Because commercial properties would benefit from all the same large scale and community level flood defence operations, the only difference would be the effectiveness in their business continuity planning versus the ability of individual homeowners to move property. Since these two values are effectively the same across the literature, the same values can be used to calculate damages avoided for commercial and residential properties.

3.7.2.7.5 Damage Reductions for Current Study

For the purposes of this study a 30% reduction of contents damage was assumed for both residential and commercial structures. This would result in a reduction of approximately $8 million in the average annual damages.

3.7.3 Land Use Regulations

Gilbert White wrote "Floods are 'acts of God', but flood losses are largely acts of man" (White, 1953). White was a pioneer in adapting a broad triple bottom line approach to mitigation that considered the influence of human behavior. He cautioned against an overconfidence in structural mitigation and design standards that could ultimately lead to increased damages. "Flood plain land use regulation may be the single adjustment most likely to reduce flood losses. Structural measures, flood warning systems and flood proofing will be of little value if the reduction in damages is more than offset by new damage potential in the flood plains" (White & Haas, Assessment of Research on Natural Hazards, 1975).

While a bias towards large structural options remains for both the public and responsible agencies, there is growing acknowledgement of the efficacy of holistic floodplain management that includes land use regulation and/or conservation and naturalization. This is strengthened by recognition that climate change may eliminate confidence in design standards and increased awareness of the ecological utility of preserving or restoring watershed environments.

It is obvious that not developing in a floodplain in the first place is the most effective mitigation. However, historic development patterns have led to a complex relationship between cities and floodplains and the social and economic value of floodplain development is significant. Population growth and previous mitigation efforts have further increased the intensity of floodplain development, all compounded by the influences of individuals' risk perception and private property rights. Because a risk cannot be effectively eliminated by structural measures alone, mitigation must consider some degree of development regulations. The 2014 Alberta Floodway Development Regulation Task Force stated:

"From a public health and safety perspective and to minimize the taxpayers' financial burden associated with property damage and loss, it is most effective to keep people and property away from the flood water, rather than attempting to keep the flood water away from people and property." [12]

3.7.3.1 Provincial Regulations

After the 2013 flooding in Alberta, the provincial government enacted Bill 27, the Flood Recovery and Reconstruction Act, amending the Municipal Government Act (MGA) to provide regulation for restriction of development within the floodway. Municipalities are still not required to address flood hazard in their land use bylaws, however this act provides a minimum level of control across the province. The 1:100 year floodway is currently the regulatory standard. However, this could potentially change to a higher level in the future.

The regulation essentially grandfathers existing development while prohibiting new development within the floodway. The City of Calgary land use bylaw, Part 3, Division 3, contains rules governing the floodway, flood fringe, and overland flow areas. These regulations align with the MGA and are summarized as follows:

- Uses approved prior to 1985 are permitted to continue within the floodway while new uses are limited to agriculture, natural and recreation areas, and utilities.
- Replacement or renovation of existing buildings within the floodway is permitted if the building footprint is not increased.
- Alterations to lands within the floodway are not permitted unless initiated by the City for protection of public infrastructure.
- All buildings within the flood fringe must be set back 6 metres from the edge of the floodway. Buildings on parcels developed after 1985 must be set back 60 metres from the Bow River and 30 metres from the Elbow River and Nose Creek.
- New buildings or additions that increase floor area by greater than 75% in the flood fringe must: be designed to "prevent structural damage by floodwaters"; have a first floor and mechanical equipment above the designated flood level, and have a sewer back-up valve installed.
- Additions that increase a building's floor area by 10% to 75% must provide electrical isolation above the designated flood level and install a sewer back-up valve.
- Buildings in the overland flow area have similar restrictions as the flood fringe except the elevation is 0.3 metres above the highest grade on the abutting street.

[12] August 2014 Task Force Discussion Paper – Floodway Development Regulation, pg 7.

In addition to the MGA amendments, the provincial government included mitigation measures that were required in relation to disaster recovery funding. In order to be eligible for provincial disaster recovery funds and to have the notice removed from a property title, the following mitigation measures must be met within the flood fringe [13]:

1. For repairs and renovations:
    - Basements must be designed to minimize moisture damage or facilitate restoration. This can be accomplished by leaving it unfinished; using cleanable, resistant, or easily disposable materials.
    - Electrical equipment must be isolated so that it can be easily de-energized and re-energized safely away from flood waters.
    - Penetrations must be sealed to minimize water seepage.
    - Backflow prevention devices must be installed on sewer connections.
2. For homes being rebuilt, floodproofing must be included with recommended design measures including:
    - Furnaces above flood level
    - Hot water heaters above flood level
    - Electrical service above flood level
    - Isolated basement circuits
    - Service disconnect above grade
    - Weeping tiles
    - Sump pumps
    - Secure fuel tanks
    - Easily disposable or water-resistant materials in basement
    - Basement insulation on exterior of foundation
    - Disconnected downspouts and foundation drains
    - Protective plumbing/backflow prevention
    - Limited foundation openings
    - Elevated ventilation system

Finally, Alberta Infrastructure has flood risk management guidelines for the location of new facilities it funds. This includes lifeline facilities, such as hospitals and legislative buildings, as well as other important facilities, such as museums and hazardous waste sites. The design flood level is as high as 1:1000 as indicated in **Exhibit 3.9**.

The current floodplain development regulations reduce future damages in relation to the extent of future redevelopment within the flood fringe but do not reduce the current risk. Furthermore, regulations, like structural alternatives, are associated with a design standard and subject to future uncertainty.

3.7.3.2 Regulation Criteria

The province of British Columbia provides guidance on floodplain regulation with a document entitled "Flood Hazard Area Land Use Management Guidelines". In issuing the voluntary guidelines, the provincial government shifted the responsibility for flood risk management to the municipalities. A 2014 review of BC municipal bylaws sought to evaluate the extent that municipalities had adopted flood management regulations (Stevens & Hanschka, 2014). The bylaw content analysis involved the creation of an evaluation protocol consisting of 52 criteria from the Guidelines as well as additional identified best practices. The list of questions from the protocol are as follows (Stevens & Hanschka, 2014):

Does the bylaw:

1. Contain a table of contents?
2. Specify that the authority to designate floodplain areas is derived from the Local Government Act (or the Municipal Act)?
3. Specify the purpose of the bylaw (e.g., to reduce the risk of injury, loss of life, and property damage because of flooding and erosion)?
4. Indicate that the adoption of the bylaw should not be taken to mean that no buildings will subsequently be damaged by flooding?
5. Indicate a particular entity (or entities) that are responsible for administering and/or enforcing the bylaw?
6. Contain a list of terms and definitions?
7. Contain a definition for designated flood?
8. Contain a definition for designated flood level?
9. Contain a definition for flood construction level?
10. Contain a definition for floodproofing?
11. Contain a definition for floodway?
12. Contain a definition for freeboard?
13. Contain a definition for habitable area?
14. Contain a definition for natural boundary?
15. Contain a definition for setback?
16. Contain a definition for watercourse?

[13] Available at "Individual mitigation measures for homes: http://www.alberta.ca/mitigation-measures-homes.cfm" (Alberta Government)

17. Make reference to the Provincial Guidelines?
18. Indicate that the Provincial Guidelines were considered when writing the bylaw?
19. Indicate that the Provincial Guidelines were considered when writing the bylaw?
20. Specify penalties for violations or noncompliance?
21. Specify the year in which it was adopted?
22. Designate an area (or areas) as a floodplain?
23. Does the floodplain bylaw prohibit all new development in the floodplain (i.e., the area subject to flooding from the designated, base, or regulatory flood)?
24. Specify a flood construction level (e.g., the 200-year flood plus freeboard) for at least part of the community or a particular land use or type of construction?
25. Specify a building setback from the natural boundary of watercourses in designated area(s)?
26. Specify an FCL for the floodplain of watercourses?
27. Specify a building setback for lakes?
28. Specify a flood construction level for lakes?
29. If No, does the floodplain bylaw specify that the FCL for lakes more 15 km in length should be 3.0 m above the natural boundary of the lake, or any pond, backwater, slough, swamp, or marsh area affected by the lake?
30. Specify a building setback for small lakes, ponds, swamps, or marsh areas?
31. Specify a FCL for small lakes, ponds, swamps, or marsh areas?
32. If Yes, does the floodplain bylaw specify that the FCL for small lakes, ponds, swamps, marsh areas should be greater than or equal to 1.5 m above the natural boundary of the lake, pond or adjacent swamp or marsh area?
33. Specify a building setback from the natural boundary of coastal waters?
34. Specify a FCL for coastal waters?
35. Specify construction standards to account for the effects of storm surge and/or wave velocities?
36. Contain a building setback for building sites that are at the top of a steep bluff and where the toe of the bluff is subject to erosion and/or is closer than 15 m from the natural boundary of a water body?
37. Specify construction standards for the supporting foundation system located below the FCL?
38. Specify construction standards for non-foundation portions of the building located below the FCL?
39. Specify that any FCL for any use or area can be achieved through the use of fill?
40. Require the installation of flood vents in foundation systems?
41. Specify that the underside of any floor system, or the top of any pad supporting any space or room, including a manufactured home, that is used for (a) dwelling purposes, (b) business, or (c) the storage of goods that are susceptible to damage by floodwater must be above the applicable flood level specified by the bylaw?
42. Specify that any landfill required to support a floor system or pad must not extend within any applicable setback specified by the bylaw?
43. Specify that building utilities and/or machinery (e.g., meters, electrical service, electrical panels, furnaces, water heaters, air-conditioning, heat pumps, electrical outlets and switches, ducting, etc.) should be either located no lower than the FCL or should be flood-proofed?
44. Contain construction standards for structures that need to be located inside the floodway or floodplain (e.g., bridges, marinas, docks, dams, some roads, etc.)?
45. If Yes, is the builder of the structure required to demonstrate that the proposed encroachment would not result in any increase in flood levels within the community during a flood event?
46. Specify that non-residential (e.g., commercial and/or industrial) buildings and/or equipment may be located beneath the FCL, provided they are flood-proofed?
47. Refer to some method of verifying building elevations?
48. Specify that all new construction and substantial improvements shall be constructed with materials and utility equipment resistant to flood damage?
49. Specify that water supply systems shall be flood-proofed and/or designed to minimize or eliminate infiltration of floodwaters into the systems?
50. Specify that sanitary sewage systems shall be flood-proofed and/or designed to minimize or eliminate infiltration of floodwaters into the system?
51. Prohibit the storage or placement toxic/hazardous materials in the floodplain?
52. Require that natural features of floodplain areas (e.g., vegetation or contours, fish and/or wildlife habitat, etc.) be protected to at least some greater-than-zero extent?

Note: FCL = Flood Construction Level

Facility Classification and Preferred Design Flood Elevation Levels for Alberta Infrastructure Owned and Funded New Facilities

Decreasing consequence assuming adequate warning		CLASS	IMPORTANCE OF AVOIDING MAJOR DAMAGE DURING A FLOOD EMERGENCY	DESIGN FLOOD LEVEL	EXAMPLES OF FACILITIES	COMMENTS
	Lifeline facilities	1	Critical to the ability to save and avoid loss of human life.	1:1000	Legislative buildings Communication centres	Including computing centres
	Lifeline facilities	2	Critical to the ability to rescue and treat the injured and to prevent secondary hazards.	1:1000	Hospitals and medical facilities Extended care facilities	Including ancillary facilities such as power plants, service and maintenance facilities
	Lifeline facilities	3	Critical urban linkages important to the maintenance of public order and welfare.	1:500	Courthouses Provincial Buildings	Serve as government centres for communication in event of emergency
	Lifeline facilities	4	Critical to the ongoing housing of substantial populations.	1:500	Schools Post-secondary educational facilities Seniors Residences High-rise buildings Correctional facilities Rehabilitation treatment centres	Schools and post-secondary educational facilities may be required to serve as emergency relief centres.
	Lifeline facilities	5	Critical to the orderly return to long term social and economic welfare.	1:500	Airports	Critical for access for supplies and support.
	Other facilities	6	Important to the ability to avoid endangering human life and environment.	1:1000	Hazardous waste disposal and treatment facilities High risk research facilities	
	Other facilities	7	Important to retention of documented historical data and artifacts.	1:1000	Museums, archives, cultural centres	
	Other facilities	8	Important to provide threshold level of protection.	1:100	Offices Retail facilities Warehouse Service & maintenance Parking Other	Other than those associated with facilities in the higher Design Flood Level categories See comments under Site Selection for short-term use facilities.

* Water and Wastewater Facilities are not included in Table A. Contact Alberta Environment and Sustainable Resource Development for guidelines, related to the location of Water and Wastewater Facilities.

The study found that the majority of municipalities did not refer to, or follow best practices as outlined in provincial flood land use guidelines, though the percentage did increase after the provincial guidelines were implemented in 2004. In the case of British Columbia, once an area has been designated a flood prone area, the provincial government will no longer provide disaster assistance to damaged properties unless they have been properly flood-proofed. For this reason, many municipalities are hesitant to move forward with adopting local flood bylaws that define and govern flood zones, as these areas may become more vulnerable. Stevens and Hanschka (2014) suggest that upper level regulations should be mandatory, not voluntary, and that they should not penalize municipal governments for adopting flood bylaws.

3.7.3.3 Regulation Impact on Property Values

A common concern among property owners and municipalities is the effect that flood hazard disclosure and flood plain regulations have on property values. Other intangible costs or benefits of regulation could result from a change in use or structural characteristics.

There are numerous studies that attempt to determine the influence of flood risk on property values but the results are varied, and range from negative to positive effects. The factors that affect property values are complex and methodologies vary such that a publication can be found to support either proponents or opponents of flood plain regulations.

Hedonic pricing models are often employed to determine the impact a certain variable has on a property's value. However, these models are insufficient at capturing the complex market reaction to flood risk or floodplain regulations and have provided mixed results. It seems obvious that, all other things being equal, a house with increased restrictions would be less desirable than a house without. However, all things are never equal and the flood risk is usually directly associated with unique locational attributes that are difficult to account for.

Surveying perceptions and attitudes is another approach to understand how people perceive the nature and extent of flooding, and the impact of regulations. This too is difficult to draw conclusions from, as individual risk perceptions vary greatly and do not always align with expectations.

The view that regulation negatively affects property values is primarily based on the restriction of development potential and infringement of the ability of an owner to utilize their property freely. However, in areas of expensive, low density housing in an attractive urban location, floodplain regulations can preserve neighbourhood amenities and character thus increasing the property value over time. Anecdotally, various regulatory regimes can, over time, create a unique sense of place, particularly when related to the connection between the built and natural environment.

The grandfathering of existing development does little to reduce damages. When property improvements are done incrementally they do not usually trigger regulations because it is normally not feasible to flood-proof a portion of a structure, nor is it economical to do so for accessory structures. This further maintains the status quo and dampens the effect of regulations on the use of a property.

A Canadian study analyzed the actual and perceived effects of regulation in the city of London, Ontario. It was unique in that it controlled for neighbourhood effects on pricing by geographical matching of home characteristics outside the floodplain. It found that most residents perceived that no impact on land values was associated with floodplain regulations, which was supported by the analysis of actual home transactions (Shrubsole, Green, & Scherer, 1997). A review of other available studies was largely inconclusive and largely context dependent.

3.7.3.4 Recommended Changes to Current City of Calgary Land Use Bylaw

When considering land use regulations as a means of reducing flood damages it is instructive to note that although the existing bylaw sets main floor elevations above the design flood level, developed basements below the design flood level remain at risk and contribute to flood damages. As described by IBI Group in the development of new stage-damage curves as part of the Provincial Flood Damage Assessment Study [14], basement damage values have risen significantly over the past 30 years as a result of increased utility, level of finishing and current renovation practices which favour total rehabilitation of flood impacted basements versus incremental rehabilitation of flood damaged components. Within the Calgary flood hazard area, basement damages are exacerbated by the high water table and the alluvial materials within the floodplain which facilitate propagation of groundwater throughout the flood hazard area, thereby contributing to basement damage during flood events. Basement damage occurs within the fringe areas of every return period where basements are below the return flood elevation. Groundwater damage contributes some $25.5 million of average annual damage, which is 22% of the total average annual damage for the City. Over time, this number is expected to increase as intensification and redevelopment continue within the flood hazard area. Accordingly, it is suggested that a more rigorous approach be taken in relation to this aspect of floodplain regulations.

[14] IBI Group/Golder Associates, Government of Alberta, ESRD, Calgary 2015.

3.7.3.4.1 Alternative Approaches

Option 1

Option 1 envisions a voluntary program of backflow preventers and sump pumps for existing development and mandatory requirements for backflow preventers, sump pumps and foundation waterproofing for renovations and new development.

Option 2

Option 2 involves the elimination of basements below the design flood level. There are a number of implications associated with this option related to impacts on cost, contextual setting/streetscape, property values, house design and compensatory bylaw changes. These are briefly highlighted as follows.

Cost

Space lost as a result of the elimination of basements would need to be constructed above grade at an additional cost of $80 per ft2. Assuming additional construction of between 700 and 1,500 ft2, costs would range from $56,000 to $120,000 above that of a similar-sized house with a basement (basement ft2 included in total ft2). However, if these regulations are uniformly applied over the flood hazard area then there is no competitive disadvantage for builders/ homeowners developing in close proximity to the river. Essentially, this is a geographic cost premium for locating in close proximity to the river for which there is an offsetting locational value or benefit premium related to the amenity characteristics associated with proximity to the river.

Contextual Setting/Streetscape

This becomes an issue when piecemeal redevelopment results in significant elevation differences between adjacent properties. However, it should be noted that this is currently the case in many inner-city communities and the first properties to be redeveloped would logically be the older dwellings that oftentimes are contextually challenged today.

Property Values

As indicated, this is a two-way street in that potential flood damages would be eliminated for these structures which already benefit from increased property values as a result of their proximity to the river. It is our contention that additional construction costs associated with replacing lost basement space above grade would be more than compensated for by the elimination of flood damages in combination with the enhanced land value as a result of location.

House Design

Conventional house design would be constrained; however, unique built form and relationships would result, potentially creating a desirable and distinct housing form and community in these areas of the city.

Compensatory Bylaw Changes

The elimination of basements and replication of this space above the design flood level would more than likely necessitate some accommodations within the existing land use bylaw in terms of reducing height restrictions, increasing lot coverage, relaxing setbacks and allowing secondary suites where eligible in the main structures, elsewhere on the property (garden suite) or above the garage (laneway suite/ carriage house).

Feasibility

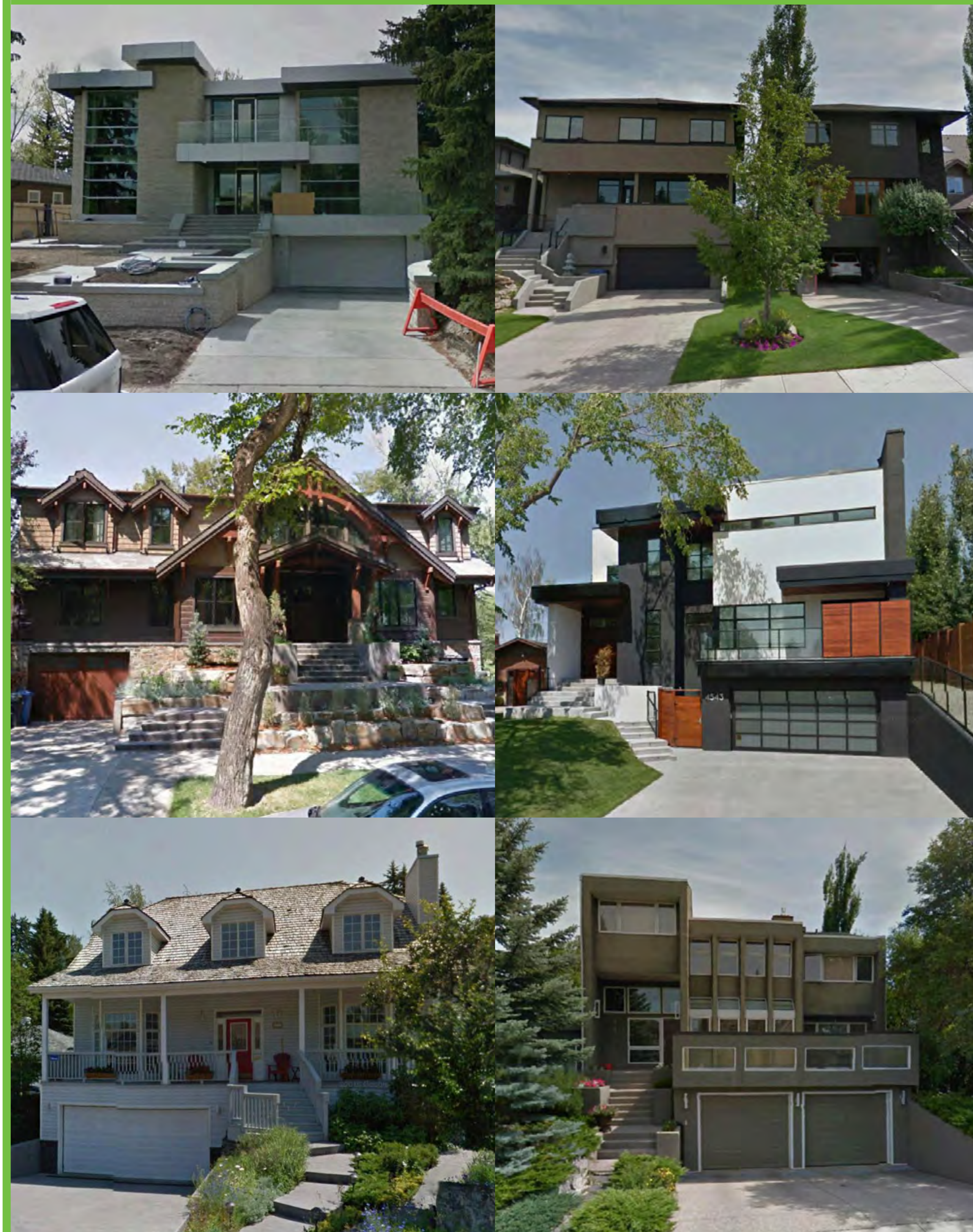
Exhibit 3.10 details the number of ground-oriented structures (single-family, townhouse and duplex) within the 1:200 year flood hazard area by depth of floodwater (proposed design height). As evidenced, in total there are 4,445 total structures affected. 837 of these are subject to less than 0.7 m (2.3 ft) of flooding, necessitating only no or only modest elevation changes. A further 467 structures require a 0.7 to 1 m (2.3 to 3.3 ft) elevation change. Another 1,089 would require a 1 m (3.3 ft) to 1.5 m (4.9 ft) elevation change. The latter is equivalent to a half level, which is a common design feature for entry and main floor units within the City of Calgary. 1,782 are between 1.5 m (4.9 ft) and 2.7 m (8.8 ft), a half to a full level above grade. In these instances some site modifications would be required (landscaping, fill or retaining walls). Once again, these design responses are quite common in various Calgary communities. The accompanying exhibit (Exhibit 3.11) provides examples of houses with comparable elevation changes from the street level or adjacent properties.

Exhibit 3.10: Number of Ground-Oriented Homes by Depth of Water at 1:200 Year Flood

Depth at Grade	Number of Buildings
0.0 - 0.7	837
0.8 - 1.0	467
1.1 - 1.5	1089
1.6 - 2.0	914
2.1 - 2.7	868
>2.7	270

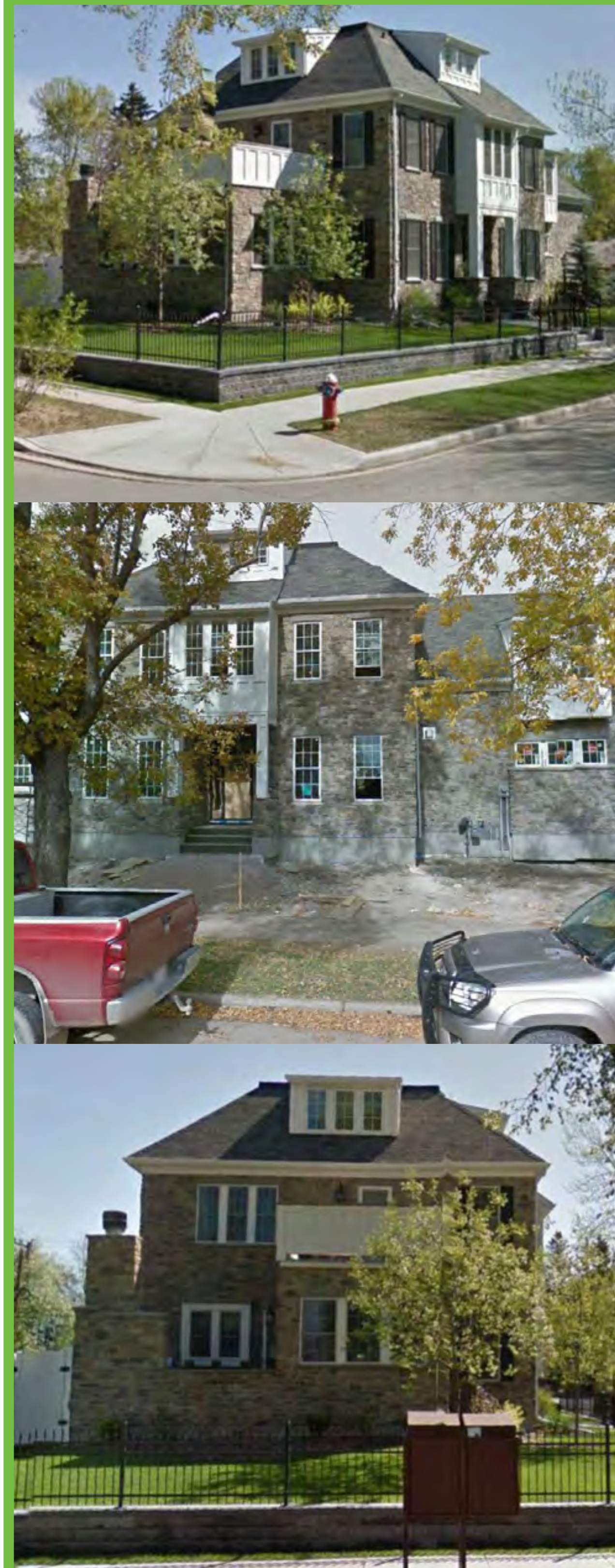
Local Examples of Elevated Main Floors

Single family homes with elevated main floor



Local Examples of Elevated Main Floors

Elevated Lot and main floor with no basement



Elevated main floor with wall

Basement with floodproofed window wells

3.7.4 Buyouts/Conservation

3.7.4.1 Description of Alternative

In the aftermath of the 2013 floods, The Province of Alberta introduced legislation to prohibit development in the floodway and initiated a program designed to help relocate homes in the floodway by buying properties from homeowners located there. Approximately a dozen properties within Calgary's floodway were purchased and the houses on them removed. No new buildings will be permitted on these properties in the future.

This initiative by The Province began to address the problem of future development in the flood plain, but it raises the issue of continued property maintenance and community integrity in the areas where these properties lie. By buying back property along the river, The City has an opportunity to create a long-term plan to create pockets of conservation in the floodplain, thereby reducing the risk of future flood damages in these areas, and minimizing potential disruption. This will create continuity along the floodplain of essential environmental functions, including floodwater storage, groundwater recharge, riverbank erosion control, water quality maintenance, and creation of wildlife habitat.

Buyouts have been used by floodplain managers as a non-structural mitigation tool to permanently stop the cycle of repetitive flood loss. As infrastructure is cleared off of properties in the floodway, and developments are gradually converted to open spaces, over time the possibility of loss due to flooding decreases, and the benefits to the community increase (Zavar, 2015).

3.7.4.2 Literature Review

Because of the inherent ability of non-structural measures to achieve flood damage reduction without modifying the characteristics of the flood, non-structural measures help achieve environmental sustainability in flood damage reduction (Buss, 2010). Ecological functions and low impact recreational opportunities are significant benefits to restoration and conservation of floodplain lands.

The U.S. Army Corps of Engineers has steadily moved towards prioritizing non-structural mitigation measures with the goal of reaching sustainable and integrated flood management. By using ecosystem restoration and/or recreation as a new use of a floodplain that was previously occupied by flood-damageable structures, the ability to develop an economically feasible floodplain buyout or relocation project has been greatly enhanced. Communities that previously were averse to buyouts because of tax base loss are now very interested in buyouts because the alternate ecosystem restoration and/or recreation use of the floodplain creates a very vibrant and attractive public area for community enhancement.

Four recent projects would not have been economically feasible if formulated on the basis of flood damage reduction only. Johnson Creek (Arlington, Texas), Little Duck (Fairfax, Virginia), Cold Brook (Hot Springs, South Dakota), and Yellow River (Gendive, Montana) have incorporated ecosystem restoration as a new use in the evacuated floodplain to help with project justification and have benefit/cost ratios ranging from 1.4 to 1.6.

St. Louis County in Missouri is located at the confluence of three rivers with a history of flood disasters: the Mississippi, the Missouri, and the Meramec. The state of Missouri has actively been acquiring thousands of properties within the floodplains. Unlike the other two larger rivers, which are lined with levees, the Meramec River is in a relatively natural state. Within the county, roughly 9,000 acres have been preserved as of 2013 as part of the Meramec Greenway as state and local parks, as well as nonprofit conservation lands. The Meramec Greenway is part of a larger River Ring plan for an extensive network of connected greenways.

A 2013 study (Kousky & Walls, 2013) sought to assess the costs and benefits of floodplain conservation as a mitigation strategy using the Meramec Greenway as a case study. The study analyzed three major components of the conservation approach: the average annual avoided flood damages; the opportunity costs of the protected lands; and the added value of the protected lands.

Damages and opportunity costs were based on a hypothetical development scenario in which the conserved lands were assumed to be developed in a manner consistent with surrounding properties. The average annual avoided flood damages were estimated at $7.7 million while the annualized opportunity cost of protecting the lands was estimated to be $17.2. However, through statistical analysis, the estimated capitalization of the greenway into adjacent properties amounted to annual benefits of $23.6 million (Kousky & Walls, 2013).

The Meramec study illustrates that while the opportunity costs of protecting flood-prone lands may exceed the savings in avoided damages, the traditional benefits provided by protected lands, such as recreation and aesthetics, can be substantial. This study, however, did not address several important factors, including the social cost to households on lands to be protected or the environmental benefits of conserving or restoring natural riparian areas.

In acquiring land for flood mitigation, local land management must be employed together with initiatives of higher levels of government. When it comes to the expropriation of land, The Province of Alberta applies its own version of the Expropriation Act (Province of Alberta, 2014), which states that land can be taken and used by the government as long as it is to be used in the public interest. If the owner of the land is being forced to give up residence, they can be compensated for this, or for any reduction in the value of their land. Under the Expropriation Act of Canada (Government of Canada, 2016), compensation for moving expenses may not exceed 15% of the market value of the property. Additionally, the government is required to pay the value of any special economic advantage that the owner gained by occupying their land (such as for agricultural use).

After the expropriation has been approved, the government must serve the landowner notice advising them of the date of possession. In Alberta, this date must be at least 90 days from the date the notice is served. If the land is going to be used for the creation of a right-of-way, the date of possession only has to be seven days from the date the notice is served (Province of Alberta, 2014).

The most cost-effective use of floodway land would be to begin by purchasing properties that have the highest assessed damages (Kousky & Walls, 2013), in order to minimize potential damage in the event of a flood. Expanding outward from these properties to create continuous tracts of green-space would be the most ecologically effective process, and would also have the most positive impact on communities.

The exact use of the newly created open-space should be determined in cooperation with those residents left in the community, and should be a use that best suits the community's needs. In older neighbourhoods with close proximity to urban centres, where lot sizes are smaller and multi-family residential units are common, open spaces can serve as an extension of or a substitute for a backyard (Zavar, 2015). While open-space development may not always result in high-utility land use for residents in buyout areas, informal recreation and passive use is still possible on reclaimed property in the floodway. Whether the investment in open-space development pays off in a certain community will depend on local conditions and community buy-in.

3.7.4.3 Benefit and Costs

A complete accounting of buyout benefits and costs would entail a complex economic assessment of the substantial social and environmental impacts. This section outlines the benefits in terms of damage averted and the direct costs associated with buying residential properties and restoration of lands.

The majority of properties within the approximate 1:200 floodway are residential. Non-residential properties in the floodway are varied and include the Calgary Stampede, the zoo, the Holy Cross Hospital site, and several schools. Because most non-residential properties would require individual assessment for buyout applicability, only residential properties were included in this analysis.

The floodway as defined includes those structures up to the 1:200 flood return period, but the calculated annual avoided flood damages include the damages saved for all 12 return periods modelled up to the 1:1000 flood period. Since the structures and contents are permanently removed, there is no maximum flood return period at which this method fails. Removal of all the damages within the floodway provides a benefit of reducing the AAD by $27.2 million.

Within the approximated 1:200 year floodway, there are approximately 980 residential buildings. The total assessed property value amounts to over $1.8 billion.

When expropriating residential property, acquisition costs can be calculated using the base cost of the market value of the property plus compensation to account for relocation expenses of residents. Further costs associated with the buyout program would include moving houses in good condition, the costs attached to the demolition of remnant structures and the rehabilitation of land or required landscaping to naturalize the area. Local quotes for property cleanup come in at an average of $32,000 per property (plus tax) and includes the following:

- Demolition of all structures on the property;
- Hauling away of dwellings, foundations and contents;
- Demolition and hauling away of asphalt or concrete driveways and sidewalks.
- Removal and disposal of fencing and miscellaneous rubble;
- Clean-up and disconnecting of sewer, water, gas and electricity;
- Dumping fees;
- Asbestos abatement where necessary.

Costs to naturalize the land have been estimated at $55/m². Additional costs may be required over time if the areas are going to be used as active green spaces, including: further landscaping; mowing grass; collecting waste and recycling; replacing fences and signs; and installation of lighting, recreational fixtures, and urban furniture.

Because the assessed property value is so high in relation to the reduction in damages, it was decided that further calculation of benefits and costs was not necessary. The assessed value of $1.8 billion compared to average annual damages for the same area of $27.2 million produces a benefit/cost ratio of 0.47. The benefit/cost ratio of this option is negative even before factoring in all the other costs, not to mention the community impact and other social costs. Investigation of select buyouts of individual properties facing specific risks in association with other mitigation scenarios may be appropriate.

3.7.5 Property Level Mitigation/Floodproofing

3.7.5.1 Introduction

There has been a shift to integrated risk-based flood management approaches, for which a greater contribution from flood-prone households and businesses is expected. Research has indicated that private mitigation measures can substantially reduce damage (Bubeck, Botzen, Kreibich, & Aerts, 2012) and can be very cost-effective (Kreibich, Christenberger, & Schwarze, 2011). Implementing property-level floodproofing measures has the potential to prevent damages from more than one flood event, so residents can see multiple returns on their investment over the lifetime of the building. Furthermore, private initiatives inherently involve a level of awareness and engagement that can improve the public discourse on risk and resilience.

Many studies have found that large-scale flood defences are not the most efficient or cost-effective solution to mitigating flood risks, and therefore there is an increasing onus on individuals to invest in property-level measures to protect their own homes (Joseph, Proverbs, & Lamond, 2015).

Property level flood risk adaptation measures refer to any and all actions that households can take on an individual basis to adapt their properties to flood risk (Joseph, Proverbs, & Lamond, 2015). In addition to the aforementioned contingency measures, these could involve the process of modifying the property to keep water out, as well as resilience measures that allow water onto the property but reduce the damage it does (known as wet floodproofing).

3.7.5.2 Description of Alternatives

Floodproofing measures are generally defined as non-structural approaches that are carried out on existing or future developments in order to reduce potential flood damages (IBI Group, 1986). Floodproofing measures can include temporary actions designed to protect properties from imminent flooding, as well as permanent methods designed to decrease the risks associated with living in the flood plain, or in some cases, remove them altogether. For the purposes of this analysis, the floodproofing options considered are: elevation of structures; seals and closures; sewer backflow prevention; and sumps and pumps.

3.7.5.3 Elevation of Structures

Existing structures in good condition can often be elevated on extended foundation walls, columns, or on compacted fill, with the objective of raising the level of the first floor above the design flood elevation. If used effectively, the end result should be a reduction of content damage to zero, and a reduction in structural damage to a nominal value (IBI Group, 1986).

When being elevated, the structure must be capable of withstanding the stress of removal from its foundation, as well as transportation to and from temporary storage, or the stress of being held on temporary supports while a new foundation is constructed below. Thus, it is best if the structure is fairly small, simple, strong, and lightweight in order for this method to be feasible. Once it is replaced on the elevated foundation, utilities and mechanical systems are reconnected, stairs are installed, and the site is rehabilitated (IBI Group, 1986).

This method has many advantages, primarily that it is highly reliable if correctly undertaken, and that it requires no further measures in the event of a flood excepting evacuation of the residents. That is, the homeowner has little else to worry about, unless flood levels are exceeded. This method is applicable to many residential units, and can even be applied to small commercial units in the right circumstances.

On the other hand, this technique can have high financial costs, and requires the right conditions in order to be effective. It may also offer residents a false sense of security in times when water levels exceed those which the building was prepared for. If the structure was not prepared for horizontal stresses, it may succumb to floodwaters in times of extreme flooding. These methods also require the residents to find temporary housing during constructing, potentially adding costs.

The most common methods to elevate structures are elevation on fill, and elevating on extended foundation, both of which are subsequently described.

3.7.5.3.1 Elevation on Fill

This option of elevation involves the removal of the structure from the site, driving pile foundations, extending existing utilities, and then filling the foundation and returning the structure to the site. Meanwhile, the structure must be relocated and stored, adding an additional cost to this mitigation measure. Some additional above-grade construction may also need to be completed to compensate for the loss of basement if it existed prior to elevating.

FEMA has calculated the cost estimates for the elevation of structures based on nationwide US averages, and has included foundation, extending existing utilities, and miscellaneous items. The costs (originally given in 2001 USD) were first converted to 2001 CAD (OzForex Group Ltd., 2016) and then to 2016 prices using the Construction Price Index (Statistics Canada, 2016) to provide an estimate of this measure today. These costs are provided in **Exhibit 3.12**.

Exhibit 3.12: Elevation Cost Estimates for Elevation on Fill (FEMA, 2001)

ITEM	COST ESTIMATES (PER SQUARE FOOT)		
2-foot raise:	2001 Prices (USD)	2001 Prices (CAD)	2016 Prices (CAD)
Wood frame building with basement/crawlspace	$18.00	$27.86	$63.54
Wood frame building with slab-on-grade foundation	$50.00	$77.40	$176.50
Masonry building with basement/crawlspace	$37.00	$57.27	$130.61
Masonry building with slab-on-grade foundation	$50.00	$77.40	$176.50
3-8 foot raise (per additional square foot)	$0.80	$1.24	$2.82

The option of elevation on fill is more suited for rural areas where large spaces are available for the slopes, terraces, or retaining walls needed to contain and support the added fill.

3.7.5.3.2 Extended Foundation

This option is more suitable for densely populated areas where such large spaces are not needed for the foundation on compacted fill. Some possible alternatives for elevating a structure on extended foundation are via: masonry or concrete piers; cantilevers; posts, poles, or piles; or low continuous walls. Usable space created under or beside the dwelling is made available for items that are easily movable or not readily damaged by flood waters. Most commonly, the new area is used for parking cars or for storage. In this case the previous basement must also be filled and in some instances new footings poured.

There are a number of variables that affect the cost of these methods, including the size, style, and condition of the existing house. The method of elevation used is also going to affect the price, in conjunction with local construction and material prices.

This option may not be suitable for those who need ramp access to their home or structure, as the addition of stairs is the most common form of access after modifications have been made. Elevation on fill would allow for easier addition of a ramp but would require large amounts of land for the appropriate length and slope of ramp needed.

3.7.5.4 Seals and Closures

Seals and closures can be effectively utilized in structures where the envelope of the structure is otherwise generally impermeable. This can be done by applying sealants and waterproof coatings to building exteriors to reduce their permeability. Since it is unlikely that all water will be kept out, sumps and pumps (refer to Section 5.7) can be employed to clear out any flood water seepage that manages to get through.

In cases of severe flooding where floodwater rises above one meter of the main floor, keeping water out of the property can cause such high hydrostatic and hydrodynamic stress on the building that it is more destructive to keep the water out than to let it in. Therefore it is not recommended that doors, windows or air vents over one meter in height be blocked. Closures and seals are generally more appropriate for commercial and industrial buildings that can withstand such high levels of stress (IBI Group, 1986).

Once the building envelope is essentially sealed, all building openings must be carefully sealed. Windows may be permanently wholly or partially filled to reduce the number and/or size of closure panels required. Windows and doors are generally very poorly sealed and lack the structural strength to hold back even low hydrostatic loads, so these are most likely to require closure panels of some sort (IBI Group, 1986). Closure panels and flood gates are removable barriers that fit into residential doorways and windows and easily expand to fit and fill the doorway. Flood boards can also be used to seal doorways or larger areas. There is an abundance of styles and sizes that can be pre-purchased out of wood, aluminum or steel. Some will require a sealant, while other prefabricated closures may come with a sealing device designed for rapid emplacement. Some common types of seals and closures are illustrated in **Exhibit 3.13**. A more extensive look at different seals and closures, as well as other barriers, can be found on the FEMA website [15].

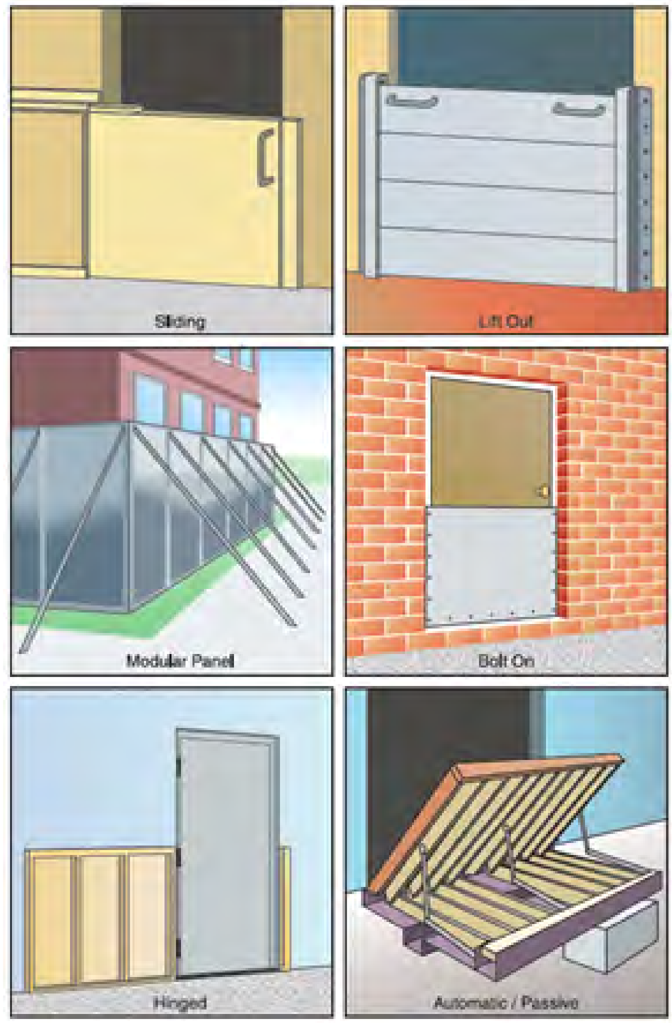
One benefit to using this option is that it does not require the use of any additional land or setbacks. It is advantageous for larger commercial and institutional structures and is relatively easy to implement. It is also appropriate for floods of short duration, in which the height and location of closures can be chosen.

On the downside, the effectiveness of this option is wholly dependent upon the timely intervention of the people implementing it, and therefore upon the warning system, making it contingent in nature. It may be difficult to check on the system for the duration of the flood, and if the sealants and gaskets require any maintenance, this could be difficult or impossible to determine if the building has been evacuated. Finally, if the flood level for which the system was designed is exceeded, or if one or more of the closures is not properly in place, there could be catastrophic damage.

3.7.5.5 Flood Walls and Berms

Control of floodwaters may also be accomplished through the use of berms and floodwalls created around individual structures or groups of structures. Local soil conditions and available space are the primary determinants in the choice between berms and floodwalls.

Exhibit 3.13: Examples of Closures and Seals (FEMA, 2013)



Since berms require substantial side-slopes in order to maintain their lateral stability under high hydrostatic loads, they are generally only used in locations with large setbacks, or where relatively shallow flood protection is required. Floodwalls, on the other hand, are able to provide protection from substantial flood depths without needing those same setbacks. Either of these options may be combined with other non-structural measures, such as building closures and seals. When properly designed, built and maintained, berms and floodwalls have the potential to eliminate structural and content damages at design flood levels. As is the case with closures and seals, some seepage may occur and can be mitigated through the use of sump pumps.

[15] Available at http://www.fema.gov/media-library/assets/documents/34270

An advantage of floodwalls and berms is that they can be built to conform to local topography, thereby providing the extent and degree of coverage required, customized to the location in question. In this regard they are well-suited for industrial, commercial, or agricultural uses which require protection of a structure as well as the surrounding outdoor storage area. Floodwalls and berms are reliable, and if they are permanent, they require little human involvement in order to maintain their effectiveness during a flood (IBI Group, 1986). Finally, their utilization does not depend on the size, type and condition of the structure being protected.

Some disadvantages of floodwalls and berms include restricted access to buildings during and after flooding. If openings are provided, the nature of the closures used may decrease the reliability of the protection the structure provides. Because of their nature, berms may require a considerable amount of space to ensure their stability, making them unsuitable in urban locations. Finally, as with any floodproofing measure, if the berm or floodwall is overtopped, catastrophic losses may be incurred.

3.7.5.6 Sewer Backflow Prevention

If a structure is to be protected by closures and seals, or berms and floodwalls, there is the need for installation of an automatic sewer line backflow valve. This valve can be installed at the perimeter of the building or property and would serve to protect all outlets within the building as long as it were maintained and inspected regularly. A backflow valve has an internal hinged plate that normally opens in the direction of flow. If flow is reversed the hinge plate closes over the pipe opening. A manually operated gate valve may also be installed, which would provide definite protection against sewer backflow if shut.

The Province of Alberta recommends that sewer backflow prevention measures be installed in most renovations, repairs and new builds in the flood hazard area. This requirement should be inclusive of all buildings located within the flood hazard area that may be susceptible to sewer backup, regardless of the size or style of renovation.

3.7.5.7 Sumps and Pumps

Aside from piping systems, sump pumps are the most common type of internal drainage equipment (FEMA, 2013). Sumps are designed so that the bottom of the pit is below the base of the floor slab so water will drain towards the pit. While in use, sump pumps should be checked periodically to ensure that they are working properly, as switch failure and debris blockage can commonly occur. It is important to know that if the building has excessive seepage or is completely inundated, it is likely that the capacity of the pump will be exceeded. It is important that sump pumps be able to operate in the event that power is shut off to maintain a dry environment, so having a generator, battery, or other form of backup power is a necessity.

In an effort to reduce basement damages, it is recommended that The City of Calgary should require mandatory sump pumps and ancillary power sources for properties located in the flood plain that are subject to flooding or basement seepage. Cost estimates for sump pumps (including digging sump, supplying pump, battery and installation) range from CAD $900 to CAD $2354 and are highly dependent on the type of pump used, basement material (concrete vs. dirt floor), and local installation costs [16].

3.7.5.8 Discussion and Recommendations

Elevation of structures can be highly effective in reducing flood damages, but the costs can be highly prohibitive, and the implementation is also dependent on the condition of the structure. When elevating structures on fill, as well as building berms, large setbacks are required, which are seldom available on inner city lots.

Many varieties of commercial seals and closures are available, but can be impractical for locations that see infrequent flooding. Some forms can also be very costly and require additional measures such as the water-proofing of the lower portion of the house. If implemented properly they can be counted on, but cannot be checked during flooding, and are not practical for large scale implementation. Seals and closures would be a recommendation for commercial, educational, and industrial institutions that are less likely to have basement windows and have stronger structures to begin with.

More appropriate for large scale residential implementation in flood hazard areas are mandatory sumps and pumps, and sewer backflow prevention systems. If these provisions are regularly inspected, they have the ability to provide reliable protection from low-level inundation and sewer backup at a comparatively low cost. They are both relatively easy to install on any site and should require no additional action from the homeowner in the event of a flood.

3.7.6 Flood Insurance

An overview of insurance offerings is provided in Section 5 of the Phase I document. This section provides further detail on coverage and premiums.

Homeowners overland flood coverage is available for damage to structures, contents and additional costs associated with flood losses, including costs associated with accommodation while homes are being repaired, clean up and debris removal following flood events, among other losses. Maximum coverage for overland flood can significantly exceed the value of a home. Typically maximum coverage may range from 2-3 times the cost of rebuilding a structure. An example scenario for maximum coverage for a $500,000 structure would be $1.25 million, and would include the following:

- $500,000 coverage for structure;

[16] Various sources investigated include (AquaGuard Injection & Waterproofing, 2016); (FEMA, 2013); and (HomeAdvisor, 2016).

- $500,000 coverage for contents, and;
- $250,000 for additional coverages.

Insureds may have the option of selecting any coverage limit up to specified maximums—the lower the coverage limit selected, the lower the premium for flood coverage. In the case of overland flood insurance, many households will likely choose to purchase lower coverage limits as a means of reducing premium costs. The table below provides a report from a major personal property flood insurance provider, and illustrates take up rates and proportion of home insureds who have opted for full coverage in Alberta. As illustrated below, the proportion of loss that is covered can be low. As flood hazard is lowered, the proportion of individuals who choose to purchase full coverage increases—but evidence indicates that the majority do not have full coverage regardless of risk level. In the case of very high-risk insureds, the average limit selected by households would cover only 5% of their losses.

Example take-up rates, coverage limits (homeowner flood coverage) for a company offering flood coverage in Alberta.

Household Flood Exposure (Defences Considered)	% With Flood Coverage	% With Full Coverage Limit	Average Flood Coverage Limits	
			$	% of full limit
1:20	50%	0%	$40,000	5%
1:40 to 1:100	75%	3%	$110,000	15%
1:100	90%	40%	$475,000	55%

3.7.6.1 Premiums

For the purposes of pricing flood coverage, insurers develop a best estimate of annual expected loss (AEL) and will load AEL for profit and expenses. A catastrophe loading variable may also be considered to offset uncertainty, extreme loss and costs associated with reinsurance. Catastrophe loadings may increase as uncertainty increases. Pricing will differ based on values for each of these loading factors applied by different insurers.

Loading for new insurance products may be more significant than loading for well established, mature products. In the Canadian context, residential flood coverage is a new product, resulting in significant loading by some insurers. Additional loading results from insurers lack of confidence in the assessment of property risk, due to limited historical claim experience. Reports from insurers for the purposes of this report indicated the loading for residential flood coverage ranged from 1.4 to 4 (for both structure and contents). It is likely that average loadings will vary between 1.5 and 2.

As a result of multiple variables applied to assess risk for individual insureds, a major insurer indicated that they could not "broadly state" how local hydrological factors and flood protection works would affect premiums for each individual insured. Further, an insurance respondent stated that they would not offer coverage for flood in 1:40 year return period hazard areas, and would likely offer a base coverage of $10,000 in areas of lower risk, with an option for insureds to purchase additional coverage.

Additional variables that may be considered in flood premium estimation include:

- Likelihood that flood defences will fail during flood events that exceed design levels
- Local vegetation conditions (e.g., wildland fire may increase flood risk due to loss of vegetation)
- Climatic factors, rainfall information
- Hydrologic factors
- Soil types
- Grading, topography
- Construction type
- Presence of basement
- Presence of lot-level risk reduction measures

3.7.6.2 Notes on structural flood mitigation measures

Generally, insurers and the industry in general is not supportive of developing in high flood risk areas, regardless of flood protection measures that may be put in place to protect properties. Insurers recognize the probability of failure of structural flood defences, and factor structural failure into pricing and other considerations related to flood insurance. To quote one of our insurance respondents:

"Flood defenses (such as dams, dykes, and berms) help to mitigate against flood; however, they are costly to build, require ongoing maintenance, and do not protect against extreme events exceeding their standard of protection. Further to this, the stated standard of protection may be accurate at the time a defense is built but can become inaccurate over time as the climate changes and extreme weather events become more common. We consider the mitigating effect of defenses when calculating insurance premiums for clients within the region protected by the defense, but their premiums may still be quite high even with a defense in place. The most prudent and cost-effective defense against flood is to simply ensure that development does not occur in known floodplains."

3.7.6.3 Summary of Key Overland Flood Insurance Issues for Alberta

- The number of companies offering flood products has expanded over the past few months and will likely continue to expand over the coming years.
- Estimated premiums for flood coverage vary widely between insurance companies.
- Insurers have reported that their flood products are evolving and will continue to evolve for a number of years.
- Most homeowners in high-risk zones do not to purchase full coverage. Some will choose very low limits as a means of reducing their flood insurance premiums.
- Many insurers will not offer flood coverage to insureds they consider to be very high risk.
- Individual property factors will have a significant impact on pricing (e.g., building type, existence of basements, proportion of basement that is finished, etc.).
- Insurers may not reflect the "full benefits" of flood mitigation structures in flood insurance pricing, based on the expectation that the reliability of structures will degrade over time and the possibility of structural failure.

3.7.6.4 Hypothetical Premium Estimation

For illustrative purposes, the viability of insurance as an option to mitigate flood impacts was assessed. The AAD is an expression of the expected annual loss and would form the basis for setting annual insurance premiums. To determine an average premium for residential properties, the associated AAD was divided by the number of affected units and then multiplied by the industry loading factor.

Residential insurance premiums were analysed for ground-oriented units (Single-family, duplex, and townhouses). Citywide, the average annual risk per unit is $3,100. With assumed loading variables between 1.5 and 2.0, the estimated average annual premium would be between $4,650 and $6,200. It is important to note that this is an average for all properties within the 1:1000-year risk area and actual premiums would vary greatly, from hundreds to tens of thousands per household, because private insurance companies would not average the risk.

Two subsets were then taken that represented higher risk areas in a manner insurance would evaluate premiums. For all homes subject to overland flooding at the 1:50-year risk level, the average annual risk per unit is over $10,000, with estimated average annual premiums between $15,000 and $20,000. At a community level, the average risk for all homes in Roxboro is over $15,000, with estimated average annual premiums between $23,000 and $31,000.

3.7.6.5 Conclusions

The premium estimations above are for full coverage of direct and displacement costs. In reality, only a portion of the costs would be covered, leaving the homeowner to pay the deductible and any uninsured costs. Additionally, third-party insurance for flooding would not likely be available to all properties. Those properties most at risk may not be covered by third-party insurers.

In a study performed in 2016 by Ipsos Public Affairs for The City of Calgary, it was found that 83% of respondents living in flood prone communities expressed concerns that their residence or property was at risk of damage from flooding. Yet the survey also found that 42% of that same population was not willing to pay for residential flood insurance if it were available to them. Of the population in flood prone communities willing to pay for flood insurance, only 19% were willing to pay more than $1000 per year (Ipsos Public Affairs, 2016).

Providing flood insurance to residents of flood prone communities has been shown to have detrimental effects on individual flood preparedness and does not reduce damages. Upon introducing subsidized flood insurance in the US, it was shown to encourage, rather than discourage development in the floodplain (Bruce, 1976). Anecdotally, one of the first people to purchase overland flood insurance in Calgary when it became available in early 2014 expressed that he was buying flood insurance instead of installing property level flood mitigation in his home during his rebuild. He also only plans to retain the policy "for five or six years … until the upstream mitigation [is] done so we're not going to have this issue facing us any longer" (interview cited in Beynon, 2014).

It is the job of an insurer to maximize premiums and minimize claims, not necessarily to reduce the risk of flooding for their clients (Oulahen, 2015). They do not wish to eliminate the risk altogether, they only need to price it correctly to benefit, therefore introducing flood insurance is not necessarily beneficial to those living in flood prone areas, as they will remain vulnerable to damages. Information from the insurance industry indicates that average premium costs will be in the order of 150-200% of the anticipated damages, offering no net economic benefit. Furthermore, the industry has indicated that it would discount the presence of structural mitigation in determining expected loss for the purpose of premium pricing. Uncertainty is a major risk with third party insurance and in general, it should not be relied upon as part of a public policy for major flood risk.

3.7.7 Summary of Non-Structural Recommendations

3.7.7.1 Contingency Measures

Contingency measures are an essential part of the non-structural recommendations because they provide a flexible, low-cost option that is relatively fast and easy to implement, and is adaptable to local conditions. Many of the recommendations offered in Section 2 are centered on the formalization and implementation of a clear, effective, and up-to-date warning plan; keeping citizens safe and informed, particularly those in the flood hazard area; defining roles in the event of a flood; and creating connections and partnerships to enhance flood preparedness. By using Alberta's flood history in conjunction with a number of other case studies, it is possible to combine best practices both in Alberta and abroad to create safer communities around flood prone areas. A 30% reduction in contents damage due to contingency measures amounts to $8 million in annual benefits over the existing baseline.

3.7.7.2 Land Use Regulations

Based on the principle outlined in the 2014 Floodway Development Regulation Discussion Paper that, "it is most effective to keep people and property away from the flood water, rather than attempting to keep the flood water away from the people and property", development in the floodplain should be limited as much as possible (Floodway Development Regulation Task Force, 2014). Through a combination of land use regulations and property level mitigation, over time The City of Calgary has the ability to drastically reduce the amount of basement damage due to flooding and related events. By implementing land use regulations that eliminate the development of space below the design flood, and requiring sump pumps and sewer backflow preventers, in addition to bylaws already in place, The City will all but eliminate basement damages in the floodplain over time.

To get an estimate of the potential damage reduction possible by implementing these regulations, we have assumed a 1% uptake per year over 100 years, as these measures will take some time to penetrate the entire area. Administration costs attributable to the implementation of such regulations are deemed to be negligible. The present value of removing developed space below the 1:200 flood level over 100 years is $166 million.

3.7.7.3 Buyouts

Changing the use of high risk lands by purchasing properties and relocating residents is a theoretically desirable scenario with many benefits. However, it presents very big economic and social obstacles. The purchase of all residential properties within the approximated 1:200 year floodway would cost $1.8 billion and provide only $27 million in annual benefits. Although these benefits would be perpetual, discounting future benefits yields negative benefit/cost results.

Additionally, implementation in established inner-city communities would be challenging. As evidenced in the 2013 Southern Alberta Floods, peoples' connection to their community can be overwhelmingly strong, even in the face of catastrophic danger. For this reason, public support for a large scale buyout in riverside communities is likely to be low.

3.7.7.4 Property Level Mitigation/Floodproofing

Property level flood mitigation practices encourage property owners to undertake floodproofing measures at an individual, property-level scale. They have shown to be cost-effective and also keep flood readiness front of mind.

In order to alleviate flooding and seepage in basements in the flood hazard area, it is recommended that The City of Calgary initiate a program to encourage the voluntary installation of sump pumps and backflow preventers for existing residents and businesses within the flood hazard area while making this requirement mandatory for significant renovation and redevelopment initiatives.

Other potential options for property level floodproofing include elevation of main floors, removal of basements and installation of seals and closures for commercial and larger buildings where appropriate.

Groundwater infiltration accounts for a large portion of the estimated damages and floodproofing against it is viable. If over the course of 100 years (1% per year) all buildings experiencing groundwater damages had sealed foundations, sump pumps, and backflow preventers, the present value of benefits would amount to $232 million. If completed over 20 years it would amount to $607 million.

3.7.7.5 Flood Insurance

Risk due to hazards such as flooding are best reduced using a combination of mitigation strategies, where the responsibility is spread among stakeholders. The viability of insurance as a flood mitigation risk is challenged by a lack of randomness and the mutuality of flood losses resulting in extremely high costs for at-risk properties and thus adverse selection. Providing flood insurance does not reduce flood damages, however, after applying other cost-effective measures, it may be an appropriate mechanism to help redistribute residual risks and, if implemented effectively, may discourage development in the floodplain.

Hypothetical insurance premiums were calculated based on these loading factors and annualized damages. The average annual full-coverage premium for all residential houses within the 1:1000 year risk area would be between $4,650 and $6,200 but vary greatly with risk. Within the 1:50 year risk area, it would average between $15,000 and $20,000.

For all possible insurance options, the required premium would be a perpetual cost. It would also likely be a perpetually increasing cost as the quantity and value of at-risk properties increases. Given the costs and level of uncertainty, insurance for high risk of flood damages is not a viable option for property owners. It may remain an option for individual purchase once the risk has been mitigated to an acceptable level through structural or regulatory options. In other words, insurance should not be relied upon to achieve the acceptable level of protection.

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3.8 Review of Flood Mitigation Measures for the City of Winnipeg

The City of Winnipeg has experienced major floods since the early 1800s. In the past 60 years, the floods in 1950, 1997, 2009 and 2011 have caused substantial damage along the Red River and Assiniboine Rivers. The City of Winnipeg is one of the major cities in Canada where flooding occurs periodically.

Southern Manitoba has extensive flood control measures in place, particularly in the Red River Valley, from Winnipeg, south to the U.S. border. Flood controls were built after the flood of 1950, which flooded the Red River Valley and the City of Winnipeg. Construction of the Red River Floodway was completed in 1968. Additional flood control improvements, including an expansion of the floodway, were made after the Flood of the Century in 1997.

The measures implemented to date and their effectiveness for mitigating against flooding in the City of Winnipeg are reviewed in this study to learn from the practices and to help identify and evaluate flood mitigation options applicable to Calgary. The results of this review are summarized in **Appendix F.** The most effective flood mitigation measures based on the Winnipeg experience are listed in **Exhibit 3.14.**

Exhibit 3.14: Most Effective Flood Mitigation Measures Based on Winnipeg Experience

Category	Type
Structural Measures	Permanent dykes in the City of Winnipeg and at the floodway inlet structure, ring dykes, and floodwalls.
	Red River floodway, and portage diversion channel.
	Temporary flood protection barriers, including super sandbags, Hesco barriers, water-filled geomembrane flood tubes, and sandbags.
	River bank stabilization works to protect critical infrastructure and properties.
Non-Structural Measures	Emergency Preparedness Program, including planning and response to flood events (e.g., EmergWeb providing flood-related information).
	Integrated basin flood management planning and operation, provided by the International Red River Board, the Red River Basin Commission, and the International Water Institute.
	Flood monitoring, forecasting and warning, including use of MIKE-11 model for flood routing, and GIS-based flood manual for forecasting requirements for mitigation works.
	River flood hazard and inundation mapping, including significant improvements in the databases following the 1997 flood.

3.9 Screening of Potential Flood Mitigation Options

3.9.1 Purpose

As described in the previous sections, there are a large number of structural and non-structural flood mitigation options for potential application and implementation in the Bow and Elbow River watersheds for reducing flood damage in Calgary. In this study, these potential options were screened using a qualitative option evaluation method based on high-level and broad-based criteria. The result of this high-level evaluation was a prioritized list of potential options that were considered for developing the flood mitigation scenarios for Calgary.

No potential option was eliminated during this screening process, but the resulting option preference information was used in developing the flood protection scenarios. For example, two potential options could be used for flood mitigation in a specific area, but the prioritized option received preferred consideration in the design of the flood mitigation scenarios.

3.9.2 Broad-Based Criteria

Typical flood mitigation option evaluation criteria include technical, financial and environmental/social considerations. In this study, the following broad-based criteria were used for prioritizing the potential options:

- **Functional Reliability** – This criterion is used to measure the functional reliability and effectiveness of a flood mitigation option in providing the intended flood mitigation benefit to the protected area. This criterion includes consideration of the technical robustness and reliability of the mitigation measure during its construction and operation. The risk of potential dis-function is part of the consideration and qualitatively evaluated based on past operational experience.

- **Financial Efficiency** – This criterion is used to measure the cost benefit of a flood mitigation option in consideration of the project capital cost, operational cost, and financial benefit (including damage reduction) to the protected area. Benefit-cost ratio is a typical parameter used for measuring financial efficiency. This screening evaluation includes a general consideration of cost benefit but does not include a computation of the benefit-cost ratio. However, benefit-cost ratios are computed during detailed evaluation of the flood mitigation scenarios.

- **Environmental and Social Impact** – This criterion is used to measure potential direct and indirect adverse effects of a flood mitigation option on the existing biophysical and societal conditions in the project and protected areas. For example, a structural flood mitigation measure typically involves changes of flood flow conditions in the project and protected areas, and such changes may have adverse effects on channel morphology, water quality, fish habitat, terrestrial habitat, and historical resources. For another example, a non-structural measure such as property or community relocation may negatively affect small insular communities, older established neighbourhoods, and long standing residences.

3.9.3 Screening Results

The screening criteria mentioned above were used to qualitatively rate the main flood mitigation options. The rating involved the following numeric scheme:

- 3 - High level of functional reliability and financial efficiency; low level of environmental and social impact;
- 2 - Medium level of functional reliability, economic efficiency, and environmental and social impact; and
- 1 - Low level of functional reliability and economic efficiency; high level of environmental and social impact.

Equal weight (i.e., 33%) was assigned to each of the three screening criteria. The weighted score of each mitigation option is equal to the sum of the three weighted ratings. The weighted scores were used to categorize the flood mitigation options under the following three priority groupings:

- preferred options for consideration in the flood mitigation scenarios – these options have weighted scores between 2 and 3;
- options with medium level of preference for consideration in the flood mitigation scenarios – these options have weighted scores between 1.5 and 2; and
- least favored options with the lowest level of preference for consideration in the flood mitigation scenarios – these options have weighted scores below 1.5.

Exhibit 3.15 presents the screening evaluation results. These results are considered in the development of the flood mitigation scenarios.

3.10 Development of Flood Mitigation Scenarios to be Modelled

Exhibit 3.16 outlines the flood mitigation measures that are either going ahead or have been completed; those that are planned/or will go ahead when funding is obtained; and, finally those that are being considered for implementation as components of the mitigation scenarios to be developed. The orange and yellow highlighted measures are the focus of mitigation scenarios and include:

- new flood storage facilities along with updated operating rules to the existing hydro facilities and reservoirs in the Bow River Basin;
- permanent barriers along the Bow River;
- permanent barriers along the Elbow River;
- stormwater and drainage improvements;
- groundwater flood control measures at select locations;
- temporary flood barriers at various locations as part of the Emergency Response Plan;
- selective buy-out of flood affected houses;
- flood insurance; and
- a variety of contingency measures along with modifications to the floodplain regulations and grant programs related to the installation of sump pumps and backflow preventers.

There are 13 scenarios in total, each with multiple individual components, some common to several. With the exception of 1a and 2, the scenarios are based on a 1:200 year design standard. The 2013 flood approximated a 1:200 year event. Consequently, there is consideration by the Province to review the design standard to reflect this new reality. Scenario 1a includes extra protection for downtown to the 1:350 year flood levels. It is assumed that a single new reservoir on the Bow River would provide significant mitigation.

Details of the barriers included in each scenario can be found in **Exhibit 3.17**.

3.10.1 Description of Scenarios

The scenarios are briefly summarized as follows:

3.10.1.1 Scenario 0

- Baseline case involving existing improvements only.

3.10.1.2 Scenario 0a

- Existing improvements.
- Non-structural measures independently assessed.

3.10.1.3 Scenario 1

- SR1 - Springbank off-stream reservoir.
- New TransAlta operating agreement in the Bow River Basin.
- Stormwater and drainage improvements.

3.10.1.4 Scenario 1a

- SR1 - Springbank off-stream reservoir.
- Barriers protecting downtown to a 1:350 year flood level.
- New TransAlta operating agreement in the Bow River Basin.
- Stormwater and drainage improvements.

3.10.1.5 Scenario 2

- SR1 - Springbank off-stream reservoir.
- One new Bow River upstream storage reservoir.
- New TransAlta operating agreement in the Bow River Basin.
- Stormwater and drainage improvements.

3.10.1.6 Scenario 3

- One new Bow River upstream storage reservoir.
- Elbow River barriers.
- New TransAlta operating agreement in the Bow River Basin.
- Stormwater and drainage improvements.

3.10.1.7 Scenario 3a

- One new Bow River upstream storage reservoir.
- Elbow River barriers with groundwater control.
- New TransAlta operating agreement in the Bow River Basin.
- Stormwater and drainage improvements.

3.10.1.8 Scenario 4

- SR1 - Springbank off-stream reservoir.
- Bow River barriers.
- New TransAlta operating agreement in the Bow River Basin.
- Stormwater and drainage improvements.

3.10.1.9 Scenario 4a

- SR1 - Springbank off-stream reservoir.
- Bow River barriers with groundwater control.
- New TransAlta operating agreement in the Bow River Basin.
- Stormwater and drainage improvements.

3.10.1.10 Scenario 5

- Elbow River barriers.
- Bow River barriers.
- Stormwater and drainage improvements.

3.10.1.11 Scenario 5a

- Elbow River barriers with groundwater control.
- Bow River barriers with groundwater control.
- Stormwater and drainage improvements.

3.10.1.12 Scenario 6

- Buy-out of residential properties within the floodway.

3.10.1.13 Scenario 7

- SR1 - Springbank off-stream reservoir.
- One new Bow River upstream storage reservoir.
- Barriers on the Bow River as needed to supplement upstream storage to 1:200 level.
- New TransAlta operating agreement in the Bow River Basin.
- Stormwater and drainage improvements.

Screening of Flood Mitigation Options

Category	Type *	Functional Reliability	Financial Efficiency	Environmental & Social Impact	Weighted Score
	Weight	33%	33%	33%	
Structural Measures	Dams and Reservoirs	3	3	2	2.6
	Permanent Dykes, Levees, Floodwalls	2	3	1	2.0
	Channel Improvements	1	1	1	1.0
	Bypass and Diversion Channels	3	1	1	1.7
	Watershed Treatment	1	1	2	1.3
	Temporary Flood Barriers	1	3	3	2.3
	Channel Bank Erosion Protection	3	2	2	2.3
	Groundwater Flood Control	2	1	2	1.7
Non-Structural Measures	Urban Redevelopment	3	1	1	1.7
	Property Relocation/Acquisition	3	1	1	1.7
	Storm Water Management	1	1	2	1.3
	River Flood Hazard and Inundation Mapping	3	3	3	3.0
	Floodplain Regulations	1	3	2	2.0
	Zoning and Land Use Bylaws	1	3	2	2.0
	Subdivision Regulations	1	3	2	2.0
	Building Codes	1	1	2	1.3
	Emergency Preparedness Program and Measures	3	3	3	3.0
	Flood Proofing	2	1	2	1.7
	Integrated Basin Flood Management Planning and Operation	3	3	3	3.0
	Flood Monitoring, Forecasting and Warning	1	3	3	2.3
	Development Policies	3	3	2	2.6
	Tax Adjustments	1	1	2	1.3
	Flood Insurance	1	2	1	1.3

Rating Scheme:
3 - High level of functional reliability and financial efficiency; low level of environmental and social impact
2 - Medium level of functional reliability, financial efficiency, and environmental and social impact
1 - Low level of functional reliability and financial efficiency; high level of environmental and social impact

Color Scheme:
Green - Preferred options for consideration in the flood mitigation scenarios – these options have weighted scores between 2 and 3
Yellow - Options with medium level of preference for consideration in the flood mitigation scenarios – these options have weighted scores between 1.5 and 2
White - Least favored options with the lowest level of preference for consideration in the flood mitigation scenarios – these options have weighted scores below 1.5

* See **Appendix E** for Details

Definition of Flood Mitigation Scenarios to be Modelled

Flood Mitigation Measures			Scenario Number												
			0	0a	1	1a	2	3	3a	4	4a	5	5a	6	7
Category	Type	Brief Description	Baseline	Baseline + Non-structural	SR1	#1 with high downtown barriers	SR1 + new Bow reservoir	Bow reservoir + Elbow barriers	#3 with ground water mitigation	SR1 + Bow bariers	#4 with ground water mitigation	Bow and Elbow barriers	#5 with ground water mitigation	Floodway buyouts	SR1 + Bow reservoir + select Bow barriers
Structural	Flood Storage/ Regulation Reservoir	TransAlta's hydro facilities and reservoirs in the Bow River basin - historical operating rules	✓	✓											
		TransAlta's hydro facilities and reservoirs in the Bow River basin - current TA and GoA agreement			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		One new flood storage facility on the Bow River (likely between Cocrane and Calgary)					✓	✓	✓						✓
		Glenmore reservoir on the Elbow River, including gate improvements	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Springbank off-stream reservoir (SR1) in the Elbow River basin			✓	✓	✓			✓	✓			✓	✓
	Permanent Barriers	Existing barriers (existing conditions without raising dykes)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Discovery Ridge barrier (not in the hydraulic model domain)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Stampede barrier (designed based on 494 m^3/s in Elbow River)	50	50	200	200	200	50	50	200	200	50	50	200	200
		Zoo barrier (designed based on 2820 m^3/s in Bow River)	100	100	200	200	350	200	200	200	200	100	100	200	350
		Eau Claire West barrier (designed based on 2390 m^3/s in Bow River)	200	200	200	200	1000	1000	1000	200	200	200	200	200	1000
		Heritage Dr./Glendeer Circle barrier (designed based on 2820 m^3/s in Bow River)	100	100	200	200	350	200	200	200	200	100	100	200	350
		Centre Street bridge lower deck – gates (designed based on 1660 m^3/s in Bow River)	50	50	75	75	350	350	350	75	75	75	75	75	350
		Bonnybrook improvements (designed based on 2820 m^3/s in Bow River)	100	100	200	200	350	200	200	200	200	100	100	200	350
		Deane House barrier (designed based on 803 m^3/s in Elbow River)	100	100	200	200	200	100	100	200	200	100	100	200	200
		Downtown barriers including those along Elbow & Bow Rivers (designed based on 2627m^3/s in Bow River and 879 m^3/s in Elbow River)				350									
		Bow River barriers (designed based on 2280m^3/s upstream of Elbow confluence and 3506 m^3/s downstream of Elbow confluence)								200	200				
		Bow River barriers (designed based on 2280m^3/s upstream of Elbow confluence and 3520 m^3/s downstream of Elbow confluence)										200	200		
		Elbow River Barriers (designed based on 1130m^3/s in Elbow River)						200	200			200	200		
		Bow River barriers (Bowness North and South, Sunnyside) (designed based on 1300m^3/s in Bow River)													200
		Bow River barriers (Fish Hatchery) (designed based on 1729m^3/s in Bow River)													200
		Bow River barriers (Bowness North and South, Sunnyside) (designed based on 2020m^3/s in Bow River)													
		Bow River barriers (Inglewood, Fish Hatchery) (designed based on 2820m^3/s in Bow River)													
		Bow River barrier for downtown (designed based on 2390m^3/s in Bow River)													
	Stormwater and Drainage Improvements	Existing stormwater outfall gates (e.g. downtown, Mission, Eau Claire, Bowness)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Gates and pump stations at planned permanent barriers	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Sunnyside pump station / Sunnyside stormwater (Community Drainage Improvement CDI additional #2 pumps)			✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
		Quarry Park pump station			✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
	Groundwater Flood Control	Groundwater control as supplemental feature of planned permanent barriers							✓		✓		✓		
	Temporary Barriers	Temporary flood barriers at various locations per the City's flood emergency response plan	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Non-structural	Contingency Measures	Flood warning protocols		✓											
		Education & awareness		✓											
		Emergency measures - protection of highest risk or best B/C areas		✓											
	Flood Plain Regulations	Land use bylaws (no below-grade suites)		✓											
		Develoment policies (basement floodproofing)		✓											
		Homeowner grant program - sump pumps/backflow preventers		✓											
	Buyouts	Select buyouts (200 year floodway)												✓	

Color scheme:
- Going ahead/done
- Planned/will go ahead when funding obtained
- No immediate plans to implement, may consider in scenarios

Note: The values for the permanent barriers under the various scenarios refer to the minimum return periods of floods (in unit of year) which the barriers are designed to protect against (or the minimum flood protection level).

Barrier Location and Details (Approximate Dimensions)

Structure	Community	Average Height	Max Height	Total Length	Private Land
Scenario 1a					
Sunalta	Downtown West End, Sunalta	0.6	1	900	N
Downtown - Raised Pathway	Eau Claire, Chinatown, Downtown East Village	1.4	2.7	2,700	Y
Elbow Park North / Elbow Park South	Elbow Park	2.7	6.3	3,100	Y
5 St SW (Mission)	Cliff Bungalow, Elbow Park, Mission	3	4.4	300	N
East Mission	Cliff Bungalow, Elbow Park, Mission	2.5	4.4	1,200	Y
Stampede	Beltline	2.2	4.4	2,900	Y
Macdonald Bridge / St Marys High School	Downtown East Village, Beltline, Mission	1.6	4.4	3,200	Y
Scenario 3					
Britannia	Elbow Park, Elboya	2.4	4.3	1,300	Y
Elboya	Parkhill, Elboya	2.9	4.1	700	N
Rideau Roxboro	Roxboro, Rideau Park	3	5.3	1,500	Y
Elbow Park North / Elbow Park South	Elbow Park	2.7	6.3	3,100	Y
5 St SW (Mission)	Cliff Bungalow, Elbow Park, Mission	3	4.4	300	N
East Mission	Cliff Bungalow, Elbow Park, Mission	2.5	4.4	1,200	Y
Erlton	Erlton	2.2	3.3	400	Y
Stampede	Beltline	2.2	4.4	2,900	Y
Macdonald Bridge / St Marys High School	Downtown East Village, Beltline, Mission	1.6	4.4	3,200	Y
Scenario 3a					
Britannia	Elbow Park, Elboya	2.4	4.3	1,300	Y
Elboya	Parkhill, Elboya	2.9	4.1	700	N
Rideau Roxboro	Roxboro, Rideau Park	3	5.3	1,500	Y
Elbow Park North / Elbow Park South	Elbow Park	2.7	6.3	3,100	Y
5 St SW (Mission)	Cliff Bungalow, Elbow Park, Mission	3	4.4	300	N
East Mission	Cliff Bungalow, Elbow Park, Mission	2.5	4.4	1,200	Y
Erlton	Erlton	2.2	3.3	400	Y
Stampede	Beltline	2.2	4.4	2,900	Y
Macdonald Bridge / St Marys High School	Downtown East Village, Beltline, Mission	1.6	4.4	3,200	Y
Scenario 4					
Bowness North	Bowness	2.2	4.8	1,800	Y
Bowness South	Bowness	2.2	3.7	2,500	Y
Montgomery North	Montgomery	1.6	2.4	300	Y
Montgomery South	Montgomery	1.4	1.9	300	N
Bow Manor	Montgomery	1.5	2.6	600	N
Crowchild	West Hillhurst	0.7	1.3	1,000	N
Sunnyside Op1	Hillhurst, West Hillhurst, Sunnyside	1.5	3.2	2,400	N
Memorial East / Memorial West	Crescent Heights, Sunnyside	1.7	2.3	1,200	N
Downtown - Raised Pathway	Eau Claire, Chinatown, Downtown East Village	1.1	2.3	2,600	Y
Bridgeland	Crescent Heights, Bridgeland/Riverside	1.4	2.6	1,400	N
Fish Hatchery / Inglewood	Inglewood	1.7	4.3	3,300	Y
Deerfoot at 17 Ave	Albert Park/Radisson Heights	2.7	3.8	600	N
Inglewood Golf Club - Option 2	Inglewood	1.4	3	1,000	N
Bonnybrook	Alyth/Bonnybrook, Burns Industrial	1.7	2.9	2,200	Y
Heritage Drive	Burns Industrial	2.4	4.2	2,800	Y
Deerfoot at Southland	Acadia, Maple Ridge	1.8	3.5	1,000	N
River Bend North	Riverbend	0.9	1.4	600	Y
River Bend South	Riverbend	0.9	1.4	500	N
Quarry Park	Riverbend, Douglasdale/Douglasglen	2.2	3.1	1,500	N
Douglas Glen	Douglasdale/Douglasglen	1.7	2	100	N
Douglasbank	Douglasdale/Douglasglen	2.8	3.7	1,600	N

Barrier Location and Details (Approximate Dimensions)

Structure	Community	Average Height	Max Height	Total Length	Private Land
Scenario 4a					
Bowness North	Bowness	2.2	4.8	1,800	Y
Bowness South	Bowness	2.2	3.7	2,500	Y
Montgomery North	Montgomery	1.6	2.4	300	Y
Montgomery South	Montgomery	1.4	1.9	300	N
Bow Manor	Montgomery	1.5	2.6	600	N
Crowchild	West Hillhurst	0.7	1.3	1,000	N
Sunnyside Op1	Hillhurst, West Hillhurst, Sunnyside	1.5	3.2	2,400	N
Memorial East / Memorial West	Crescent Heights, Sunnyside	1.7	2.3	1,200	N
Downtown - Raised Pathway	Eau Claire, Chinatown, Downtown East Village	1.1	2.3	2,600	Y
Bridgeland	Crescent Heights, Bridgeland/Riverside	1.4	2.6	1,400	N
Fish Hatchery / Inglewood	Inglewood	1.7	4.3	3,300	Y
Deerfoot at 17 Ave	Albert Park/Radisson Heights	2.7	3.8	600	N
Inglewood Golf Club - Option 2	Inglewood	1.4	3	1,000	N
Bonnybrook	Alyth/Bonnybrook, Burns Industrial	1.7	2.9	2,200	Y
Heritage Drive	Burns Industrial	2.4	4.2	2,800	Y
Deerfoot at Southland	Acadia, Maple Ridge	1.8	3.5	1,000	N
River Bend North	Riverbend	0.9	1.4	600	Y
River Bend South	Riverbend	0.9	1.4	500	N
Quarry Park	Riverbend, Douglasdale/Douglasglen	2.2	3.1	1,500	N
Douglas Glen	Douglasdale/Douglasglen	1.7	2	100	N
Douglasbank	Douglasdale/Douglasglen	2.8	3.7	1,600	N
Scenario 5					
Britannia	Elbow Park, Elboya	2.4	4.3	1,300	Y
Elboya	Parkhill, Elboya	2.9	4.1	700	N
Rideau Roxboro	Roxboro, Rideau Park	3	5.3	1,500	Y
Elbow Park North / Elbow Park South	Elbow Park	2.7	6.3	3,100	Y
5 St SW (Mission)	Cliff Bungalow, Elbow Park, Mission	3	4.4	300	N
East Mission	Cliff Bungalow, Elbow Park, Mission	2.5	4.4	1,200	Y
Erlton	Erlton	2.2	3.3	400	Y
Stampede	Beltline	2.2	4.4	2,900	Y
Macdonald Bridge / St Marys High School	Downtown East Village, Beltline, Mission	1.6	4.4	3,200	Y
Bowness North	Bowness	2.2	4.8	1,800	Y
Bowness South	Bowness	2.2	3.7	2,500	Y
Montgomery North	Montgomery	1.6	2.4	300	Y
Montgomery South	Montgomery	1.4	1.9	300	N
Bow Manor	Montgomery	1.5	2.6	600	N
Crowchild	West Hillhurst	0.7	1.3	1,000	N
Sunnyside Op1	Hillhurst, West Hillhurst, Sunnyside	1.5	3.2	2,400	N
Memorial East / Memorial West	Crescent Heights, Sunnyside	1.7	2.3	1,200	N
Downtown - Raised Pathway	Eau Claire, Chinatown, Downtown East Village	1.1	2.3	2,600	Y
Bridgeland	Crescent Heights, Bridgeland/Riverside	1.4	2.6	1,400	N
Fish Hatchery / Inglewood	Inglewood	1.7	4.3	3,300	Y
Deerfoot at 17 Ave	Albert Park/Radisson Heights	2.7	3.8	600	N
Inglewood Golf Club - Option 2	Inglewood	1.4	3	1,000	N
Bonnybrook	Alyth/Bonnybrook, Burns Industrial	1.7	2.9	2,200	Y
Heritage Drive	Burns Industrial	2.4	4.2	2,800	Y
Deerfoot at Southland	Acadia, Maple Ridge	1.8	3.5	1,000	N
River Bend North	Riverbend	0.9	1.4	600	Y
River Bend South	Riverbend	0.9	1.4	500	N
Quarry Park	Riverbend, Douglasdale/Douglasglen	2.2	3.1	1,500	N
Douglas Glen	Douglasdale/Douglasglen	1.7	2	100	N
Douglasbank	Douglasdale/Douglasglen	2.8	3.7	1,600	N

Barrier Location and Details (Approximate Dimensions)

Structure	Community	Average Height	Max Height	Total Length	Private Land
Scenario 5a					
Britannia	Elbow Park, Elboya	2.4	4.3	1,300	Y
Elboya	Parkhill, Elboya	2.9	4.1	700	N
Rideau Roxboro	Roxboro, Rideau Park	3	5.3	1,500	Y
Elbow Park North / Elbow Park South	Elbow Park	2.7	6.3	3,100	Y
5 St SW (Mission)	Cliff Bungalow, Elbow Park, Mission	3	4.4	300	N
East Mission	Cliff Bungalow, Elbow Park, Mission	2.5	4.4	1,200	Y
Erlton	Erlton	2.2	3.3	400	Y
Stampede	Beltline	2.2	4.4	2,900	Y
Macdonald Bridge / St Marys High School	Downtown East Village, Beltline, Mission	1.6	4.4	3,200	Y
Bowness North	Bowness	2.2	4.8	1,800	Y
Bowness South	Bowness	2.2	3.7	2,500	Y
Montgomery North	Montgomery	1.6	2.4	300	Y
Montgomery South	Montgomery	1.4	1.9	300	N
Bow Manor	Montgomery	1.5	2.6	600	N
Crowchild	West Hillhurst	0.7	1.3	1,000	N
Sunnyside Op1	Hillhurst, West Hillhurst, Sunnyside	1.5	3.2	2,400	N
Memorial East / Memorial West	Crescent Heights, Sunnyside	1.7	2.3	1,200	N
Downtown - Raised Pathway	Eau Claire, Chinatown, Downtown East Village	1.1	2.3	2,600	Y
Bridgeland	Crescent Heights, Bridgeland/Riverside	1.4	2.6	1,400	N
Fish Hatchery / Inglewood	Inglewood	1.7	4.3	3,300	Y
Deerfoot at 17 Ave	Albert Park/Radisson Heights	2.7	3.8	600	N
Inglewood Golf Club - Option 2	Inglewood	1.4	3	1,000	N
Bonnybrook	Alyth/Bonnybrook, Burns Industrial	1.7	2.9	2,200	Y
Heritage Drive	Burns Industrial	2.4	4.2	2,800	Y
Deerfoot at Southland	Acadia, Maple Ridge	1.8	3.5	1,000	N
River Bend North	Riverbend	0.9	1.4	600	Y
River Bend South	Riverbend	0.9	1.4	500	N
Quarry Park	Riverbend, Douglasdale/Douglasglen	2.2	3.1	1,500	N
Douglas Glen	Douglasdale/Douglasglen	1.7	2	100	N
Douglasbank	Douglasdale/Douglasglen	2.8	3.7	1,600	N
Scenario 7 (20 year Barriers)					
Bowness North	Bowness	1.1	1.8	1,300	Y
Bowness South	Bowness	1.1	2.5	1,600	Y
Sunnyside Op1	Hillhurst, West Hillhurst, Sunnyside	0.7	1.2	800	N
Fish Hatchery	Inglewood	0.6	0.9	700	N

DEVELOPMENT AND EVALUATION OF FLOOD MITIGATION SCENARIOS

4

4 Development and Evaluation of Flood Mitigation Scenarios

4.1 Introduction

The following section describes the development and evaluation of flood mitigation scenarios considered for implementation within the flood study area. The initial four sub-sections, 4.2, 4.3 4.4 and 4.5, outline the methodology and assumptions employed, while the results of the evaluations are summarized by scenario in sub-section 4.6.

4.2 Updating of Risk Profiles by Area

For the areas protected by the various scenarios, new overland and groundwater inundation surfaces were produced and associated damages recalculated including direct, indirect and intangible damages.

4.3 Costs of Flood Mitigation Measures

The costs for the various flood mitigation measures included in the scenario analysis were obtained from The City. Only a high level review of the cost information was conducted in this Study. The available cost information was generated by the various sources (e.g. The City, the Province, and consultants engaged by The City or the Province). The available cost information was based on various levels of design ranging from conceptual to detailed engineering. Project cost assumptions are detailed in **Exhibit 4.1**.

4.4 Benefit/Cost Analysis for Each Scenario

For flood mitigation projects, economic evaluation requires a comparison between the events predicted to occur if the project is built and those predicted to occur if the project is not built. This is called the “with and without principle”. For flood control, one cannot directly equate an exchange in the market, however flood control benefits can be estimated by assuming they are equivalent to the flood damage prevented.

For flood mitigation projects the probabilistic approach to benefit/cost estimates is used. To reiterate, within the defined flood risk area, flood damages were estimated with the application of depth-damage curves applied to the various return flood events (probability). The flood damage probability distribution was then plotted and the average annual damage (AAD) estimated for project evaluation purposes.

Considering average annual damages and cost estimates for the various scenarios, an economic efficiency evaluation was performed. This evaluation is based upon the net present value (NPV) of respective benefits and costs. The net present value of any project is governed by three variables: the average annual cost or benefit, discount rate and discount period. A common discount rate of 3% was agreed upon and applied. The discount period is the estimate of the scenario’s project life.

The benefit/cost (B/C) ratio of a project is the ratio of net present value of the benefits (average annual damages) over the net present value of the costs. This value is the indicator of economic efficiency. Where the benefits exceed costs, the ratio would be greater than 1.0, and where benefits are less than costs, then the ratio would be less than 1.0. An economically-efficient project would have a B/C ratio greater than 1.0. At a B/C ratio of 1.0, the project is at a breakeven point.

Project Cost Assumptions

Capital Cost Component	Capital Cost for Each Scenario				
	1	1a	2	3	3a
	SR1	#1 with high downtown barriers	SR1 + new Bow reservoir	Bow reservoir + Elbow barriers	#3 with groundwater mitigation
SR1 (Elbow River)	$ 500,000,000	$ 500,000,000	$ 500,000,000		
One new Bow reservoir			$ 900,000,000	$ 900,000,000	$ 900,000,000
Sunnyside Pump Station / Sunnyside stormwater (Community Drainage Improvement CDI, and addition of #2 pump station)	$ 10,000,000	$ 10,000,000	$ 10,000,000	$ 10,000,000	$ 10,000,000
Barriers protecting downtown area (i.e. 350-year flood protection, considering SR1) including permanent barriers along the Elbow and Bow Rivers		$ 482,645,885			
Barriers identified by Associated Engineering (AE) on the Bow River (200-year flood protection)					
Barriers identified by Associated Engineering (AE) on the Elbow River (200-year flood protection)				$ 892,850,000	$ 1,049,100,000
Selected Barriers identified by Associated Engineering (AE) on the Bow River - Bowness, Sunnyside, Fish Hatchery, Inglewood					
Total	**$ 510,000,000**	**$ 992,645,885**	**$ 1,410,000,000**	**$ 1,802,850,000**	**$ 1,959,100,000**

Capital Cost Component	Capital Cost for Each Scenario				
	4	4a	5	5a	7
	SR1 + Bow bariers	#4 with groundwater mitigation	Bow and Elbow barriers	#5 with groundwater mitigation	SR1 + Bow reservoir + select 1:25 Bow barriers
SR1 (Elbow River)	$ 500,000,000	$ 500,000,000			$ 500,000,000
One new Bow reservoir					$ 900,000,000
Sunnyside Pump Station / Sunnyside stormwater (Community Drainage Improvement CDI, and addition of #2 pump station)	$ 10,000,000	$ 10,000,000	$ 10,000,000	$ 10,000,000	$ 10,000,000
Barriers protecting downtown area (i.e. 350-year flood protection, considering SR1) including permanent barriers along the Elbow and Bow Rivers					
Barriers identified by Associated Engineering (AE) on the Bow River (200-year flood protection)	$ 393,286,859	$ 624,672,408	$ 420,186,113	$ 666,562,291	
Barriers identified by Associated Engineering (AE) on the Elbow River (200-year flood protection)			$ 892,850,000	$ 1,049,100,000	
Selected Barriers identified by Associated Engineering (AE) on the Bow River - Bowness, Sunnyside, Fish Hatchery, Inglewood					$ 37,534,050
Total	**$ 903,286,859**	**$ 1,134,672,408**	**$ 1,323,036,113**	**$ 1,725,662,291**	**$ 1,447,534,050**

Capital Cost Component	Capital Cost for Each Scenario				
	7	7a	8	8a	9
	SR1 + Bow reservoir + select 1:25 Bow barriers	#7 without Bow reservoir	#7 + gw mitigation @ Sunnyside + 1:200 Downtown barriers	#8 without Bow reservoir	#8 + 1:100 barriers @ Bowness/ Sunnyside
SR1 (Elbow River)	$ 500,000,000	$ 500,000,000	$ 500,000,000	$ 500,000,000	$ 500,000,000
One new Bow reservoir	$ 900,000,000		$ 900,000,000		
Sunnyside Pump Station / Sunnyside stormwater (Community Drainage Improvement CDI, and addition of #2 pump station)	$ 10,000,000	$ 10,000,000	$ 10,000,000	$ 10,000,000	$ 10,000,000
Barriers protecting downtown area (i.e. 350-year flood protection, considering SR1) including permanent barriers along the Elbow and Bow Rivers			$ 18,826,945	$ 18,826,945	$ 18,826,945
Barriers identified by Associated Engineering (AE) on the Bow River (200-year flood protection)					
Barriers identified by Associated Engineering (AE) on the Elbow River (200-year flood protection)					
Selected Barriers identified by Associated Engineering (AE) on the Bow River - Bowness, Sunnyside, Fish Hatchery, Inglewood	$ 37,534,050	$ 37,534,050	$ 40,758,468.69	$ 40,758,469	$ 129,550,000
Total	**$ 1,447,534,050**	**$ 547,534,050**	**$ 1,469,585,414**	**$ 569,585,414**	**$ 658,376,945**

Capital Cost Component	Annual Operation and Maintenance Cost(1)	Major Repair Cost (once every 30 years)(2)	Data Source
SR1 (Elbow River)	$ 5,000,000	$ 50,000,000	City of Calgary
One new Bow reservoir	$ 9,000,000	$ 90,000,000	
Sunnyside Pump Station / Sunnyside stormwater (Community Drainage Improvement CDI, and addition of #2 pump station)	$ 100,000	$ 1,000,000	
Barriers protecting downtown area (i.e. 350-year flood protection, considering SR1) including permanent barriers along the Elbow and Bow Rivers	See Note (1)	See Note (3)	Associated Engineering
Barriers identified by Associated Engineering (AE) on the Bow River (200-year flood protection)			
Barriers identified by Associated Engineering (AE) on the Elbow River (200-year flood protection)			
Selected Barriers identified by Associated Engineering (AE) on the Bow River - Bowness, Sunnyside, Fish Hatchery, Inglewood			
Total			

Note: (1) assumed to be 1% of capital cost for SR1,Bow Reservoir and Sunnyside Pump Station; the NPV of annual operation and maintenance costs for the permanent barriers have been included in the capital cost

(2) assumed to be 10% of capital cost to occur at an interval of every 30 years

(3) Associated Engineering did not provide the major repair costs and it is assumed the major repair cost has been included in the annual operating and maintenance cost

4.5 Evaluation and Rating of Scenarios Employing Triple Bottom Line Criteria

Traditional economic analyses of flood mitigation alternatives have generally assumed a straightforward objective of maximizing the net benefits (total benefits minus total costs) that accrue to a project. Society however, has other goals besides economic efficiency. These goals or objectives are the results of outcomes that society desires and have more recently been described as Triple Bottom Line objectives which include considerations of economic, environmental and social impacts. The purpose of Triple Bottom Line evaluation is to account for these various goals in the evaluation process.

Past precedents were examined with respect to flood mitigation evaluation criteria along with evaluation procedures. These are outlined in **Appendix G**.

For the purposes of this study, the criteria, objectives and weightings were selected by assessing priorities identified by community engagement, Community Advisory Group, City subject matter expertise, the IBI Group draft evaluation criteria and the City's sustainability appraisal tool.

Criteria were subdivided into four basic categories:

1. Social Criteria: Community Well-Being
2. Environmental Criteria
3. Scenario Implementation
4. Economic Criteria

Each category was assigned an equal weighting of 12 points and then each individual criteria was scored from -6 to +6, depending upon its achievement of the stated Triple Bottom Line objective. Scores were tallied for each scenario under each category rendering a total score and then a rank with respect to the other scenarios. Scoring was carried out by the entire project team, representing a variety of departments and expertise. The scoring was undertaken collectively in two separate sessions with discussion as to how each of the scenarios responded to the criteria by category. Essentially, this process resulted in a consensus score following the round table discussion.

Exhibit 4.2 details the criteria and objectives of the Triple Bottom Line analysis. **Exhibits 4.3 and 4.4** detail the rating and weighting scheme employed along with the results.

4.6 Summary of Evaluation of Flood Mitigation Scenarios

The following sub-section is devoted to an evaluation of the flood mitigation scenarios.

Exhibit 4.3 details the results of the benefit/cost analysis, illustrating the benefit/cost ratio, damages averted, residual damages and present value of total costs for the 12 scenarios. All scenarios, save 3, 3a, and 6 render positive benefit/cost ratios with Scenario 1 achieving the highest ratio at 3.22 followed by Scenarios 4 and 4a at 2.45 and 2.14 respectively. Scenario 7 provides the greatest benefits at $90.6 million of average annual damages averted. This is followed by Scenario 4a at $87.7 million of average annual damages averted.

Scenarios 3 and 3a have the highest cost base at $2.58 and $2.88 billion respectively while Scenario 1 has the lowest cost base at $0.7 billion in present value of costs.

Exhibit 4.4 illustrates the Triple Bottom Line scoring and ranking for the 12 scenarios. As evidenced, Scenario 7 achieves the highest overall score and therefore is first ranked, followed by Scenario 2 and 1.

Exhibit 4.5 illustrates how the various scenarios ranked with respect to the Triple Bottom Line goals. Scenario 7 ranks high with respect to social and environmental criteria. Despite having a low score compared with the top two ranked for implementation, Scenario 7 still ranks 3rd and achieves a middle ranking for economic considerations.

Following **Exhibits 4.2-4.5** are summary evaluations of the individual scenarios, highlighting the salient features and providing a brief discussion of each. Additional details on these scenarios are found in the various standalone design reports as referenced in Section 3.

Scenario 7 maintains the first rank if the percent weight for the social or environmental criteria is doubled. Scenario 7 is ranked close second if the percent weight is doubled for the economic or implementation criteria, while Scenario 1 is ranked first. This shows that Scenario 7 is relatively robust as a favored or preferred scenario.

Flood Mitigation Evaluation Criteria

Goal	Criteria	To what extent does the scenario help achive the following objectives, **compared to the baseline existing condition?** (refer to **Exhibit 3.10**)
Social	Complete communities	**Maintains community fabric** *Preserves existing communities, homes and heritage. Maintains opportunities for revitalisation/densification (eg. East Village). Amenities and transportation choices are not negatively impacted.*
	Equitable protection	**Provides equitable protection from flooding** *across communities, the city and does not negatively impact upstream or downstream*
	Vulnerable populations	**Protects vulnerable populations** *Risk-sensitive development, protection of Calgarians who because of age, disability or other circumstances are at greater risk.*
	River aesthetics	**Maintains community and river aesthetics** *River views from private and public property, natural-looking river*
	Recreation access	**Maintains or enhances accessibility and recreation opportunities** *Protects/provides access to the river, riparian areas, natural areas, and parks.*
	Emergency access	**Protects connectivity and ease of access and departure during flooding or other emergencies/disasters** *Does not negatively impact emergency response, reduces residential and non-residential loss of life*
	Risk transparency	**Increased transparency/visibility of risk** *For property owners/prospective buyers regarding flooding risk*
Environmental	Water security	**Protects/provides water supply security** *Promotes efficient, sustainable water management so that the region's water supply meets the current and future needs of a growing city and region of users (municipalities and irrigation districts).*
	Riparian health and ecosystem functions	**Protects riparian health and species habitat and allows natural ecosystem functions** *Protects/enhances riparian areas and health of aquatic and terrestrial species. Lets the floodplan flood, provides room for the river, allows the river to flood*
	Water quality and contamination prevention	**Protects river water quality and prevents contamination of air, land, and water** *Does not have a short or long term detrimental impact on water quality and prevents contamination from spills, stormwater and groundwater flooding, transportation of goods, construction of scenario.*
Implementation	Timeliness of Implementation	**Contributes to orderly implementation of investments.** - *Timeliness and ease of implementation. How quickly can it be implemented and does it complement future measures?*
	Adaptability/Flexibility	**Contributes to flexibility of implementation.** How ***adaptable*** *the solution is - ease of future adaptability and flexibility (can it be raised/improved, can it address climate change issues?)*
	Jurisdictional control	***How easy it is for the City to implement.*** *Jurisdictional ability of The City to implement; financial ability for The City to implement; dependent on other jurisdictions to commit to/implement/fund.*
	Regulatory complexity	**Complexity of regulating land use and development with respect to different structural mitigation measures.** *(City: bylaws; At the Provincial and Federal levels: environmental and land/building regulations, mapping, funding, disaster relief programs)*
Economic	Economic Environment	**Indirect Protection of Calgary's economic engine** *Protects the downtown and business continuity. Protects critical infrastructure and essential services, transportation corridors.*
	Economic Efficiency	*Benefit/Cost Ratio*
	Damages Averted	*Total Benefits*
	Total Cost	*Present Value of deveopment and operating costs*

Net Present Value - Benefit/Cost Summary

Indicator	Scenario										
	1	1a	2	3	3a	4	4a	5	5a	6	7
	SR1	#1 with high downtown barriers	SR1 + new Bow reservoir	Bow reservoir + Elbow barriers	#3 with groundwater mitigation	SR1 + Bow bariers	#4 with groundwater mitigation	Bow and Elbow barriers	#5 with groundwater mitigation	Floodway buyouts	SR1 + Bow reservoir + select 1:25 Bow barriers
Development Cost	$510,000,000	$992,645,885	$1,410,000,000	$1,802,850,000	$1,959,100,000	$903,286,859	$1,134,672,408	$1,323,036,113	$1,725,662,291	$1,818,000,000	$1,447,534,050
O&M*	$5,100,000	$5,100,000	$14,100,000	$9,100,000	$9,100,000	$5,100,000	$5,100,000	$100,000	$100,000	$0	$14,100,000
PV Benefits (average annual damages)	$2,255,422,000	$2,394,764,000	$2,676,498,000	$2,270,535,000	$2,476,359,000	$2,773,550,000	$2,773,550,000	$2,241,871,000	$2,672,673,000	$853,170,000	$2,688,400,000
PV Costs (development & operating total cost)	$701,065,000	$1,183,711,000	$1,988,997,000	$2,143,770,000	$2,300,020,000	$1,094,352,000	$1,325,737,000	$1,326,782,000	$1,729,409,000	$1,818,000,000	$2,026,531,000
Benefit / Cost Ratio	3.22	2.02	1.35	1.06	1.08	2.53	2.09	1.69	1.55	0.47	1.33
Net Present Value	$1,554,357,000	$1,211,053,000	$687,501,000	$126,765,000	$176,339,000	$1,679,198,000	$1,447,813,000	$915,089,000	$943,264,000	-$964,830,000	$661,869,000

TBL Scenario Scoring

Goal	Criteria	Objective To what extent does the scenario help achive the following objectives, **compared to the baseline existing condition?**	Scenario Rating (-6 to +6) 0a Non-structural	1 SR1	1a SR1 + DT barrier	2 SR1 + Bow Res	3 Bow Res + Elbow barriers	3a 3 w/ GW	4 SR1 + Bow barriers	4a 4 w/ GW	5 Barriers on Bow+ Elbow	5a 5 w/ GW	6 Flood-way buyouts	7 SR1, Bow Res, Select barriers	Weight (1-6)	Highest Ranked Scenario by Criteria
Social	Complete communities	**Maintains community fabric** *Preserves existing communities, homes and heritage. Maintains opportunities for revitalisation/densification (eg. East Village). Amenities and transportation choices are not negatively impacted.*	-1	3	4	6	-4	-4	-5	-5	-6	-6	-5	5	2	2
	Equitable protection	**Provides equitable protection from flooding** *across communities, the city and does not negatively impact upstream or downstream*	1	-4	-5	3	-2	-2	2	2	5	5	-3	4	3	5
	Vulnerable populations	**Protects vulnerable populations** *Risk-sensitive development, protection of Calgarians who because of age, disability or other circumstances are at greater risk.*	0	3	4	5	2	2	2	2	1	1	-1	5	1	2
	River aesthetics	**Maintains community and river aesthetics** *River views from private and public property, natural-looking river*	-1	5	1	5	-5	-5	-4	-4	-6	-6	6	4	2	6
	Recreation access	**Maintains or enhances accessibility and recreation opportunities** *Protects/provides access to the river, riparian areas, natural areas, and parks.*	1	5	-1	5	-4	-4	-5	-5	-6	-6	3	4	2	1
	Emergency access	**Protects connectivity and ease of access and departure during flooding or other emergencies/disasters** *Does not negatively impact emergency response, reduces residential and non-residential loss of life*	2	3	2	3	-1	-1	-1	-1	-2	-2	-2	3	1	1
	Risk transparency	**Increased transparency/visibility of risk** *For property owners/prospective buyers regarding flooding risk*	2	1	2	1	3	3	3	3	4	4	1	3	1	5
		TOTAL Community Well-Being score	**5**	**21**	**1**	**50**	**-28**	**-28**	**-18**	**-18**	**-18**	**-18**	**-3**	**49**	12	2
Environmental	Water security	**Protects/provides water supply security** *Promotes efficient, sustainable water management so that the region's water supply meets the current and future needs of a growing city and region of users (municipalities and irrigation districts).*	0	1	1	6	6	6	1	1	0	0	0	6	6	2
	Riparian health and ecosystem functions	**Protects riparian health and species habitat and allows natural ecosystem functions** *Protects/enhances riparian areas and health of aquatic and terrestrial species. Lets the floodplan flood, provides room for the river, allows the river to flood*	1	-1	-1	-1	-4	-4	-4	-4	-6	-6	1	-2	4	0a
	Water quality and contamination prevention	**Protects river water quality and prevents contamination of air, land, and water** *Does not have a short or long term detrimental impact on water quality and prevents contamination from spills, stormwater and groundwater flooding, transportation of goods, construction of scenario.*	-1	-2	-2	0	2	2	-2	-2	0	0	0	0	2	3
		TOTAL Environmental score	**2**	**-2**	**-2**	**32**	**24**	**24**	**-14**	**-14**	**-24**	**-24**	**4**	**28**	12	2
Implementation	Timeliness of Implementation	**Contributes to orderly implementation of investments.** *- Timeliness and ease of implementation. How quickly can it be implemented and does it complement future measures?*	-2	5	4	-3	-5	-5	1	1	-4	-4	-1	-2	4	1
	Adaptability/Flexibility	**Contributes to flexibility of implementation.** How ***adaptable*** *the solution is - ease of future adaptability and flexibility (can it be raised/improved, can it address climate change issues?)*	1	2	2	4	3	3	2	2	-1	-1	3	5	3	7
	Jurisdictional control	***How easy it is for the City to implement.*** *Jurisdictional ability of The City to implement; financial ability for The City to implement; dependent on other jurisdictions to commit to/implement/fund.*	4	0	1	-3	-2	-2	1	1	3	3	2	-2	3	0a
	Regulatory complexity	**Complexity of regulating land use and development with respect to different structural mitigation measures.** *(City: bylaws; At the Provincial and Federal levels: environmental and land/building regulations, mapping, funding, disaster relief programs)*	-3	-2	-2	3	-3	-3	-3	-3	2	2	-1	4	2	7
		TOTAL Implementation score	**1**	**22**	**21**	**-3**	**-23**	**-23**	**7**	**7**	**-6**	**-6**	**9**	**9**	12	1
Economic	Economic Environment	**Indirect Protection of Calgary's economic engine (attracts businesses, business continuity)** *Protects the downtown and business continuity. Protects critical infrastructure and essential services, transportation corridors.*	-1	3	5	5	2	2	2	2	2	2	-1	5	3	1a
	Economic Efficiency	*Benefit/Cost Ratio*	6	5	0	-2	-4	-4	2	0	-1	-2	-6	-3	3	0a
	Damages Averted	*Total Benefits*	-6	3	4	6	3	5	5	7	3	6	-5	6	3	4a
	Total Cost	*Present Value of deveopment and operating costs*	6	5	2	-4	-5	-6	2	1	1	-2	-3	-4	3	0a
		TOTAL Economin score	**15**	**49.19**	**33.4**	**13.73**	**-9.231**	**-8.53**	**35.9**	**29.13**	**14.69**	**12.42**	**-44.1**	**12.94**	12	1
		Total Score	**23**	**90.2**	**53.4**	**92.7**	**-36.2**	**-35.5**	**10.9**	**4.13**	**-33.3**	**-35.6**	**-34.1**	**98.94**		**7**
		Rank	5	3	4	2	12	10	6	7	8	11	9	1		

TBL Scenario Ranking

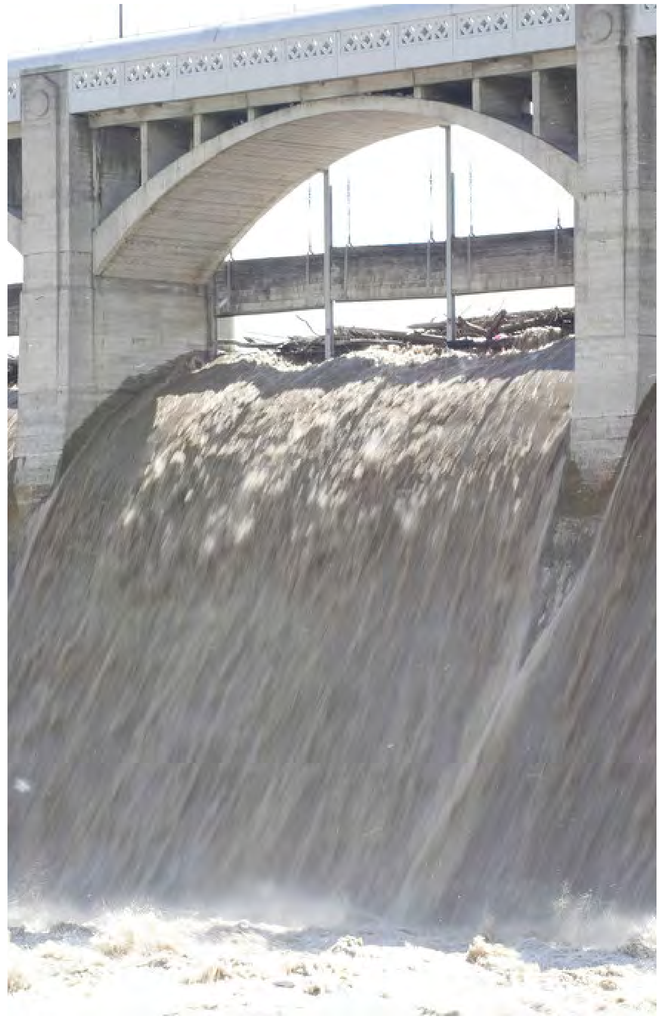
Scenario		0a	1	1a	2	3	3a	4	4a	5	5a	6	7
Goal	**Criteria**	Non-structural	SR1	SR1 + DT barrier	SR1 + Bow Res	Bow Res + Elbow barriers	3 w/ GW	SR1 + Bow barriers	4 w/ GW	Barriers on Bow+ Elbow	5 w/ GW	Flood-way buyouts	SR1, Bow Res, Select barriers
Social	Complete communities Equitable protection Vulnerable populations River aesthetics Recreation access Emergency access Risk transparency	4	3	5	1	11	11	7	7	7	7	6	2
Environmental	Water security Riparian health and ecosystem functions Water quality and contamination prevention	6	7	7	1	3	3	9	9	11	11	5	2
Implementation	Timeliness of Implementation Adaptability/Flexibility Jurisdictional control Regulatory complexity	7	1	2	8	11	11	5	5	9	9	3	3
Economic	Economic Environment Economic Efficiency Damages Averted Total Cost	5	1	3	7	11	10	2	4	6	9	12	8
Overall Rank		**5**	**3**	**4**	**2**	**12**	**10**	**6**	**7**	**8**	**11**	**9**	**1**

4.6.1 EVALUATION OF FLOOD MITIGATION SCENARIO 0 - BASELINE

Description & Discussion

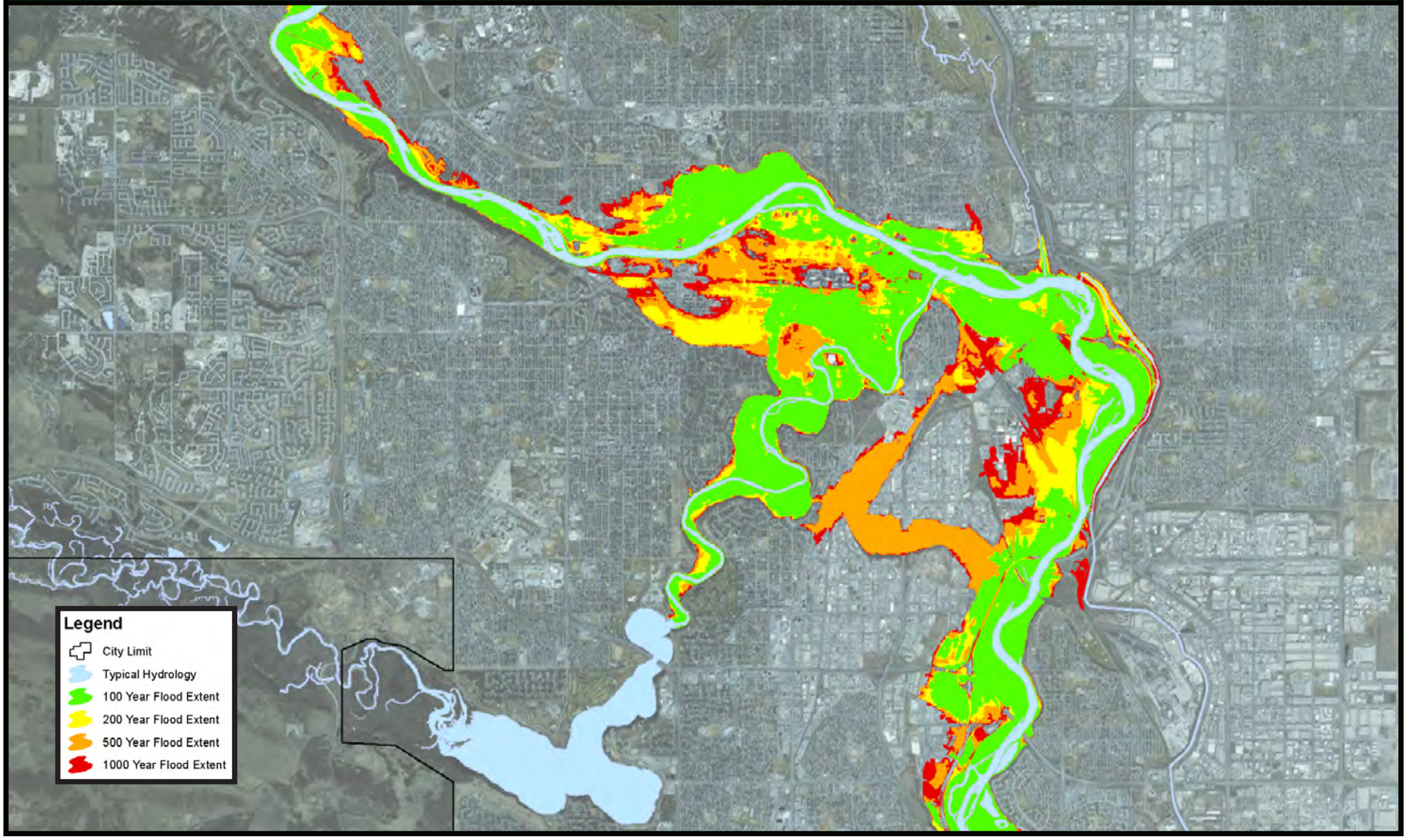
The baseline case involves existing improvements and modifications that were initiated after the 2013 flood. This includes historic dykes, new barriers and stormwater improvements.

No costs have been attached to this scenario. However, benefits have been calculated in relation to flood events without mitigation. As indicated, total unmitigated average annual damages are $168 million versus $117 million with the aforementioned mitigation measures in place, a reduction of $51 million. However, significant damages remain city-wide. Changes to the operating agreement for the TransAlta hydro facilities are not included in Scenario 0 or 0a.

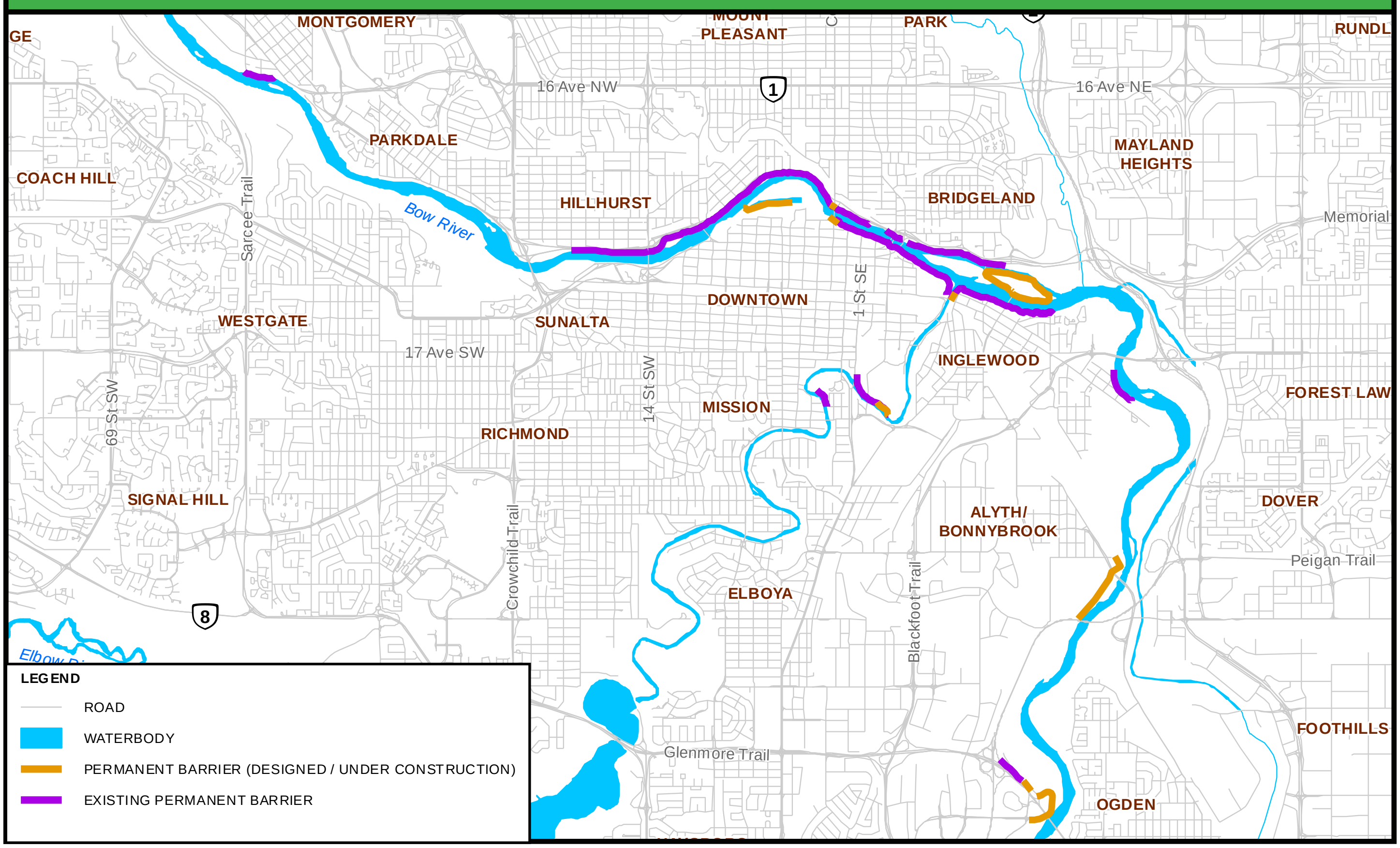


Category of Damages		Scenario 0			
		Benefits		Residual AAD	
Total Average Annual Damages (AAD)		$51,421,567		$116,578,433	
Building-related (Direct, Displacement, Intangible)	Overland	$18,274,067	35.5%	$50,319,967	43.2%
	Groundwater	$21,444,885	41.7%	$25,966,261	22.3%
Infrastructure, Traffic, Habitat, Emergency Response		$12,814,984	24.9%	$19,757,271	16.9%
Isolated (all categories)		-$996,982	-1.9%	$19,974,968	17.1%
Evacuation (no direct damage)		-$115,387	-0.2%	$559,966	0.5%
Bow River		$41,997,960	81.7%	$75,127,711	64.4%
Elbow River		$9,423,607	18.3%	$41,450,721	35.6%

Unmitigated Inundation Extents



Location of Existing Barriers



4.6.2 EVALUATION OF FLOOD MITIGATION SCENARIO 0a

Description & Discussion

This scenario entails the implementation of non-structural measures along with the existing improvements. Further details on non-structural options is presented in Section 3.7.

Non-structural measures selected for implementation include improved flood warning and homeowner response protocols; emergency measures focused on key damage areas with the implementation of temporary flood barriers and cut-offs to spill areas; land use regulations aimed at reducing potential future damages; and, programs to facilitate the installation of backflow preventers and sump pumps to reduce basement damages from higher frequency events.

Contingency measures including flood warning, forecasting, and emergency measures can reduce residential contents damage by some 30%, with commercial damages reduced by an equivalent amount. This equates to a reduction of $8 million in average annual damages.

Average annual damages are estimated to be reduced by between $8 million and $12 million with the installation of temporary barriers.

Residential damages up to and including the 1:200 return period represent over $48 million. The annual redevelopment of 1% of at-risk residential properties to a new design standard will reduce average annual damages by nearly $500,000 each year over a 100 year period. The present value would be $441 million. Despite the nominal annual accumulation, the annual benefit only increases for the first 35 years due to discounting. For redevelopment of non-residential properties, the annual reduction would be $182,000 with a present value of $166 million. These measures would essentially eliminate all residential and commercial damages up to the 1:200 year event.

Groundwater flooding amounts to $26 million in average annual damages, or some 22% of the total. Installation of backflow preventers, sump pumps and foundation waterproofing could mitigate damage by this amount. If this is aggressively completed within 20 years it would have a present value of $607 million. Over 100 years, it would be $232 million.

While the benefits of these measures are calculated to be high in relation to anticipated cost, there is still significant residual damage. In addition, the timeframe for implementation, and therefore achievement of full benefits, is long-term.

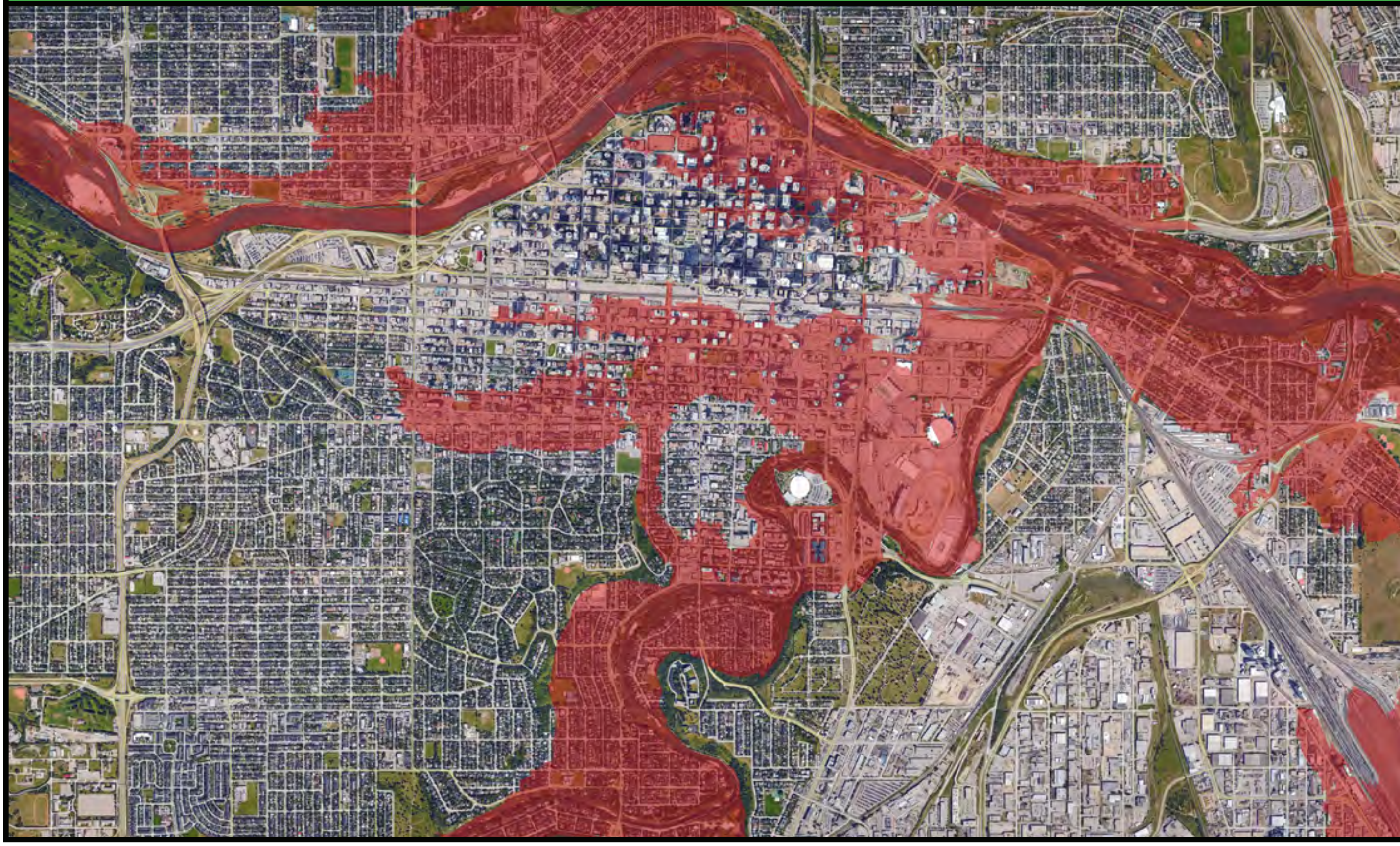
Notwithstanding, given the impact of groundwater flooding, implementation of a mandatory/voluntary sump pump/backflow preventer program is prudent and extremely beneficial in terms of reducing damages.

Recommended improvements to the contingency measures program, along with more restrictive development/redevelopment standards for properties within the flood hazard area, will also render cost beneficial flood damage reductions.

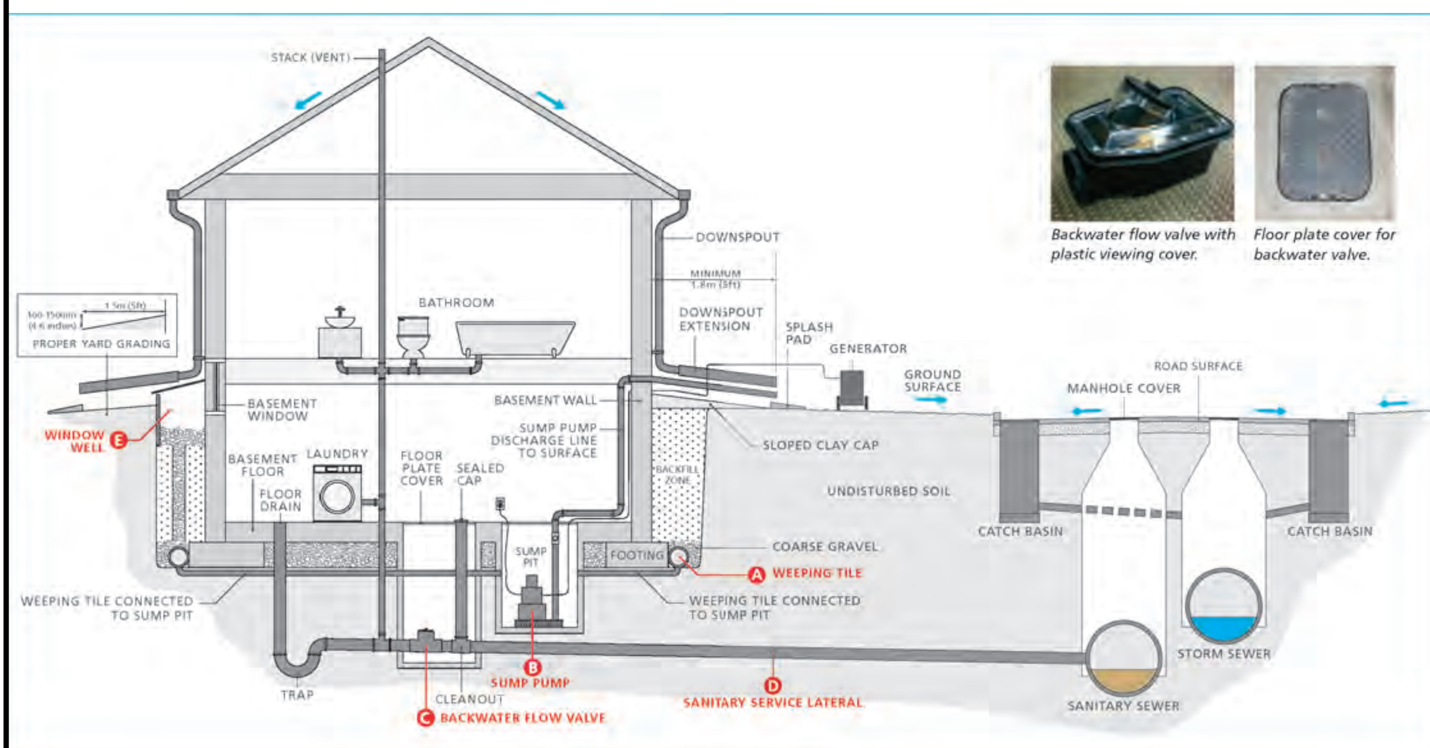
Triple Bottom Line Analysis

GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	-2	5
	Equitable protection	3	7
	Vulnerable populations	0	11
	River aesthetics	-2	6
	Recreation access	2	5
	Emergency access	2	4
	Risk transparency	2	8
ENVIRONMENTAL	Water security	0	9
	Riparian health and ecosystem functions	4	1
	Water quality and contamination prevention	-2	8
IMPLEMENTATION	Timeliness of Implementation	-8	6
	Adaptability/Flexibility	3	10
	Jurisdictional control	12	1
	Regulatory complexity	-6	8
ECONOMIC	Economic Environment	-3	11
	Economic Efficiency	18	1
	Damages Averted	-18	12
	Total Cost	18	1
	TOTAL SCORE	23	5

1:200 Flood Hazard Area



Backflow Preventer and Sump Pump



Source: ICLR

4.6.3 EVALUATION OF FLOOD MITIGATION SCENARIO 1

Description & Discussion

This scenario entails a new operating agreement between TransAlta Utilities and the Government of Alberta aimed at managing flows for improvement of flood protection. It also includes stormwater and drainage improvements at Sunnyside and Quarry Park. The major piece of infrastructure is the SR1 storage reservoir.

The project consists of three basic components:

1. a river diversion structure;
2. a diversion channel and reservoir inlet structure; and
3. an off-stream storage dam and reservoir.

The diversion structure system would consist of a concrete overflow weir section crossing the Elbow River, a gated concrete sluiceway/fishway located adjacent to the left side valley abutment with its invert at the river thalweg level, and a gated diversion outlet structure located in the left valley abutment immediately upstream of the sluiceway.

The diversion channel is designed to convey a peak diversion flow of 300 m^3/s from the Elbow River into the off-stream storage reservoir. The channel is designed with a 24 m bottom width, three horizontal to one vertical side slopes and a 3.6 m water depth.

The development cost estimate was provided by the City and operating expenses assumed to be 1% of development cost annually, with a 10% repairs or upgrade expense every 30 years.

This scenario renders the highest benefit/cost ratio under the assumptions employed. It should be noted that significant benefits accrue to the Bow River flood hazard area due to the revised operating regime upstream as well as the assumption of temporary barrier protection for which no costs have been assigned. There are still significant damages on the Bow River, particularly for the lower frequency events (> 50 year).

Essentially this scenario provides good protection for the Elbow, with some level of benefits for the Bow, particularly for the higher frequency events.

Triple Bottom Line Analysis

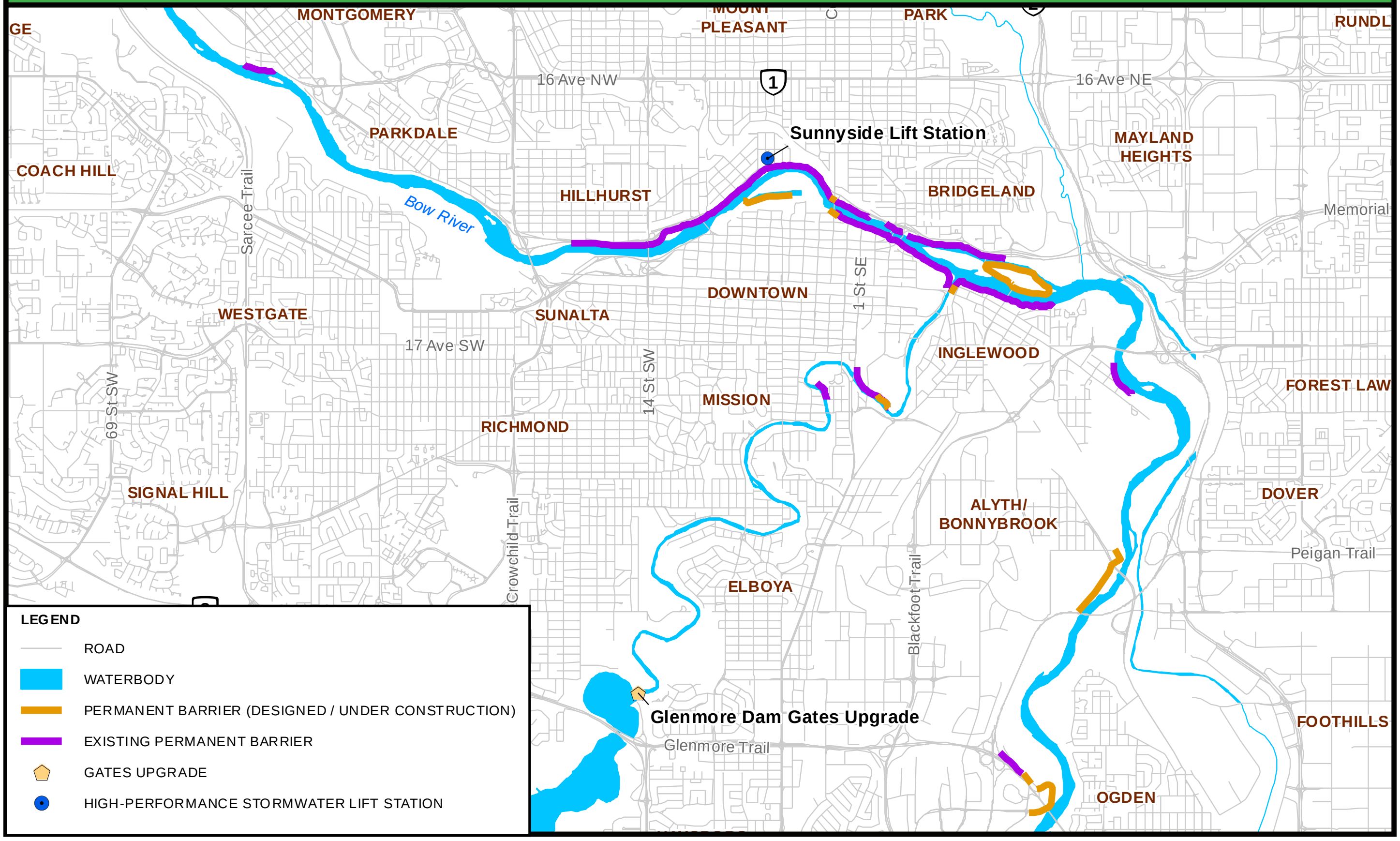
GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	6	4
	Equitable protection	-12	11
	Vulnerable populations	3	4
	River aesthetics	10	2
	Recreation access	10	1
	Emergency access	3	1
	Risk transparency	1	10
ENVIRONMENTAL	Water security	6	5
	Riparian health and ecosystem functions	-4	3
	Water quality and contamination prevention	-4	9
IMPLEMENTATION	Timeliness of Implementation	20	1
	Adaptability/Flexibility	6	6
	Jurisdictional control	0	8
	Regulatory complexity	-4	6
ECONOMIC	Economic Environment	9	4
	Economic Efficiency	15	2
	Damages Averted	10	9
	Total Cost	15	2
	TOTAL SCORE	90	3

Benefit/Cost Analysis

Development Cost	$510,000,000
O&M	$5,100,000
PV Benefits (average annual damages)	$2,255,422,000
PV Costs (development & operating total cost)	$701,065,000
Benefit / Cost Ratio	3.22
Net Present Value	$1,554,357,000

Category of Damages		Scenario 1 Benefits		Scenario 1 Residual AAD	
Total Average Annual Damages (AAD)		$71,376,591		$45,201,842	
Building-related (Direct, Displacement, Intangible)	Overland	$28,713,460	40.2%	$21,606,507	47.8%
	Groundwater	$13,175,420	18.5%	$12,790,841	28.3%
Infrastructure, Traffic, Habitat, Emergency Response		$12,739,140	17.8%	$7,018,131	15.5%
Isolated (all categories)		$17,032,942	23.9%	$2,942,026	6.5%
Evacuation (no direct damage)		-$284,372	-0.4%	$844,338	1.9%
Bow River		$43,640,325	61.1%	$31,487,386	69.7%
Elbow River		$27,736,265	38.9%	$13,714,456	30.3%

Location



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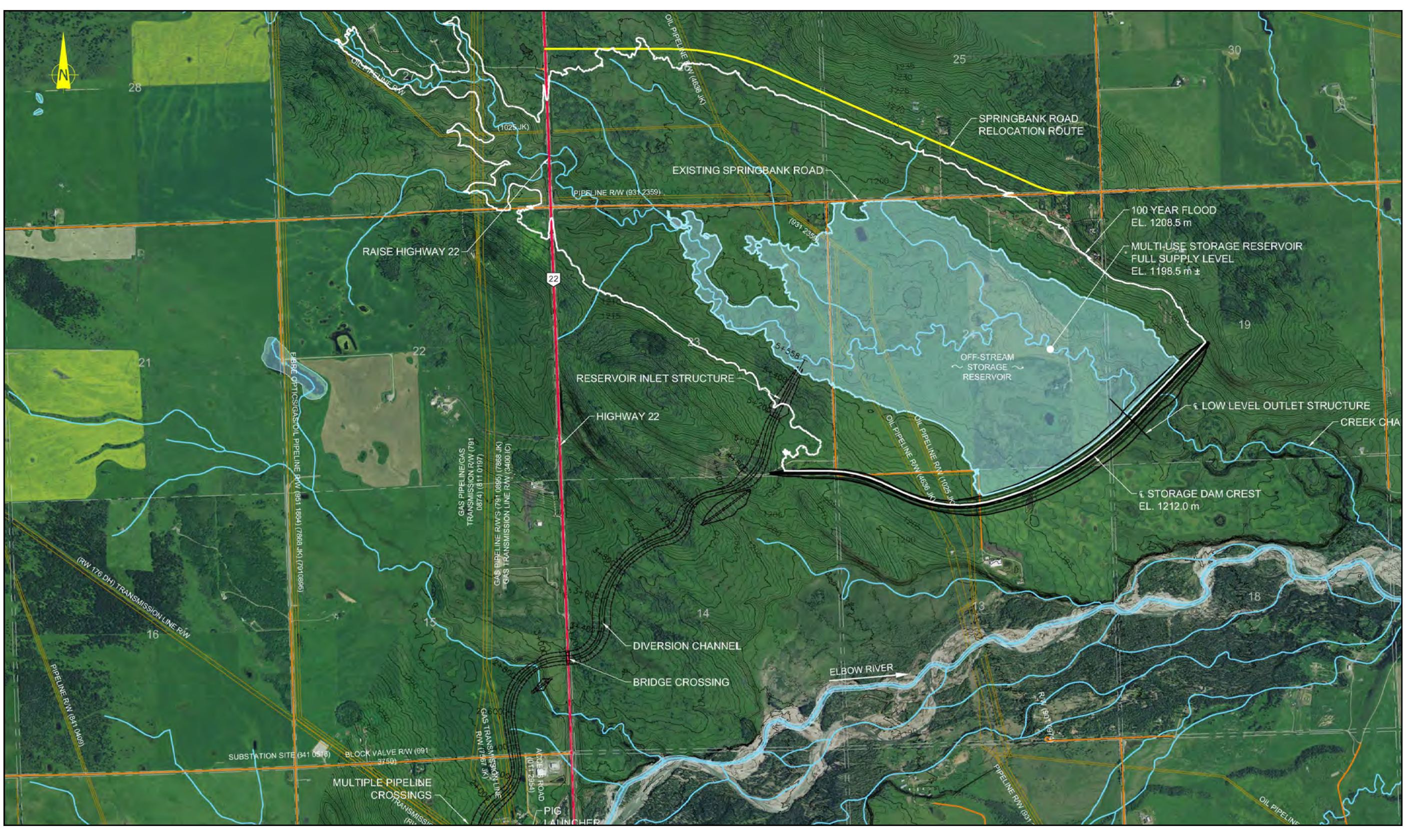


4.6.4 EVALUATION OF FLOOD MITIGATION SCENARIO 1a

Description & Discussion

This scenario includes SR1, stormwater drainage improvements at Sunnyside and Quarry Park and a new operating regime for TransAlta's hydro facilities and reservoirs in the Bow River basin. The additional component is the installation of barriers to the 1:350 year level of protection for the downtown area. The barriers would total approximately 14 km in length and average between 0.6 and 3.0 m in height.

This scenario provides an additional measure of benefits in the order of $4 million in average annual damages averted; however, at a much higher cost (± $800 million over Scenario 1). The high downtown barriers would have a detrimental impact in terms of aesthetics, access and resident psychology (walled city effect).

Triple Bottom Line Analysis

GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	8	3
	Equitable protection	-15	12
	Vulnerable populations	4	3
	River aesthetics	2	5
	Recreation access	-2	6
	Emergency access	2	4
	Risk transparency	2	8
ENVIRONMENTAL	Water security	6	5
	Riparian health and ecosystem functions	-4	3
	Water quality and contamination prevention	-4	9
IMPLEMENTATION	Timeliness of Implementation	16	2
	Adaptability/Flexibility	6	6
	Jurisdictional control	3	5
	Regulatory complexity	-4	6
ECONOMIC	Economic Environment	15	1
	Economic Efficiency	1	5
	Damages Averted	13	7
	Total Cost	5	4
	TOTAL SCORE	53	4

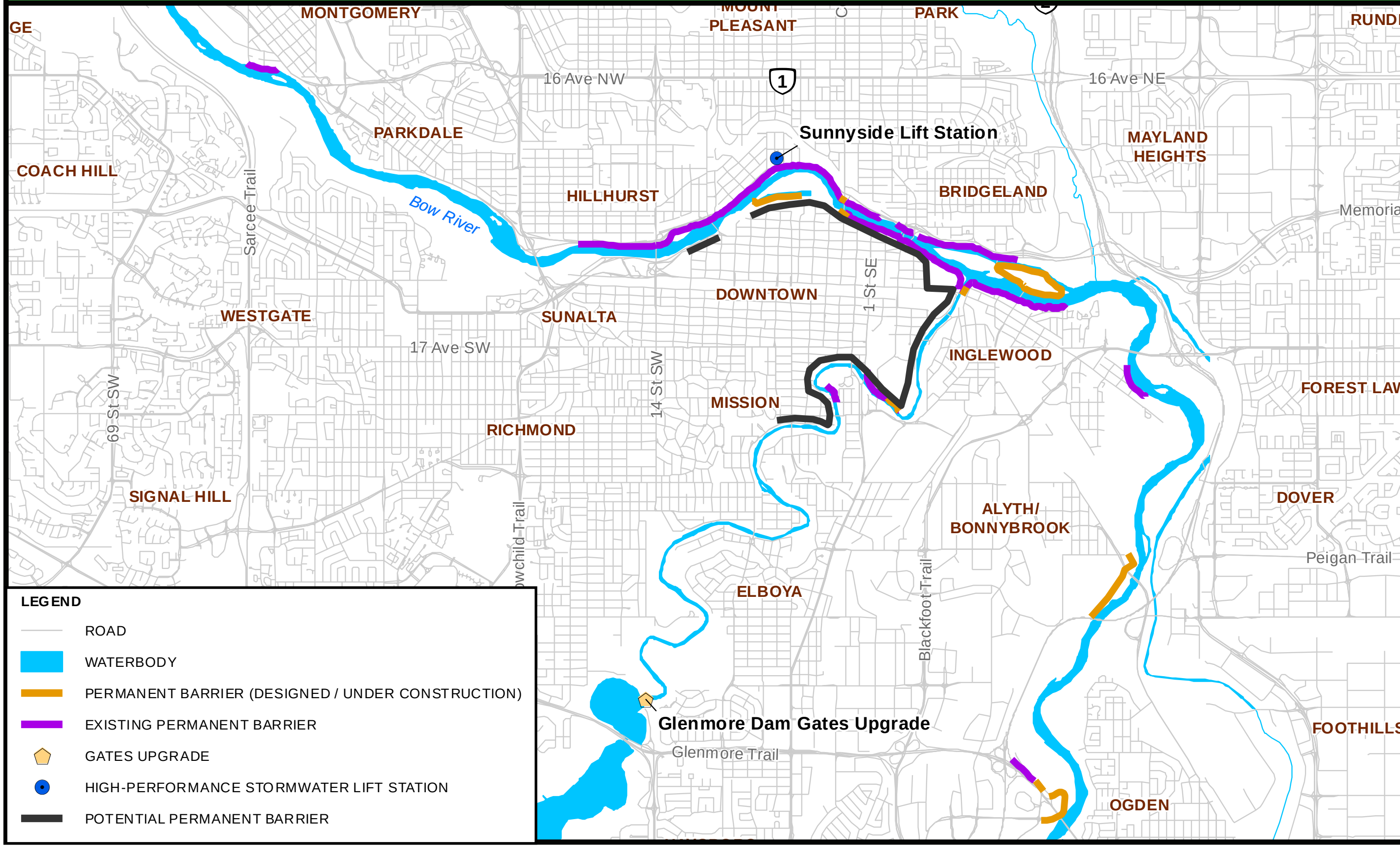
Benefit/Cost Analysis

Development Cost	$992,645,885
O&M*	$5,100,000
PV Benefits (average annual damages)	$2,394,764,000
PV Costs (development & operating total cost)	$1,183,711,000
Benefit / Cost Ratio	2.02
Net Present Value	$1,211,053,000

* Net present value of barrier operation and maintenance is included in Development Cost provided by Associated Engineering.

Category of Damages		Scenario 1a			
		Benefits		Residual AAD	
Total Average Annual Damages (AAD)		$75,786,288		$40,792,145	
Building-related (Direct, Displacement, Intangible)	Overland	$31,476,345	41.5%	$18,843,622	46.2%
	Groundwater	$13,362,214	17.6%	$12,604,047	30.9%
Infrastructure, Traffic, Habitat, Emergency Response		$13,032,971	17.2%	$6,724,300	16.5%
Isolated (all categories)		$18,328,021	24.2%	$1,646,947	4.0%
Evacuation (no direct damage)		-$413,263	-0.5%	$973,229	2.4%
Bow River		$46,728,017	61.7%	$28,399,694	69.6%
Elbow River		$29,058,269	38.3%	$12,392,452	30.4%

Location



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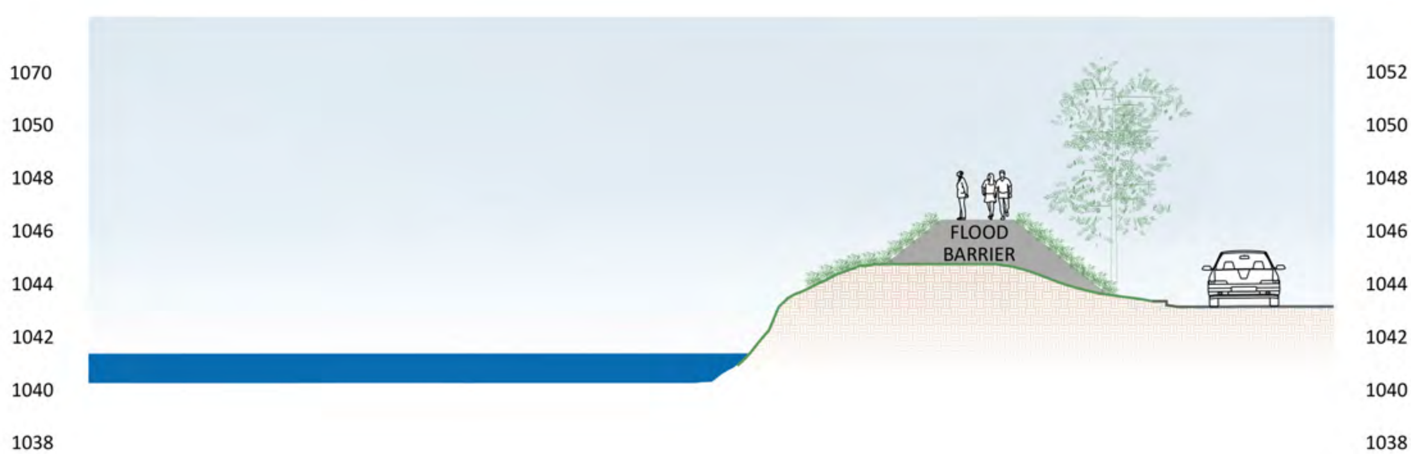


4.6.5 EVALUATION OF FLOOD MITIGATION SCENARIO 2

Description & Discussion

This scenario includes SR1 plus a new reservoir upstream on the Bow in addition to TransAlta's modified operating regime and stormwater and drainage improvements. The development cost and estimated attenuation provided by a single reservoir on the Bow River was provided by The City.

This scenario provides the third highest benefits/level of protection, with average annual damages averted estimated at $85 million. It has a benefit/cost ratio of 1.35, with the fourth highest capital cost. It has the least impact at the community level – being the least intrusive. It also has the potential for very high incidental benefits related to water supply, irrigation and recreation.

Triple Bottom Line Analysis

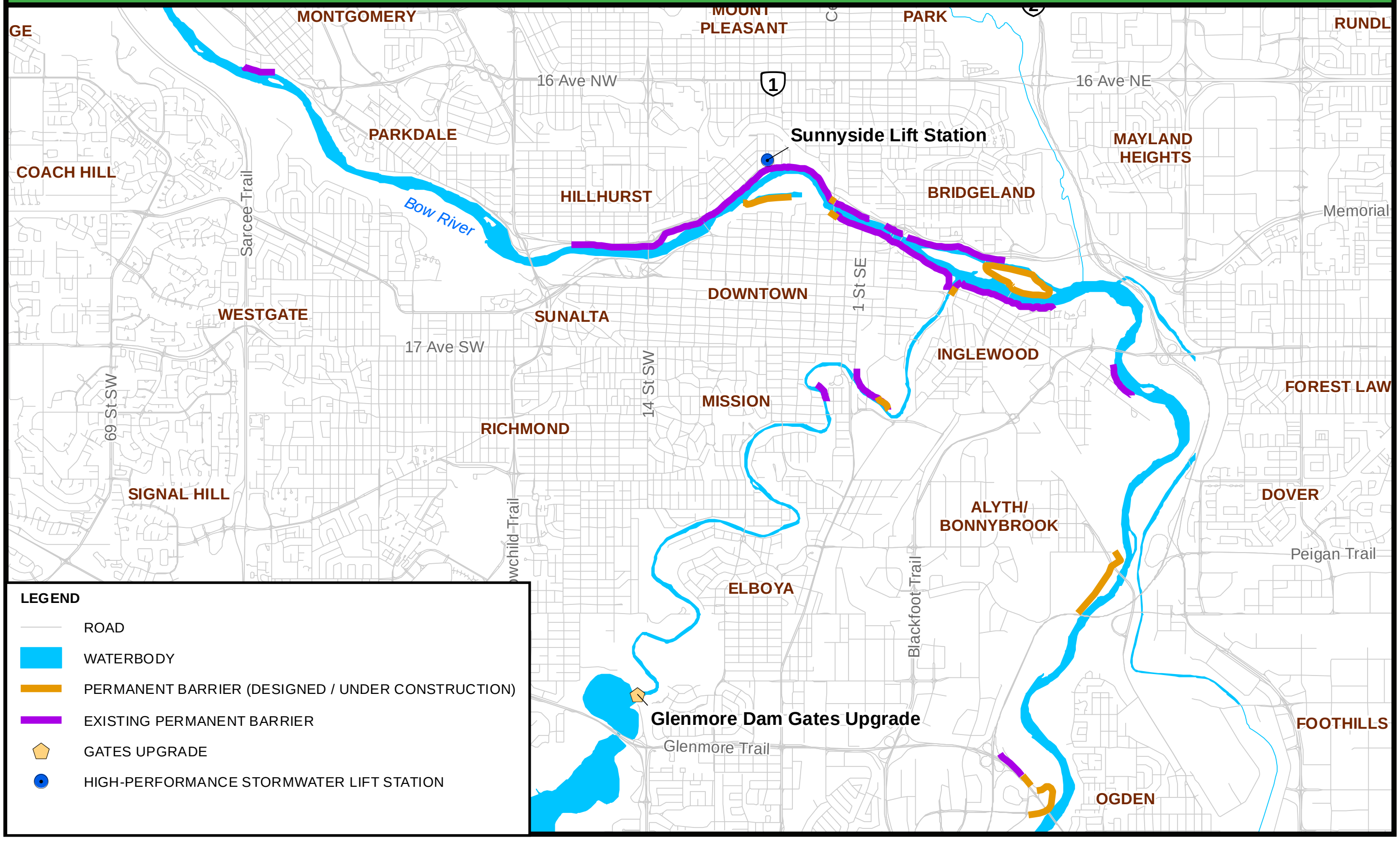
GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	12	1
	Equitable protection	9	4
	Vulnerable populations	5	1
	River aesthetics	10	2
	Recreation access	10	1
	Emergency access	3	1
	Risk transparency	1	10
ENVIRONMENTAL	Water security	36	1
	Riparian health and ecosystem functions	-4	3
	Water quality and contamination prevention	0	3
IMPLEMENTATION	Timeliness of Implementation	-12	8
	Adaptability/Flexibility	12	2
	Jurisdictional control	-9	12
	Regulatory complexity	6	2
ECONOMIC	Economic Environment	15	1
	Economic Efficiency	-7	8
	Damages Averted	18	3
	Total Cost	-12	9
	TOTAL SCORE	93	2

Benefit/Cost Analysis

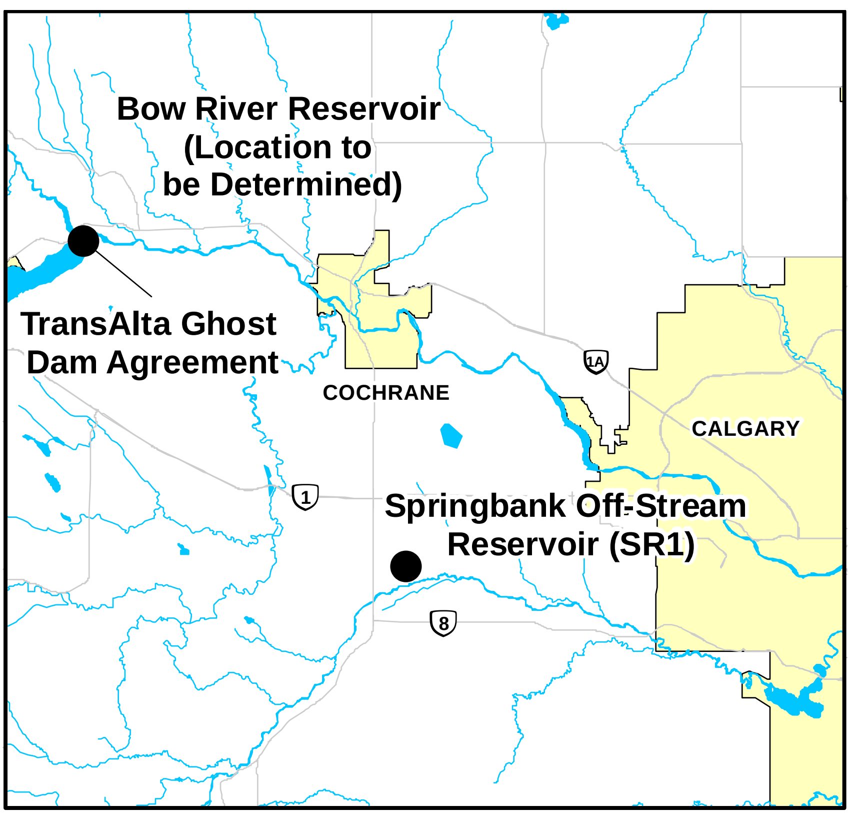
Development Cost	$1,410,000,000
O&M	$14,100,000
PV Benefits (average annual damages)	$2,676,498,000
PV Costs (development & operating total cost)	$1,988,997,000
Benefit / Cost Ratio	1.35
Net Present Value	$687,501,000

Category of Damages		Scenario 2			
		Benefits		Residual AAD	
Total Average Annual Damages (AAD)		$84,702,228		$31,876,205	
Building-related (Direct, Displacement, Intangible)	Overland	$43,628,028	51.5%	$6,691,939	21.0%
	Groundwater	$6,262,418	7.4%	$19,703,843	61.8%
Infrastructure, Traffic, Habitat, Emergency Response		$17,087,199	20.2%	$2,670,072	8.4%
Isolated (all categories)		$18,073,212	21.3%	$1,901,756	6.0%
Evacuation (no direct damage)		-$348,630	-0.4%	$908,596	2.9%
Bow River		$56,180,864	66.3%	$18,946,847	59.4%
Elbow River		$28,521,363	33.7%	$12,929,358	40.6%

Location



Reservoir Location Map



4.6.6 EVALUATION OF FLOOD MITIGATION SCENARIO 3

Description & Discussion

This scenario entails a new reservoir upstream on the Bow River along with barriers on the Elbow River. The barriers total 14.6 km and average between 1.6 and 3.0 m in height with a max height of 6.3 m. The barriers are a combination of walls and berms. Buyouts would be required in many location where they would be located on what is currently private property.

This scenario provides one of the lower levels of overall protection with benefits estimated at $72 million in average annual damages averted. The Elbow barriers are costly and difficult to integrate into the community, in addition to impacting aesthetics and access to the river. Flood damages related to groundwater remain high because of groundwater propagation beneath the barriers and the increased duration of high flows released from the upstream storage facility on the Bow River. Barriers do not provide any additional benefits to the watershed such as drought management, energy generation or recreation and depending upon the size of the flood event, communities protected by barriers may still need to be evacuated for safety.

Benefit/Cost Analysis

Development Cost	$1,802,850,000
O&M*	$9,100,000
PV Benefits (average annual damages)	$2,270,535,000
PV Costs (development & operating total cost)	$2,143,770,000
Benefit / Cost Ratio	1.06
Net Present Value	$126,765,000

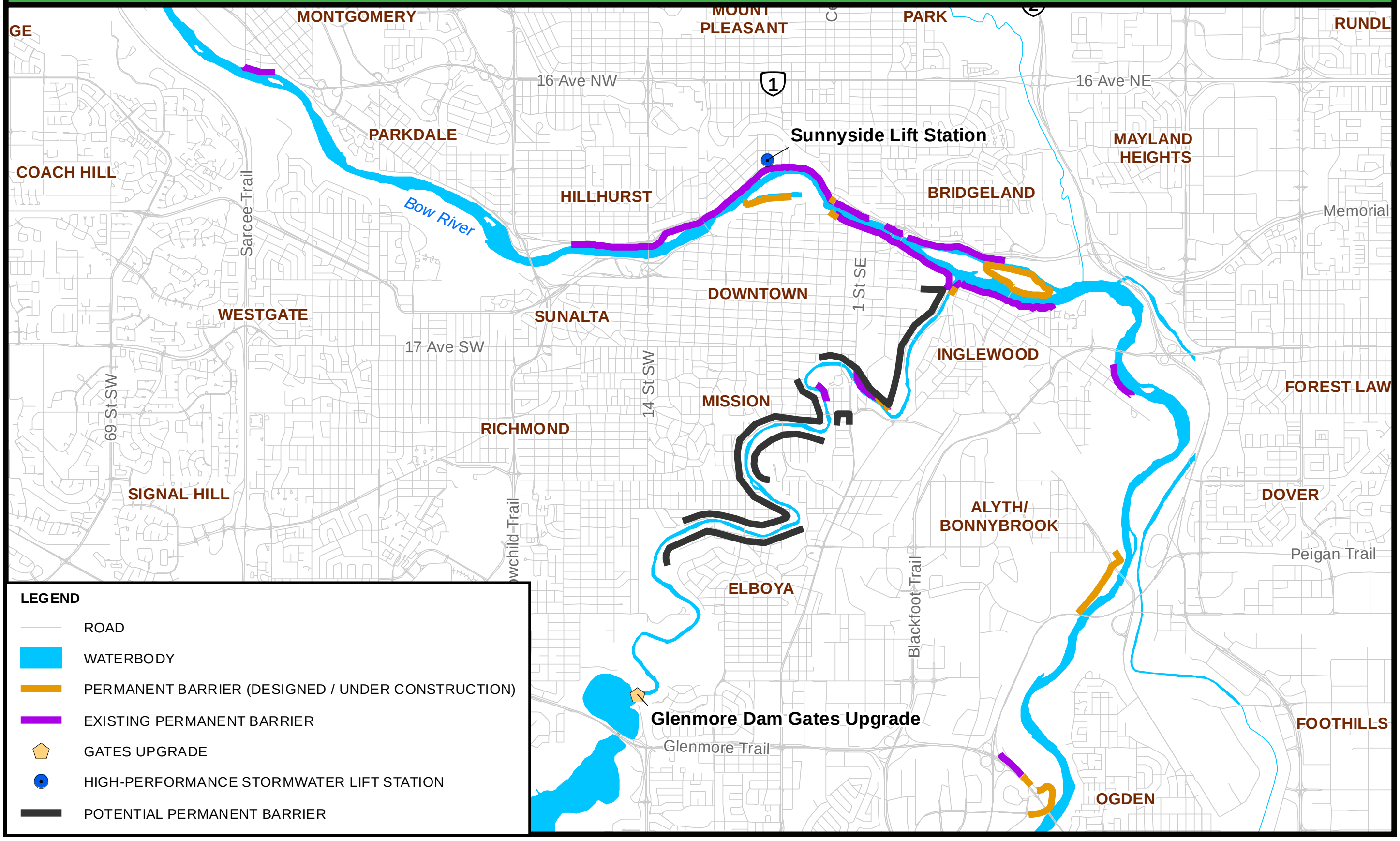
Triple Bottom Line Analysis

GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	-8	6
	Equitable protection	-6	8
	Vulnerable populations	2	5
	River aesthetics	-10	9
	Recreation access	-8	7
	Emergency access	-1	6
	Risk transparency	3	3
ENVIRONMENTAL	Water security	36	1
	Riparian health and ecosystem functions	-16	7
	Water quality and contamination prevention	4	1
IMPLEMENTATION	Timeliness of Implementation	-20	11
	Adaptability/Flexibility	9	3
	Jurisdictional control	-6	9
	Regulatory complexity	-6	8
ECONOMIC	Economic Environment	6	5
	Economic Efficiency	-11	11
	Damages Averted	10	8
	Total Cost	-15	11
	TOTAL SCORE	-36	12

* Net present value of barrier operation and maintenance is included in Development Cost provided by Associated Engineering.

Category of Damages		Scenario 3			
		Benefits		Residual AAD	
Total Average Annual Damages (AAD)		$71,854,851		$44,723,582	
Building-related (Direct, Displacement, Intangible)	Overland	$39,641,494	55.2%	$10,678,473	23.9%
	Groundwater	-$1,640,083	-2.3%	$27,606,344	61.7%
Infrastructure, Traffic, Habitat, Emergency Response		$16,100,183	22.4%	$3,657,088	8.2%
Isolated (all categories)		$17,966,624	25.0%	$2,008,344	4.5%
Evacuation (no direct damage)		-$213,367	-0.3%	$773,333	1.7%
Bow River		$49,935,679	69.5%	$25,192,032	56.3%
Elbow River		$21,919,171	30.5%	$19,531,550	43.7%

Location



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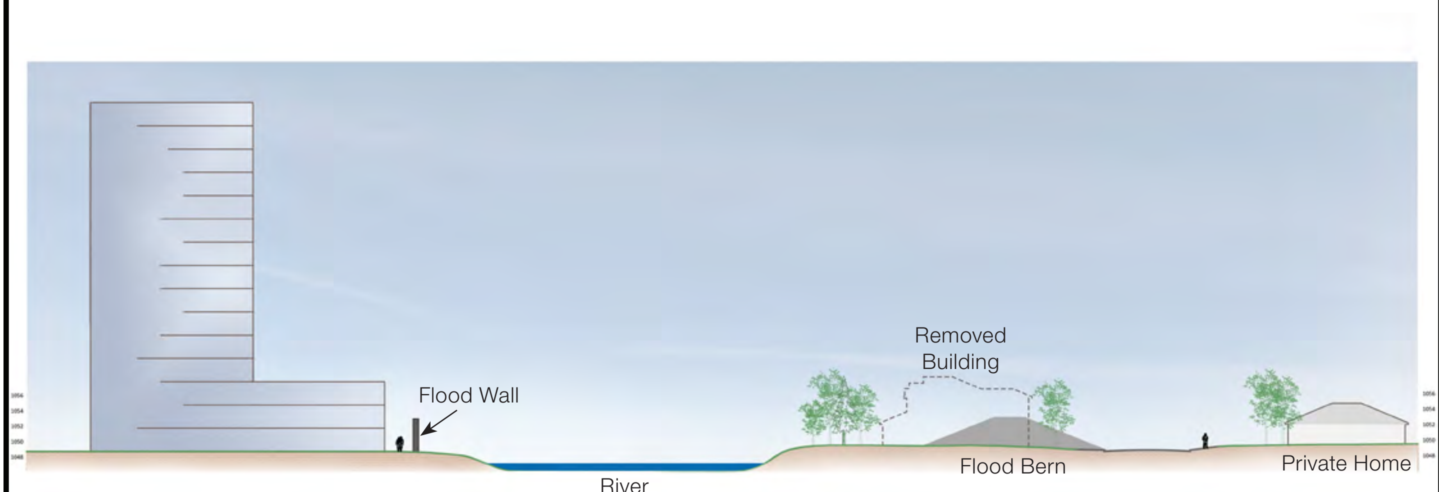


4.6.7 EVALUATION OF FLOOD MITIGATION SCENARIO 3a

Description & Discussion

This scenario includes one new reservoir upstream on the Bow River and barriers along the Elbow River (Scenario 3) with the added benefit of groundwater protection in the construction of the barriers. The barriers total 14.6 km and average between 1.6 and 3.0 m in height with a max height of 6.3 m. The barriers are a combination of walls and berms. Buyouts would be required in many location where they would be located on what is currently private property.

This scenario provides the same benefit/cost ratio as 3 as increased benefits are offset by increased costs, although the AAD averted is substantially higher by ±$6.5 million. Groundwater flooding remains an issue along the Bow River. The Elbow barriers are costly and difficult to integrate into the community, in addition to impacting aesthetics and access to the river. Flood damages related to groundwater remain high because of groundwater propagation beneath the barriers and the increased duration of high flows released from the upstream storage facility on the Bow River. Barriers do not provide any additional benefits to the watershed such as drought management, energy generation or recreation and depending upon the size of the flood event, communities protected by barriers may still need to be evacuated for safety.

Benefit/Cost Analysis

Development Cost	$1,959,100,000
O&M*	$9,100,000
PV Benefits (average annual damages)	$2,476,359,000
PV Costs (development & operating total cost)	$2,300,020,000
Benefit / Cost Ratio	1.08
Net Present Value	$176,339,000

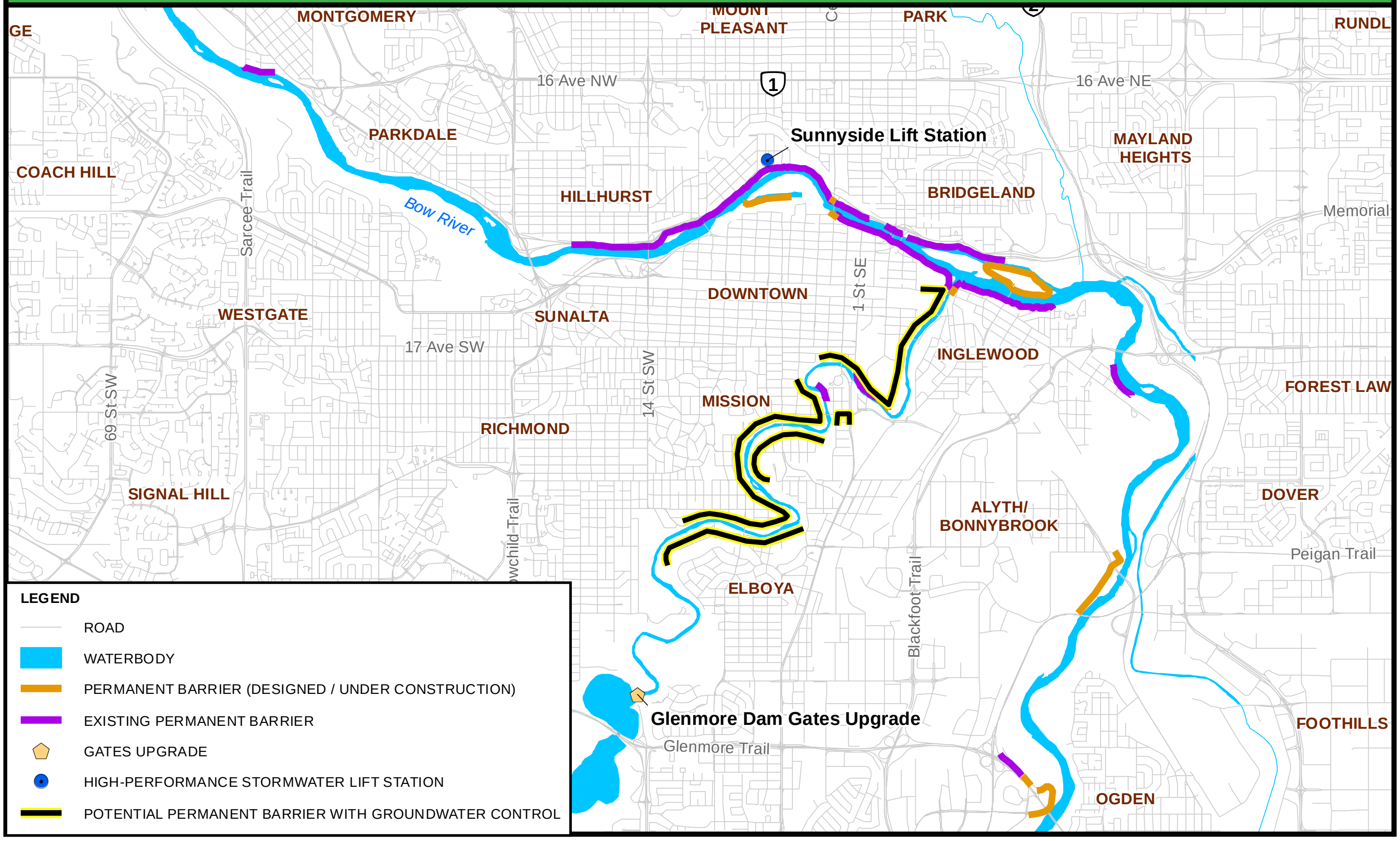
* Net present value of barrier operation and maintenance is included in Development Cost provided by Associated Engineering.

Triple Bottom Line Analysis

GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	-8	6
	Equitable protection	-6	8
	Vulnerable populations	2	5
	River aesthetics	-10	9
	Recreation access	-8	7
	Emergency access	-1	6
	Risk transparency	3	3
ENVIRONMENTAL	Water security	36	1
	Riparian health and ecosystem functions	-16	7
	Water quality and contamination prevention	4	1
IMPLEMENTATION	Timeliness of Implementation	-20	11
	Adaptability/Flexibility	9	3
	Jurisdictional control	-6	9
	Regulatory complexity	-6	8
ECONOMIC	Economic Environment	6	5
	Economic Efficiency	-11	10
	Damages Averted	14	6
	Total Cost	-18	12
	TOTAL SCORE	-36	10

Category of Damages		Scenario 3a Benefits		Scenario 3a Residual AAD	
Total Average Annual Damages (AAD)		$78,368,516		$38,209,917	
Building-related (Direct, Displacement, Intangible)	Overland	$39,641,198	50.6%	$10,678,769	27.9%
	Groundwater	$4,897,738	6.2%	$21,068,523	55.1%
Infrastructure, Traffic, Habitat, Emergency Response		$16,100,067	20.5%	$3,657,204	9.6%
Isolated (all categories)		$17,966,624	22.9%	$2,008,344	5.3%
Evacuation (no direct damage)		-$237,112	-0.3%	$797,078	2.1%
Bow River		$50,236,642	64.1%	$24,891,069	65.1%
Elbow River		$28,131,872	35.9%	$13,318,849	34.9%

Location



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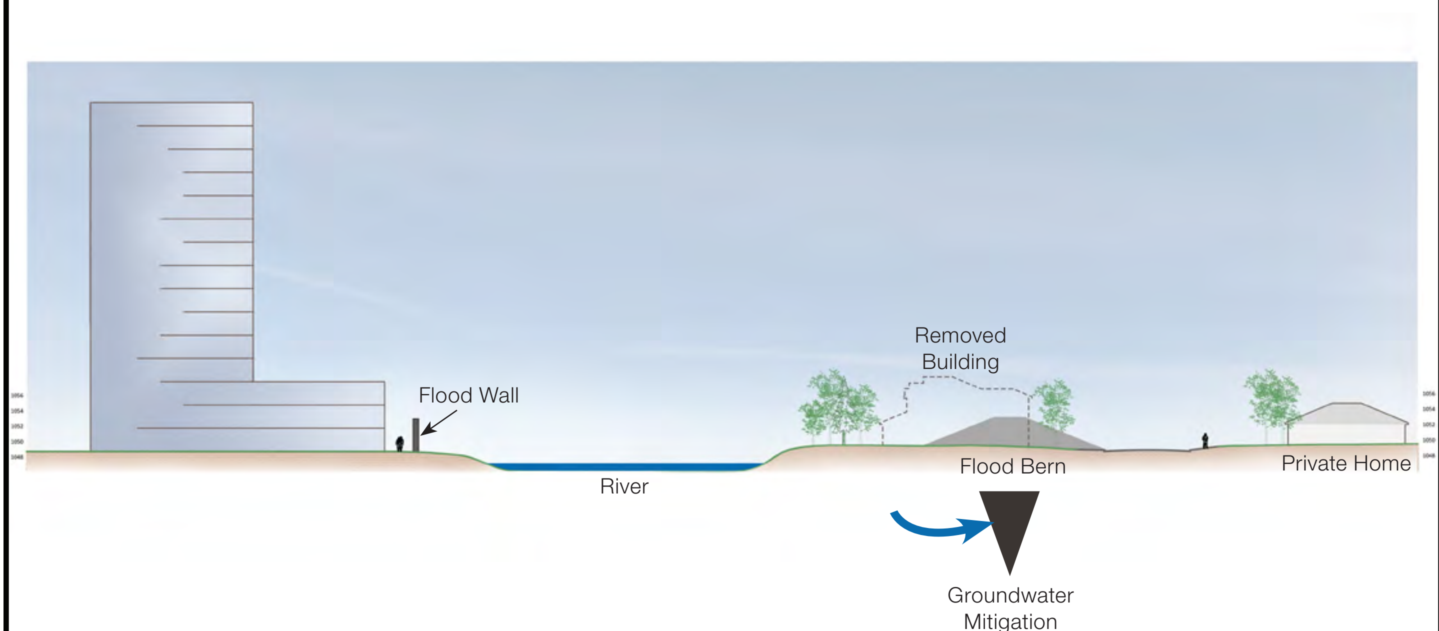


4.6.8 EVALUATION OF FLOOD MITIGATION SCENARIO 4

Description & Discussion

Scenario 4 includes the SR1 reservoir along with barriers on the Bow River. Barriers would be required in 21 locations and total nearly 30 km. The average barrier height would be lower than that required on the Elbow River, averaging between 0.9 and 2.8 m.

This scenario provides the second highest B/C ratio at 2.43 as a result of the $81 million of damages averted (second highest) along with the second lowest costs. Many barriers will require purchase of land along the river where space is needed to build them. They will also change the visual aesthetics of the river and nearby communities and may affect the location and number of access points for recreational activities. There is also significant impact of the natural riverbank environment including drainage and interactions between the river and floodplain areas. Barriers do not provide any additional benefits to the watershed such as drought management, energy generation or recreation and depending upon the size of the flood event, communities protected by barriers may still need to be evacuated for safety.

Triple Bottom Line Analysis

GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	-10	8
	Equitable protection	6	5
	Vulnerable populations	2	5
	River aesthetics	-8	7
	Recreation access	-10	9
	Emergency access	-1	6
	Risk transparency	3	3
ENVIRONMENTAL	Water security	6	5
	Riparian health and ecosystem functions	-16	7
	Water quality and contamination prevention	-4	9
IMPLEMENTATION	Timeliness of Implementation	4	3
	Adaptability/Flexibility	6	6
	Jurisdictional control	3	5
	Regulatory complexity	-6	8
ECONOMIC	Economic Environment	6	5
	Economic Efficiency	7	3
	Damages Averted	16	5
	Total Cost	7	3
	TOTAL SCORE	11	6

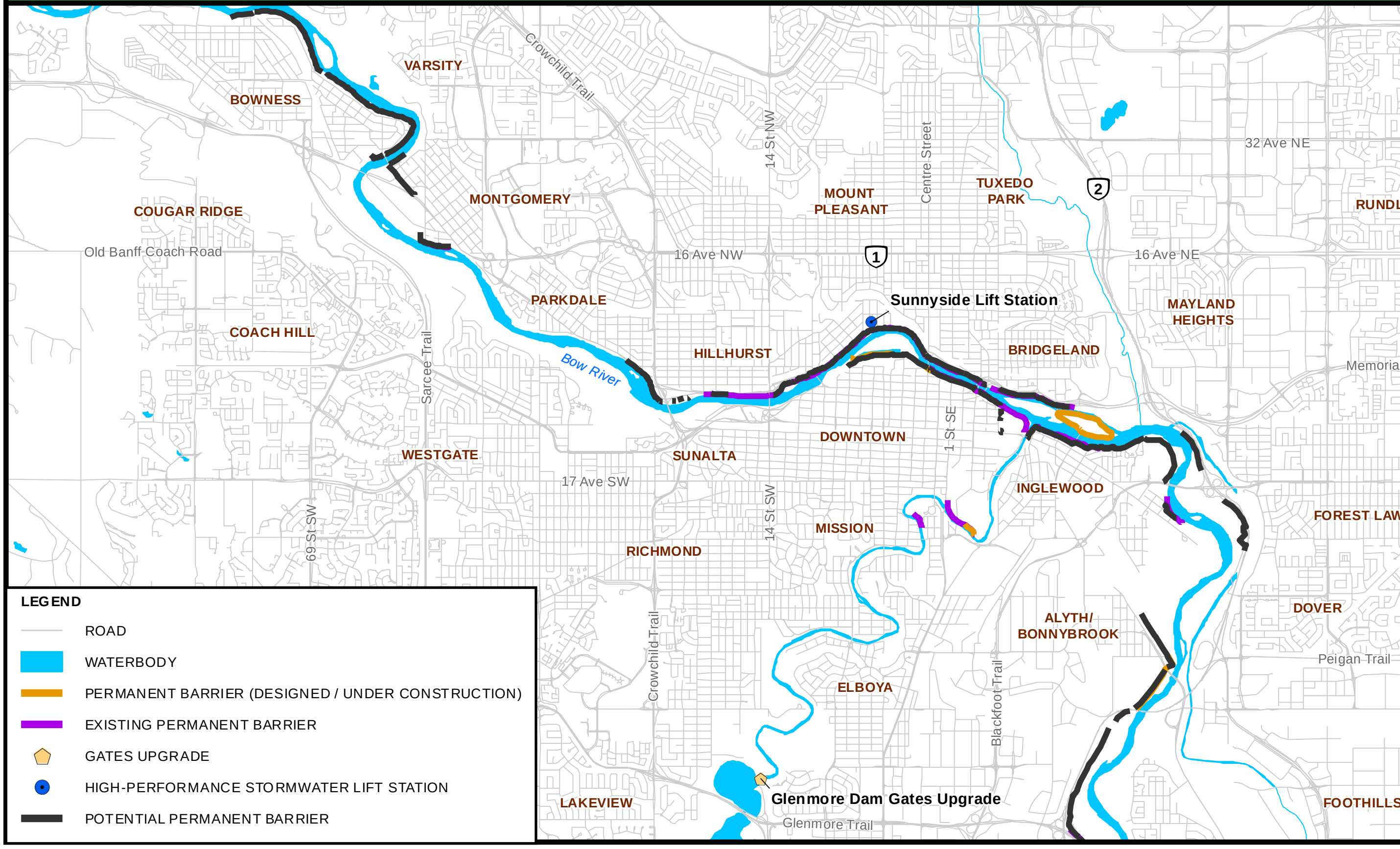
Benefit/Cost Analysis

Development Cost	$903,286,859
O&M*	$5,100,000
PV Benefits (average annual damages)	$2,773,550,000
PV Costs (development & operating total cost)	$1,094,352,000
Benefit / Cost Ratio	2.53
Net Present Value	$1,679,198,000

* Net present value of barrier operation and maintenance is included in Development Cost provided by Associated Engineering.

Category of Damages		Scenario 4			
		Benefits		Residual AAD	
Total Average Annual Damages (AAD)		$81,944,251		$34,634,182	
Building-related (Direct, Displacement, Intangible)	Overland	$36,060,137	44.0%	$14,259,830	41.2%
	Groundwater	$11,963,763	14.6%	$14,002,498	40.4%
Infrastructure, Traffic, Habitat, Emergency Response		$16,169,739	19.7%	$3,587,532	10.4%
Isolated (all categories)		$18,082,192	22.1%	$1,892,776	5.5%
Evacuation (no direct damage)		-$331,580	-0.4%	$891,546	2.6%
Bow River		$54,352,922	66.3%	$20,774,789	60.0%
Elbow River		$27,591,329	33.7%	$13,859,392	40.0%

Location



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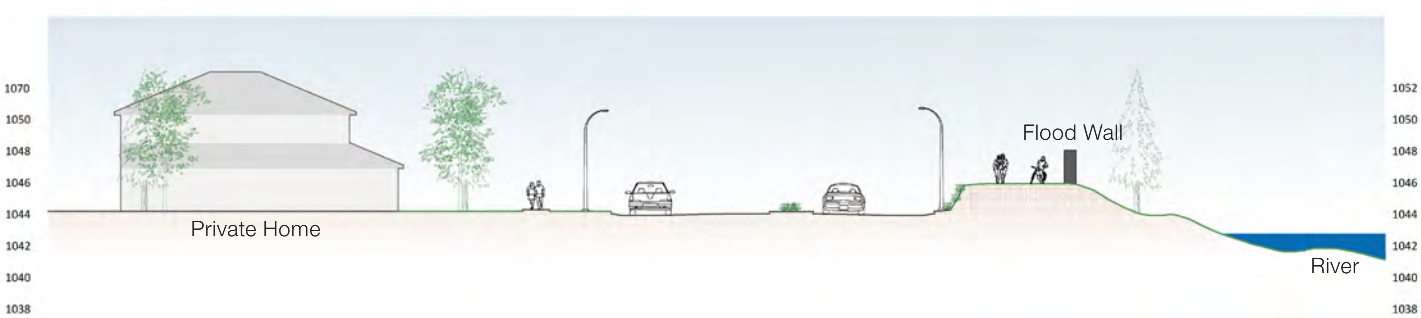


4.6.9 EVALUATION OF FLOOD MITIGATION SCENARIO 4a

Description & Discussion

This is a variation of Scenario 4 with groundwater controls installed as part of the barrier construction. Scenario 4 includes the SR1 reservoir along with barriers on the Bow River. Barriers would be required in 21 locations and total nearly 30 km. The average barrier height would be lower than that required on the Elbow River, averaging between 0.9 and 2.8 m.

The benefit/cost ratio is less than the without groundwater protection option because the present value of the costs increase is greater than the present value of the additional benefits. Additionally, there is no groundwater protection for the Elbow River. Many barriers will require purchase of land along the river where space is needed to build them. They will also change the visual aesthetics of the river and nearby communities and may affect the location and number of access points for recreational activities. There is also significant impact of the natural riverbank environment including drainage and interactions between the river and floodplain areas. Barriers do not provide any additional benefits to the watershed such as drought management, energy generation or recreation and depending upon the size of the flood event, communities protected by barriers may still need to be evacuated for safety.

Triple Bottom Line Analysis

GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	-10	8
	Equitable protection	6	5
	Vulnerable populations	2	5
	River aesthetics	-8	7
	Recreation access	-10	9
	Emergency access	-1	6
	Risk transparency	3	3
ENVIRONMENTAL	Water security	6	5
	Riparian health and ecosystem functions	-16	7
	Water quality and contamination prevention	-4	9
IMPLEMENTATION	Timeliness of Implementation	4	3
	Adaptability/Flexibility	6	6
	Jurisdictional control	3	5
	Regulatory complexity	-6	8
ECONOMIC	Economic Environment	6	5
	Economic Efficiency	1	4
	Damages Averted	20	1
	Total Cost	2	5
	TOTAL SCORE	4	7

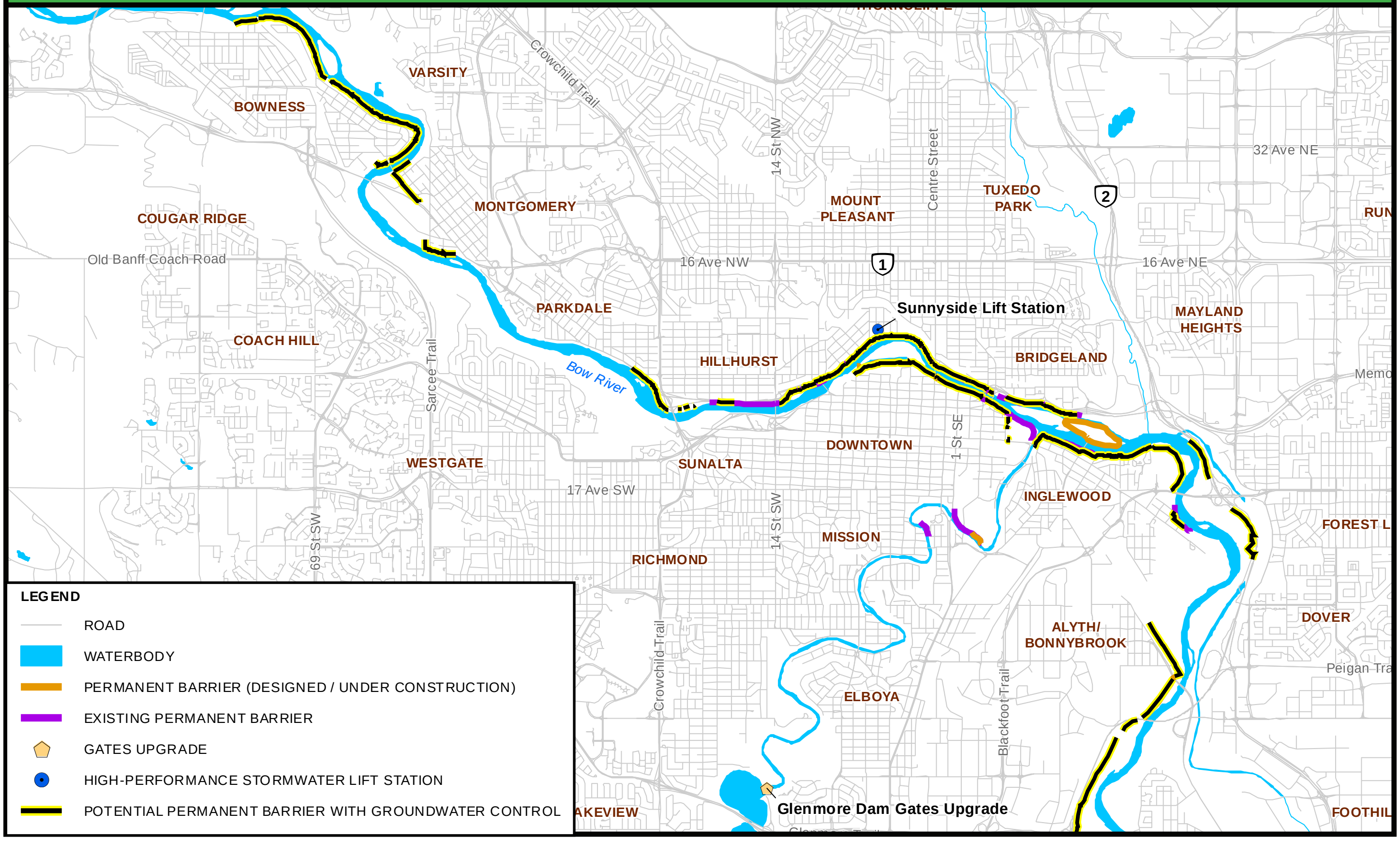
Benefit/Cost Analysis

Development Cost	$1,134,672,408
O&M*	$5,100,000
PV Benefits (average annual damages)	$2,773,550,000
PV Costs (development & operating total cost)	$1,325,737,000
Benefit / Cost Ratio	2.09
Net Present Value	$1,447,813,000

* Net present value of barrier operation and maintenance is included in Development Cost provided by Associated Engineering.

Category of Damages		Scenario 4a			
		Benefits		Residual AAD	
Total Average Annual Damages (AAD)		$87,773,605		$28,804,828	
Building-related (Direct, Displacement, Intangible)	Overland	$36,690,150	41.8%	$13,629,817	47.3%
	Groundwater	$17,080,853	19.5%	$8,885,408	30.8%
Infrastructure, Traffic, Habitat, Emergency Response		$16,240,358	18.5%	$3,516,913	12.2%
Isolated (all categories)		$18,133,617	20.7%	$1,841,351	6.4%
Evacuation (no direct damage)		-$371,373	-0.4%	$931,339	3.2%
Bow River		$60,008,834	68.4%	$15,118,877	52.5%
Elbow River		$27,764,770	31.6%	$13,685,951	47.5%

Location



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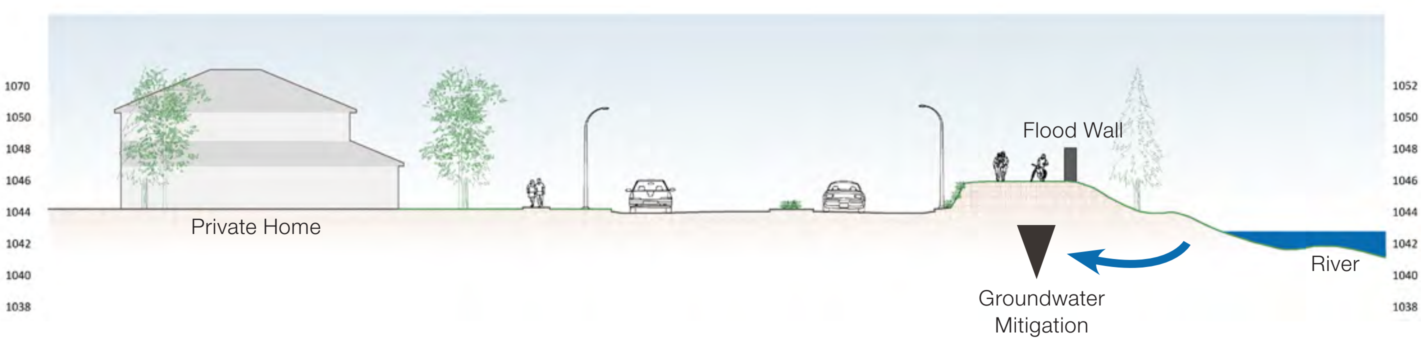


4.6.10 EVALUATION OF FLOOD MITIGATION SCENARIO 5

Description & Discussion

This option includes barriers on both the Bow and Elbow Rivers in the absence of any new upstream storage facilities. Protecting to a 1:200 year level, the barriers are extensive and total nearly 44 km of along both rivers. Average barrier height is between 0.7 m and 2.9 m. Many barriers will require purchase of land along the river where space is needed to build them. They will also change the visual aesthetics of the river and nearby communities and may affect the location and number of access points for recreational activities. There is also significant impact of the natural riverbank environment including drainage and interactions between the river and floodplain areas. Barriers do not provide any additional benefits to the watershed such as drought management, energy generation or recreation and depending upon the size of the flood event, communities protected by barriers may still need to be evacuated for safety.

The benefit/cost ratio is 1.69. This option has the lowest benefits of all the structural options because once overtopped, barriers provide no protection.

Benefit/Cost Analysis

Development Cost	$1,323,036,113
O&M*	$100,000
PV Benefits (average annual damages)	$2,241,871,000
PV Costs (development & operating total cost)	$1,326,782,000
Benefit / Cost Ratio	1.69
Net Present Value	$915,089,000

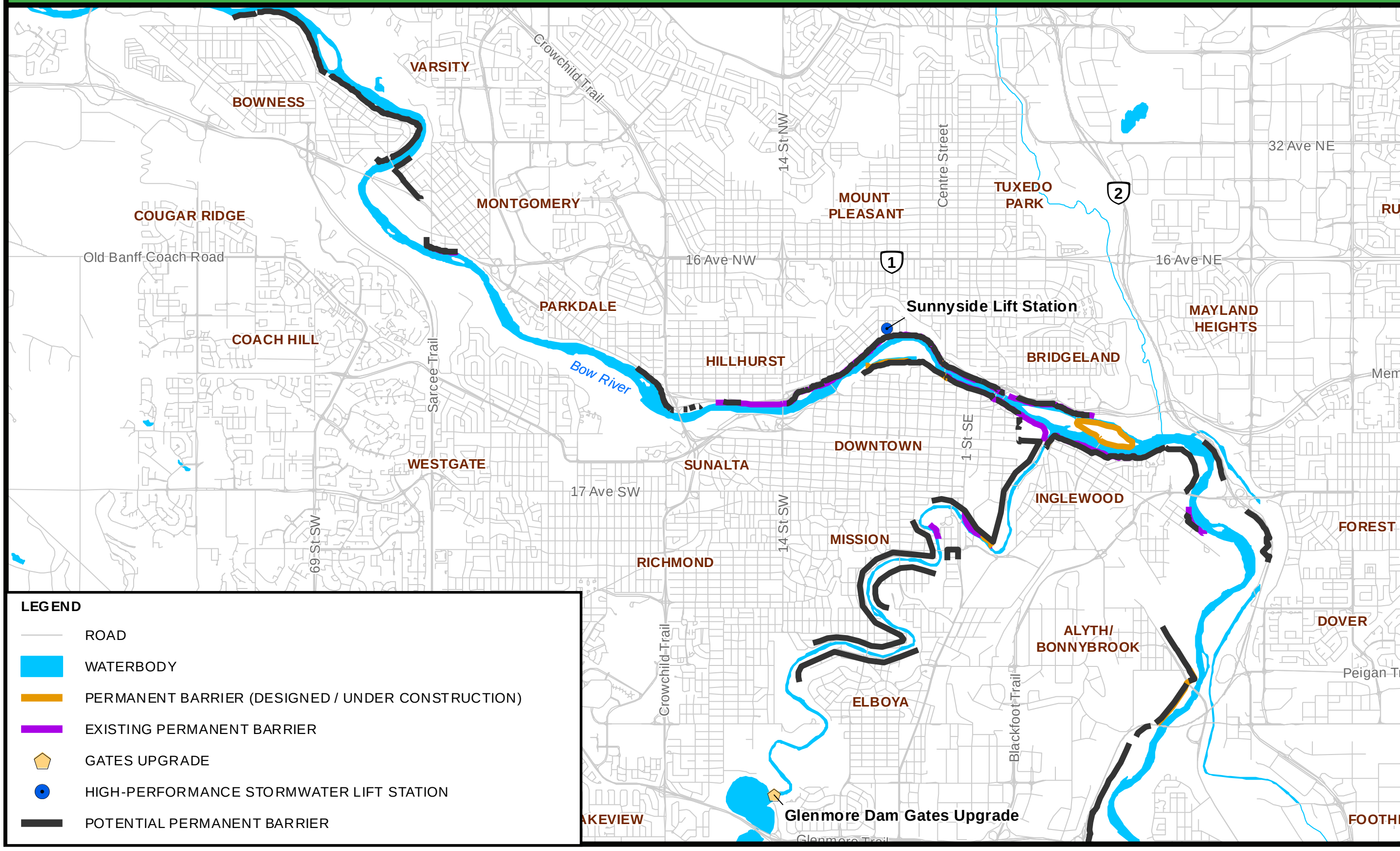
* Net present value of barrier operation and maintenance is included in Development Cost provided by Associated Engineering.

Triple Bottom Line Analysis

GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	-12	11
	Equitable protection	15	1
	Vulnerable populations	1	9
	River aesthetics	-12	11
	Recreation access	-12	11
	Emergency access	-2	10
	Risk transparency	4	1
ENVIRONMENTAL	Water security	0	9
	Riparian health and ecosystem functions	-24	11
	Water quality and contamination prevention	0	3
IMPLEMENTATION	Timeliness of Implementation	-16	9
	Adaptability/Flexibility	-3	11
	Jurisdictional control	9	2
	Regulatory complexity	4	3
ECONOMIC	Economic Environment	6	5
	Economic Efficiency	-3	6
	Damages Averted	10	10
	Total Cost	2	6
	TOTAL SCORE	-33	8

Category of Damages		Scenario 5 Benefits		Scenario 5 Residual AAD	
Total Average Annual Damages (AAD)		$70,947,758		$45,630,675	
Building-related (Direct, Displacement, Intangible)	Overland	$31,771,895	44.8%	$18,548,072	40.6%
	Groundwater	$5,899,627	8.3%	$20,066,634	44.0%
Infrastructure, Traffic, Habitat, Emergency Response		$15,602,116	22.0%	$4,155,155	9.1%
Isolated (all categories)		$17,916,899	25.3%	$2,058,069	4.5%
Evacuation (no direct damage)		-$242,778	-0.3%	$802,744	1.8%
Bow River		$50,139,681	70.7%	$24,988,030	54.8%
Elbow River		$20,808,077	29.3%	$20,642,644	45.2%

Location



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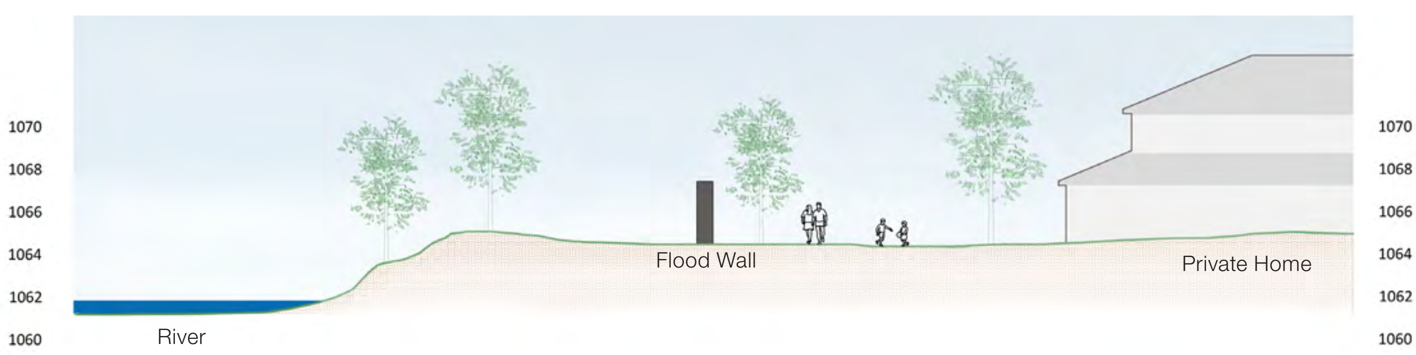


4.6.11 EVALUATION OF FLOOD MITIGATION SCENARIO 5a

Description & Discussion

This option includes barriers on both the Bow and Elbow Rivers as in Scenario 5 but with added groundwater protection. Protecting to a 1:200 year level, the barriers are extensive and total nearly 44 km of along both rivers. Average barrier height is between 0.7 m and 2.9 m. Many barriers will require purchase of land along the river where space is needed to build them. They will also change the visual aesthetics of the river and nearby communities and may affect the location and number of access points for recreational activities. There is also significant impact of the natural riverbank environment including drainage and interactions between the river and floodplain areas. Barriers do not provide any additional benefits to the watershed such as drought management, energy generation or recreation and depending upon the size of the flood event, communities protected by barriers may still need to be evacuated for safety.

The benefit/cost ratio is 1.55. Although providing substantially higher benefits than Scenario 5, the benefit/cost ratio is lower due to the increased cost of the groundwater protection on all barriers.

Triple Bottom Line Analysis

GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	-12	11
	Equitable protection	15	1
	Vulnerable populations	1	9
	River aesthetics	-12	11
	Recreation access	-12	11
	Emergency access	-2	10
	Risk transparency	4	1
ENVIRONMENTAL	Water security	0	9
	Riparian health and ecosystem functions	-24	11
	Water quality and contamination prevention	0	3
IMPLEMENTATION	Timeliness of Implementation	-16	9
	Adaptability/Flexibility	-3	11
	Jurisdictional control	9	2
	Regulatory complexity	4	3
ECONOMIC	Economic Environment	6	5
	Economic Efficiency	-5	7
	Damages Averted	18	4
	Total Cost	-6	7
	TOTAL SCORE	-36	11

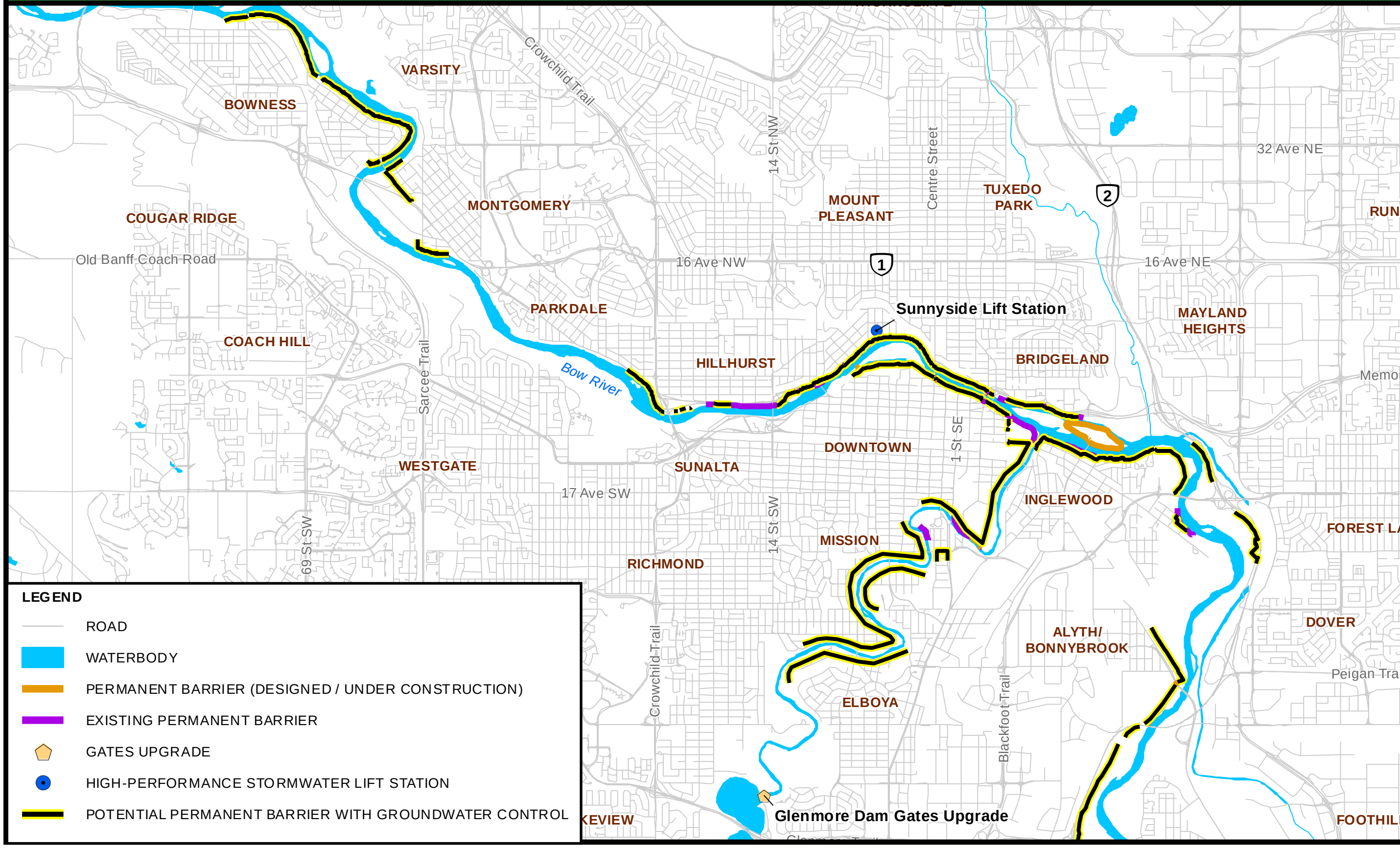
Benefit/Cost Analysis

Development Cost	$1,725,662,291
O&M*	$100,000
PV Benefits (average annual damages)	$2,672,673,000
PV Costs (development & operating total cost)	$1,729,409,000
Benefit / Cost Ratio	1.55
Net Present Value	$943,264,000

* Net present value of barrier operation and maintenance is included in Development Cost provided by Associated Engineering.

Category of Damages		Scenario 5a			
		Benefits		Residual AAD	
Total Average Annual Damages (AAD)		$84,581,198		$31,997,235	
Building-related (Direct, Displacement, Intangible)	Overland	$32,213,694	38.1%	$18,106,273	56.6%
	Groundwater	$19,194,016	22.7%	$6,772,245	21.2%
Infrastructure, Traffic, Habitat, Emergency Response		$15,602,039	18.4%	$4,155,232	13.0%
Isolated (all categories)		$17,916,899	21.2%	$2,058,069	6.4%
Evacuation (no direct damage)		-$345,450	-0.4%	$905,416	2.8%
Bow River		$57,036,702	67.4%	$18,091,009	56.5%
Elbow River		$27,544,495	32.6%	$13,906,226	43.5%

Location



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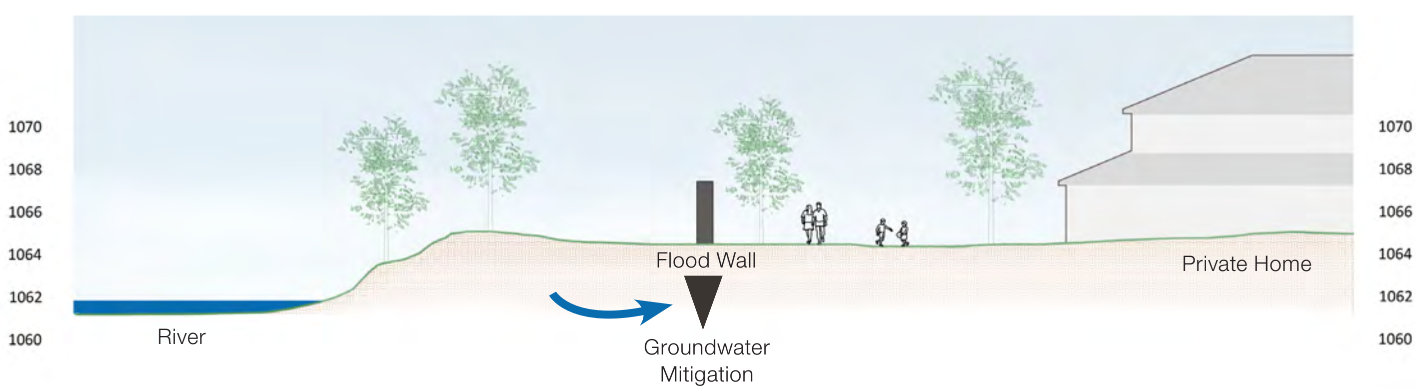


4.6.12 EVALUATION OF FLOOD MITIGATION SCENARIO 6

Description & Discussion

This option considers purchase of all residential properties within the approximate 1:200 year floodway (defined by a 1 m depth) at 2016 assessed values. The majority of properties within the approximate 1:200 floodway are residential. Non-residential properties in the floodway are varied and include the Calgary Stampede, the zoo, the Holy Cross Hospital site, and several schools. Because most non-residential properties would require individual assessment for buyout applicability, only residential properties were included in this analysis.

Within the 1:200 year floodway, there are approximately 980 residential buildings. The total assessed property value amounts to over $1.8 billion. Removal of all the damages associated with these buildings reduces the AAD by $27.2 million.

This option has a negative benefit/cost aspect with a ratio of 0.47. It achieves the lowest average annual benefits by not protecting anything beyond the floodway. In addition, no costs have been determined for restoration or rehabilitation of the land acquired, which could be significant.

Buyouts can be very disruptive to established communities, creating isolated and discontinuous pockets of housing. This can also make service provision less efficient.

Benefit/Cost Analysis

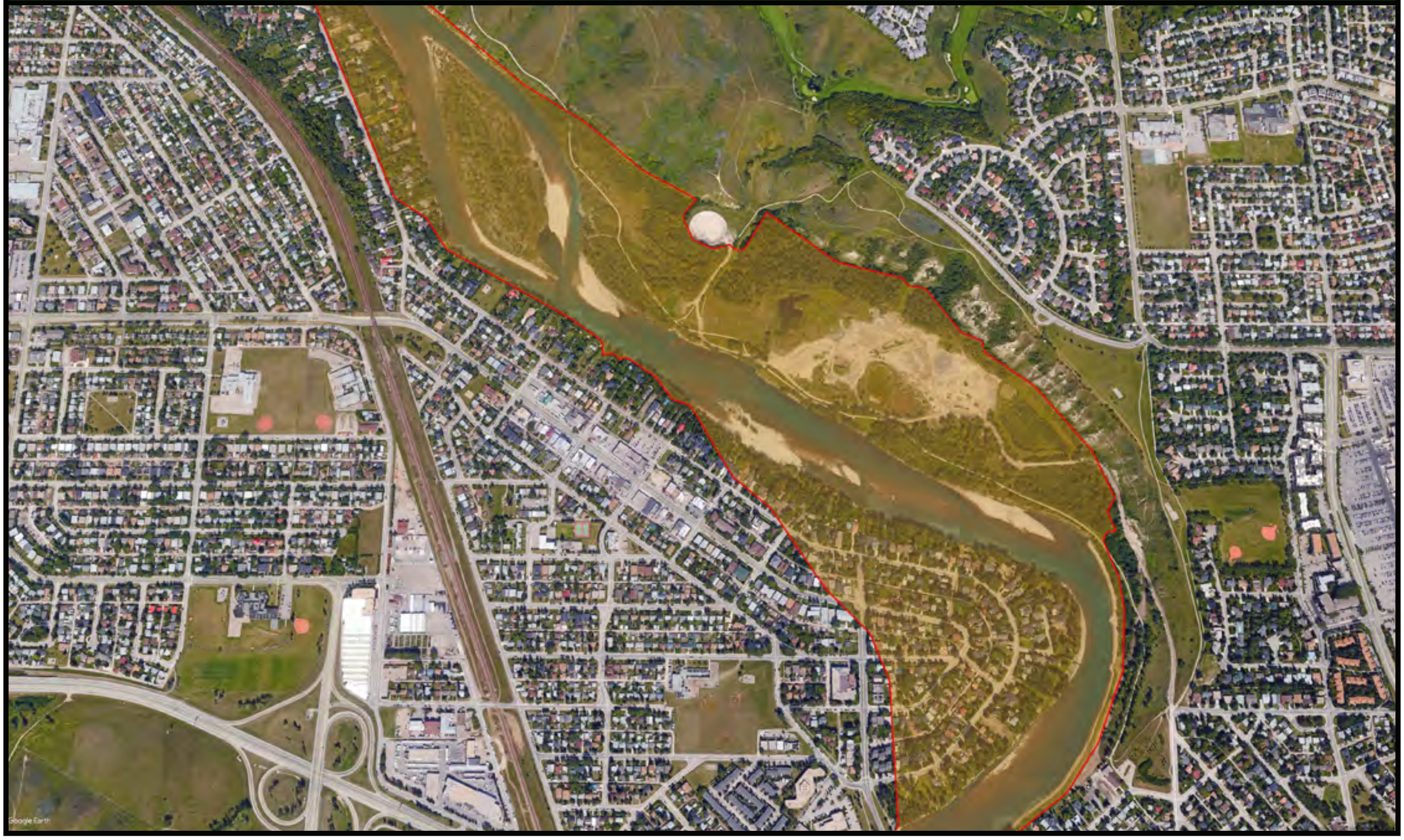
Development Cost	$1,818,000,000
O&M	$0
PV Benefits (average annual damages)	$853,170,000
PV Costs (development & operating total cost)	$1,818,000,000
Benefit / Cost Ratio	0.47
Net Present Value	-$964,830,000

Triple Bottom Line Analysis

GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	-10	8
	Equitable protection	-9	10
	Vulnerable populations	-1	12
	River aesthetics	12	1
	Recreation access	6	4
	Emergency access	-2	10
	Risk transparency	1	10
ENVIRONMENTAL	Water security	0	9
	Riparian health and ecosystem functions	4	1
	Water quality and contamination prevention	0	3
IMPLEMENTATION	Timeliness of Implementation	-4	5
	Adaptability/Flexibility	9	3
	Jurisdictional control	6	4
	Regulatory complexity	-2	5
ECONOMIC	Economic Environment	-3	11
	Economic Efficiency	-18	12
	Damages Averted	-15	11
	Total Cost	-8	8
	TOTAL SCORE	-34	9

Approximate 1:200 Floodway - Elbow River

Approximate 1:200 Floodway - Bowness



4.6.13 EVALUATION OF FLOOD MITIGATION SCENARIO 7

Description & Discussion

As with scenario 2, this option includes a new upstream storage facility on the Bow River as well as SR1 upstream on the Elbow River. However, it adds barriers in three locations along the Bow River because a single upstream dam is not expected to provide full design-level protection. The required barriers would total nearly 4.5 km and average between 0.6 and 1.1 m.

This scenario provides the highest level of benefits/ protection. The additional barriers provide more uniform protections to all communities. The estimated development costs are in the middle of all other options and the benefit cost ratio is positive at 1.41. It also has the potential for very high incidental benefits related to water supply, irrigation, and recreation. As with other upstream options, the remaining groundwater damages may be conservatively high.

Triple Bottom Line Analysis

GOAL	CRITERIA	SCORE	RANK
SOCIAL	Complete communities	10	2
	Equitable protection	12	3
	Vulnerable populations	5	1
	River aesthetics	8	4
	Recreation access	8	3
	Emergency access	3	1
	Risk transparency	3	3
ENVIRONMENTAL	Water security	36	1
	Riparian health and ecosystem functions	-8	6
	Water quality and contamination prevention	0	3
IMPLEMENTATION	Timeliness of Implementation	-8	6
	Adaptability/Flexibility	15	1
	Jurisdictional control	-6	9
	Regulatory complexity	8	1
ECONOMIC	Economic Environment	15	1
	Economic Efficiency	-8	9
	Damages Averted	18	2
	Total Cost	-12	10
	TOTAL SCORE	99	1

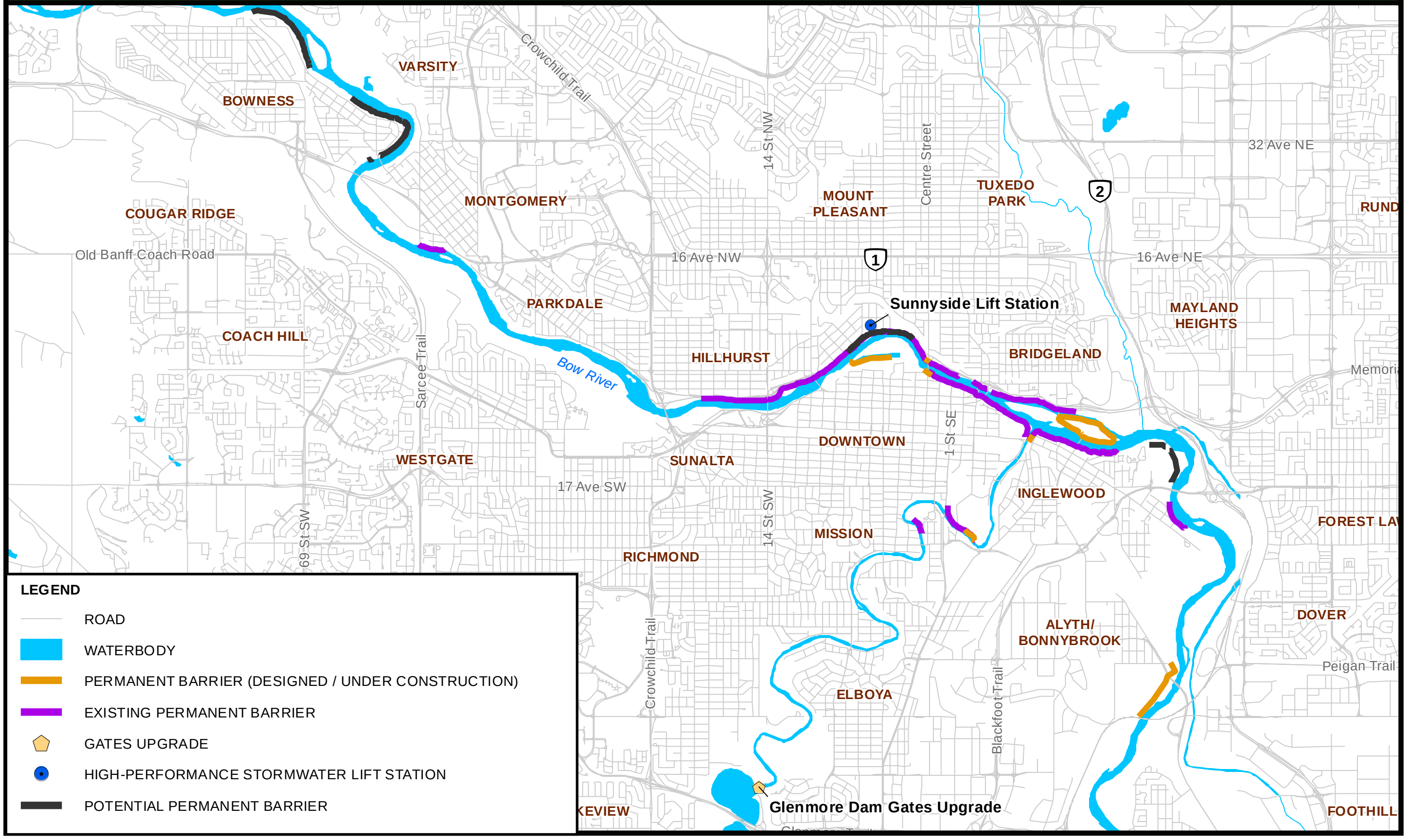
Benefit/Cost Analysis

Development Cost	$1,447,534,050
O&M*	$14,100,000
PV Benefits (average annual damages)	$2,688,400,000
PV Costs (development & operating total cost)	$2,026,531,000
Benefit / Cost Ratio	1.33
Net Present Value	$661,869,000

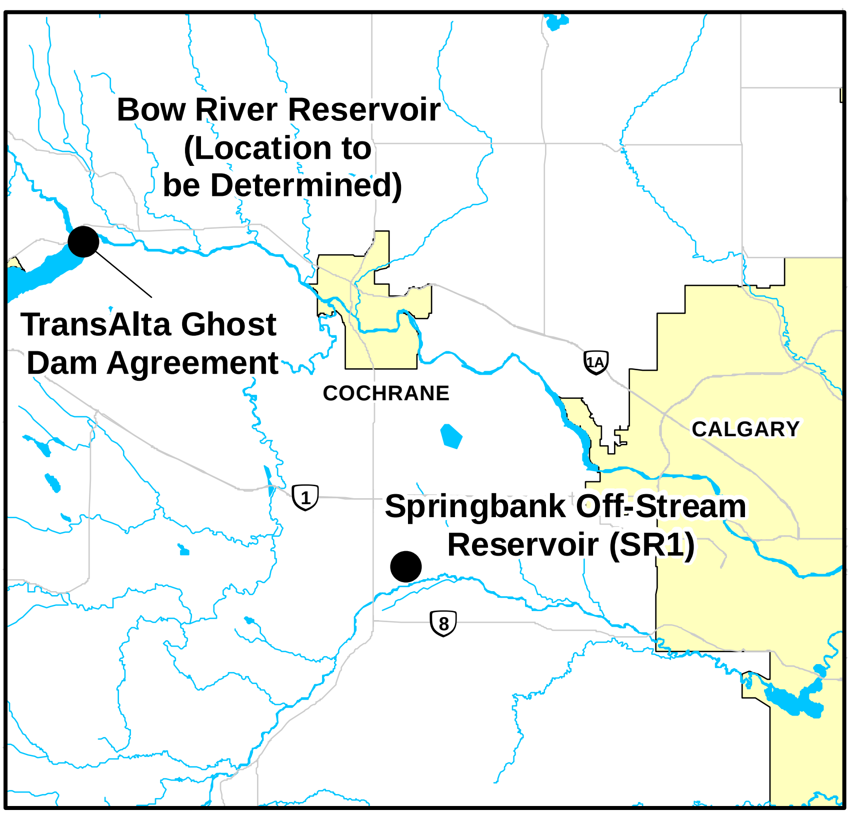
* Net present value of barrier operation and maintenance is included in Development Cost provided by Associated Engineering.

Category of Damages		Scenario 7			
		Benefits		Residual AAD	
Total Average Annual Damages (AAD)		$85,078,882		$31,499,551	
Building-related (Direct, Displacement, Intangible)	Overland	$43,800,492	51.5%	$6,519,475	20.7%
	Groundwater	$6,076,257	7.1%	$19,890,004	63.1%
Infrastructure, Traffic, Habitat, Emergency Response		$17,202,753	20.2%	$2,554,518	8.1%
Isolated (all categories)		$18,348,716	21.6%	$1,626,252	5.2%
Evacuation (no direct damage)		-$349,336	-0.4%	$909,302	2.9%
Bow River		$56,582,389	66.5%	$18,545,322	58.9%
Elbow River		$28,496,492	33.5%	$12,954,229	41.1%

Location



Reservoir Location Map



4.7 Development of Hybrid Flood Mitigation Scenarios

4.7.1 Introduction

Having identified scenario 7 as the preferred flood mitigation scenario by virtue of the highest ranking with respect to the Triple Bottom Line evaluation criteria, further analysis and design modifications were undertaken as a means of enhancing the flood damage reduction attributes. This led to the development of four additional scenarios: 7a, 8, 8a and 9.

4.7.2 Scenario 7a

The flood mitigation measures in Scenario 7a are the same as those in Scenario 7 but without the upstream storage facility on the Bow River. The purpose of this scenario is to illustrate the amount of risk remaining if the barriers along the Bow River have the lower protection levels (i.e. 1:25 years). Essentially, this scenario could be considered as an interim flood mitigation solution in consideration of the time it will take to design, gain approval and construct a new upstream Bow River reservoir.

Comparing Scenario 7a to Scenario 1 reveals that the 1:25 year barriers along the Bow River add $2.2 million in annual benefits. However, it should be noted that Scenario 1 also includes temporary barriers that provide protection in some of the same locations. Therefore, this comparison is to show the stand-alone benefit of the barriers.

Without the cost of the upstream Bow reservoir, the B/C ratio is more than double that of scenario 7 at just over 3. However, there is an additional $11.5 million in remaining annual damages.

4.7.3 Scenario 8

The flood mitigation measures in Scenario 8 are the same as scenario 7 but with the addition of higher barriers protecting the downtown areas to the 1:200 year flood level (or 1:1,000 years in combination with an upstream Bow River reservoir) and the inclusion of groundwater protection within the Sunnyside barrier. In addition to the 6 km of barriers included in scenario 7, the raised pathway barrier for downtown is 2.6 km long with an average height of 1.1 m.

With the additional barriers in place to the 1:1,000 year flood protection level for the downtown areas, benefits are not meaningfully increased, because significant flooding of the downtown does not occur until the 1:500 year flood level is exceeded with the upstream reservoir in place. With the addition of groundwater control for the Sunnyside barrier, average annual damages are reduced by $460,000, a significant reduction. With a $2.85 million cost, the benefit/cost ratio is 5:1.

This scenario provides very little benefit gain for the City overall. However, there is a significant benefit to the Sunnyside community.

4.7.4 Scenario 8a

Scenario 8a is essentially an illustration of Scenario 8 without the construction of the upstream reservoir on the Bow River. As with the comparison between scenarios 7 and 8, there is little extra benefit for scenario 8a over scenario 7a. Without the upstream Bow reservoir, the barriers provide protection to the 1:200 year flood level. With SR1 in place, the probability of flood inundation in the downtown areas is not high until the 1:200 year flood occurs in the Bow River.

4.7.5 Scenario 9

Scenario 9 further raises the barrier protection level of Scenario 8 outside of the downtown areas with higher barriers. Bowness and Sunnyside are protected to the 1:100 year flood level with barriers averaging in height between 1.1 and 1.9 m. Inglewood is protected to the 1:200 flood level with an average additional barrier height of 0.7 m.

The additional heights provide $4.4 million greater annual benefits than the barriers in Scenario 7a.

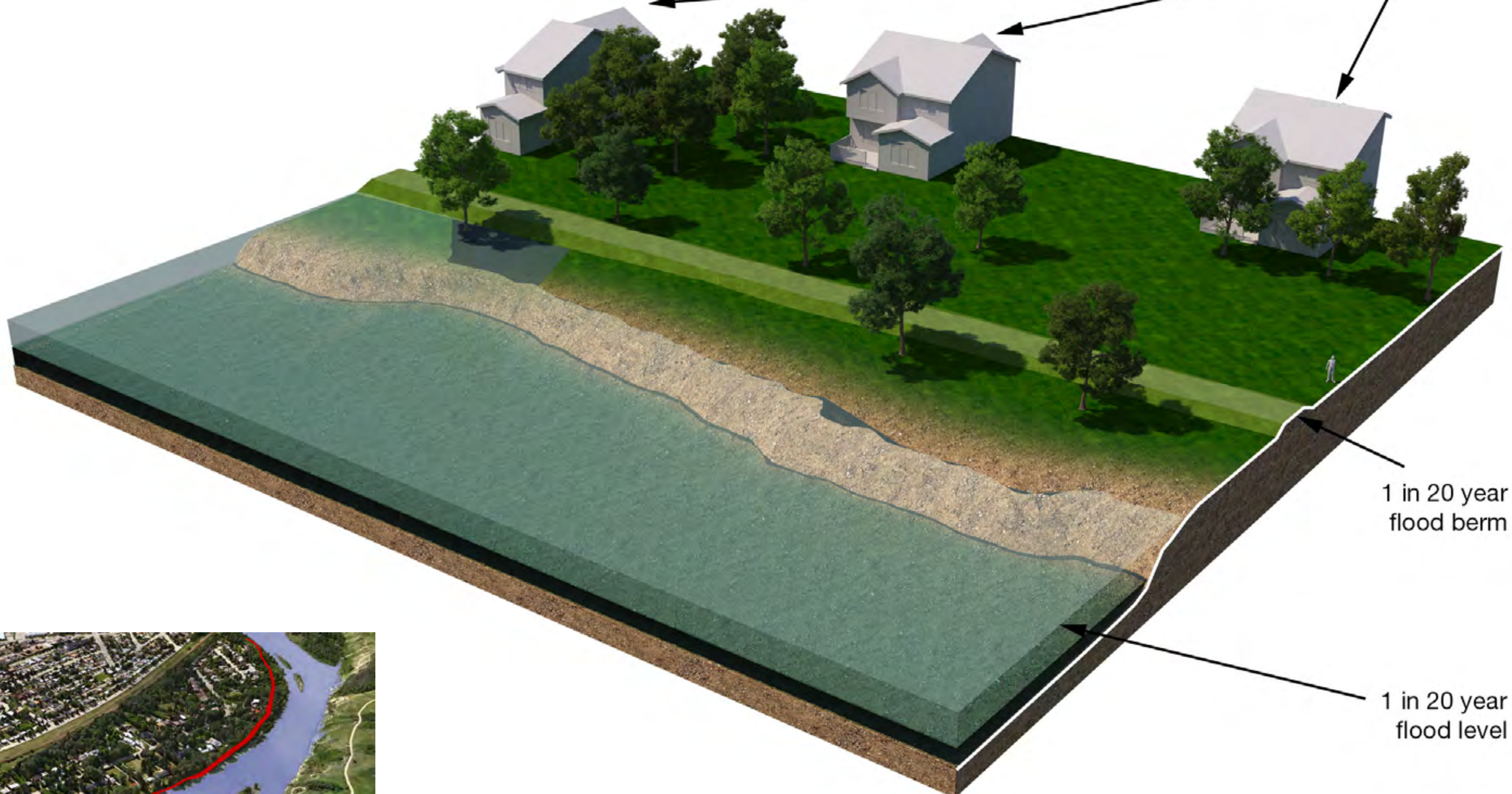
4.8 Barrier Illustrations

The following exhibits (Exhibit 4.7 to 4.17) illustrate the location and general appearance of select barriers considered for implementation as part of the various mitigation scenarios analyzed. These are conceptual in nature and for illustrative purposes only at this point. Barrier details are contained in **Exhibit 4.18.**

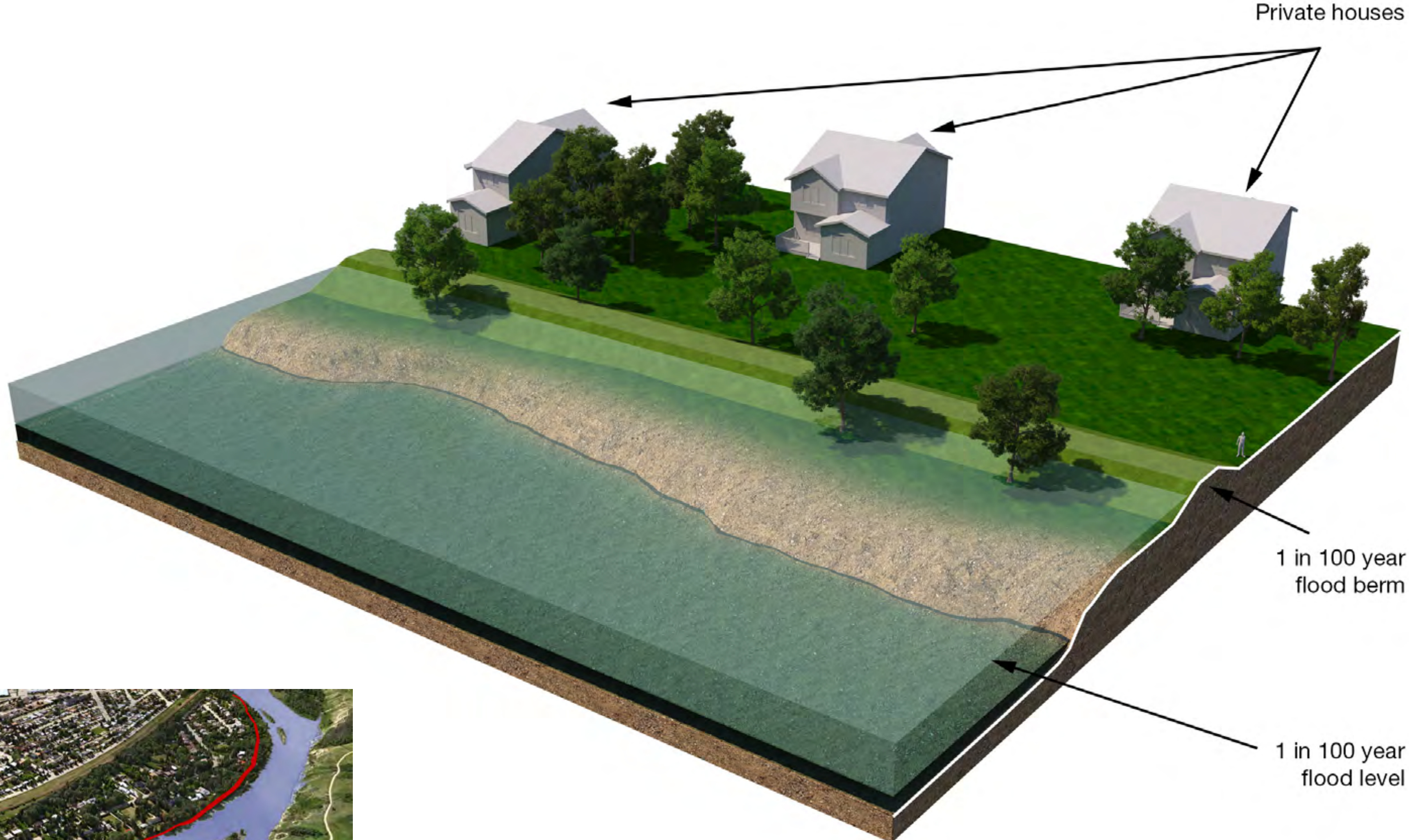
Benefit/Cost Analysis for Scenarios 7 - 9

Indicator	Scenario				
	7	7a	8	8a	9
	SR1 + Bow reservoir + select 1:25 Bow barriers	#7 without Bow reservoir	#7 + gw mitigation @ Sunnyside + 1:200 Downtown barriers	#8 without Bow reservoir	#8 + 1:100 barriers @ Bowness/ Sunnyside
Development Cost	$1,447,534,050	$547,534,050	$1,469,585,414	$569,585,414	$658,376,945
O&M*	$14,100,000	$5,100,000	$14,100,000	$5,100,000	$5,100,000
PV Benefits (average annual damages)	$2,688,400,000	$2,324,665,000	$2,704,393,000	$2,352,214,000	$2,463,578,000
PV Costs (development & operating total cost)	$2,026,531,000	$756,959,000	$2,048,582,000	$779,010,000	$867,801,000
Benefit / Cost Ratio	1.33	3.07	1.32	3.02	2.84
Net Present Value	$661,869,000	$1,567,706,000	$655,811,000	$1,573,204,000	$1,595,777,000

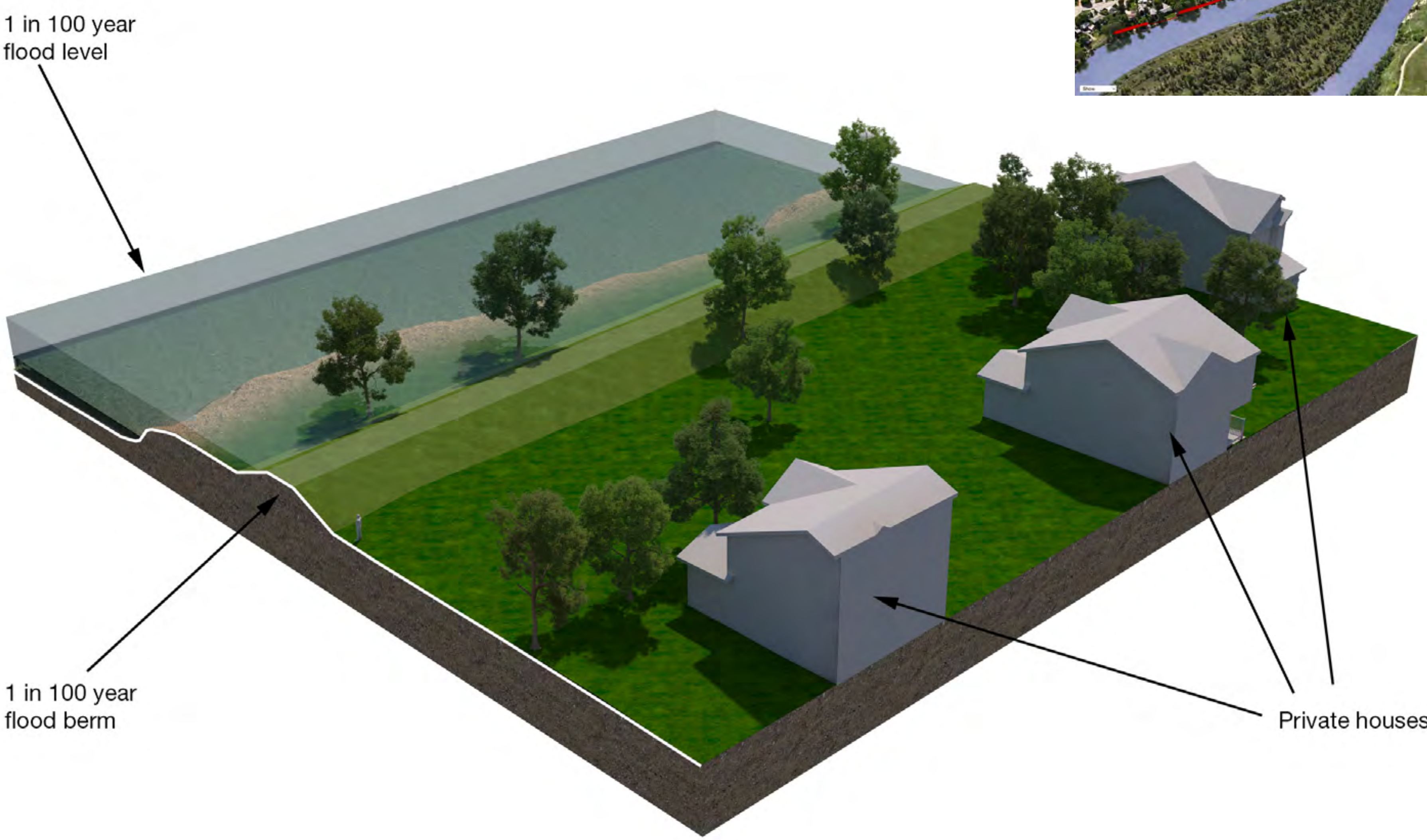
Barrier Illustration - Bowness - North - 20 Year



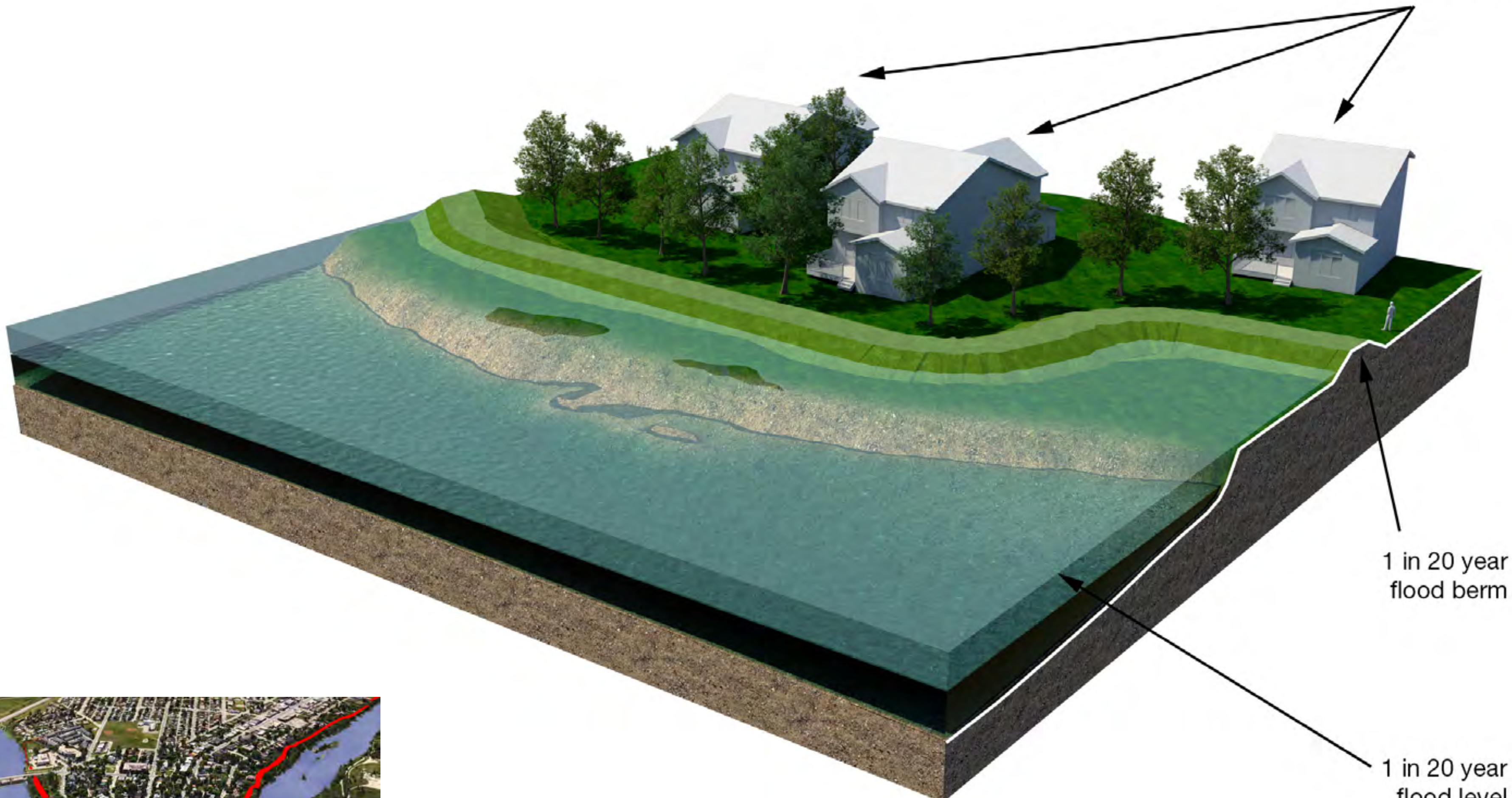
Barrier Illustration - Bowness - North - 100 Year



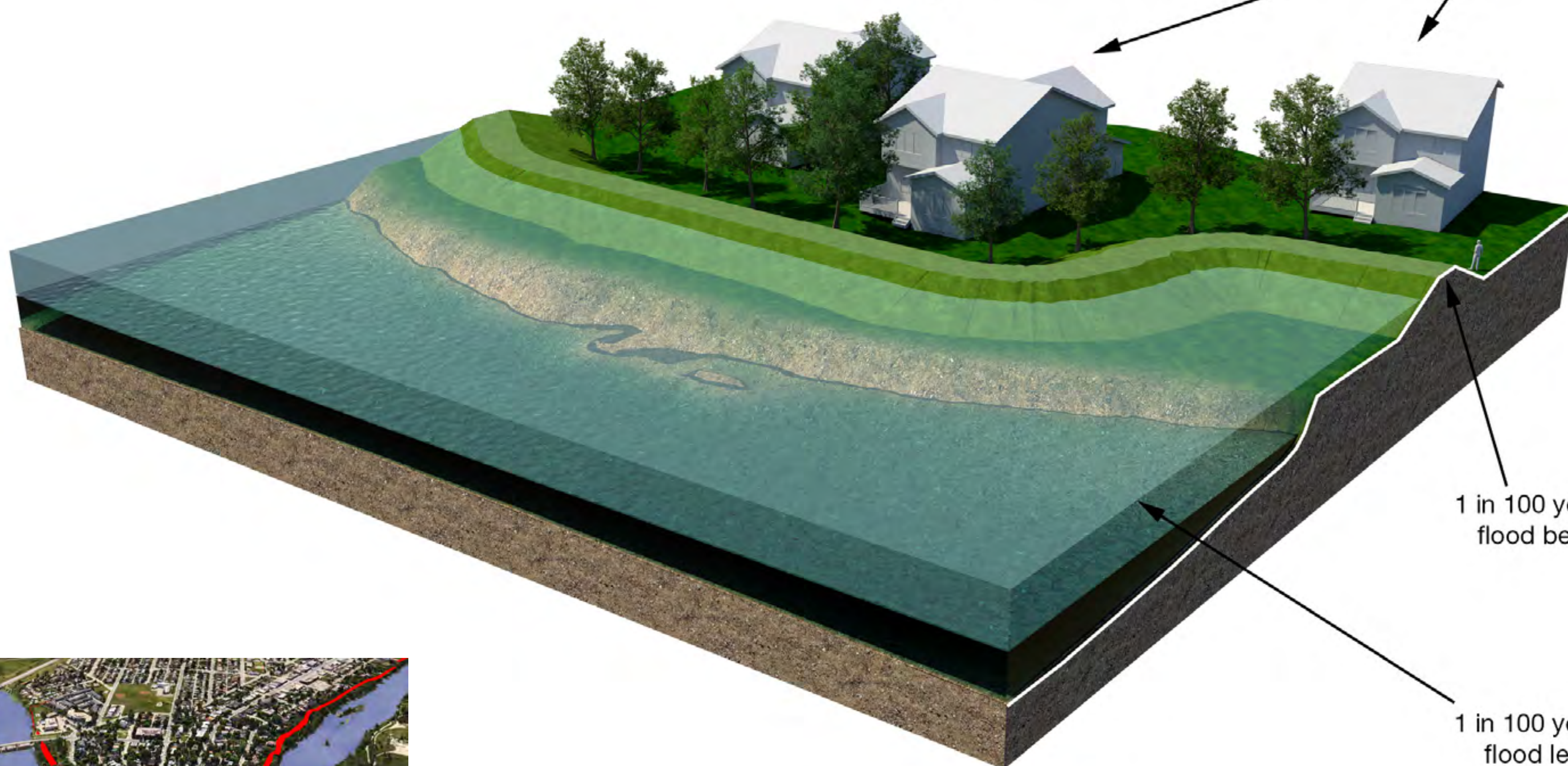
Barrier Illustration - Bowness - North - 100 Year



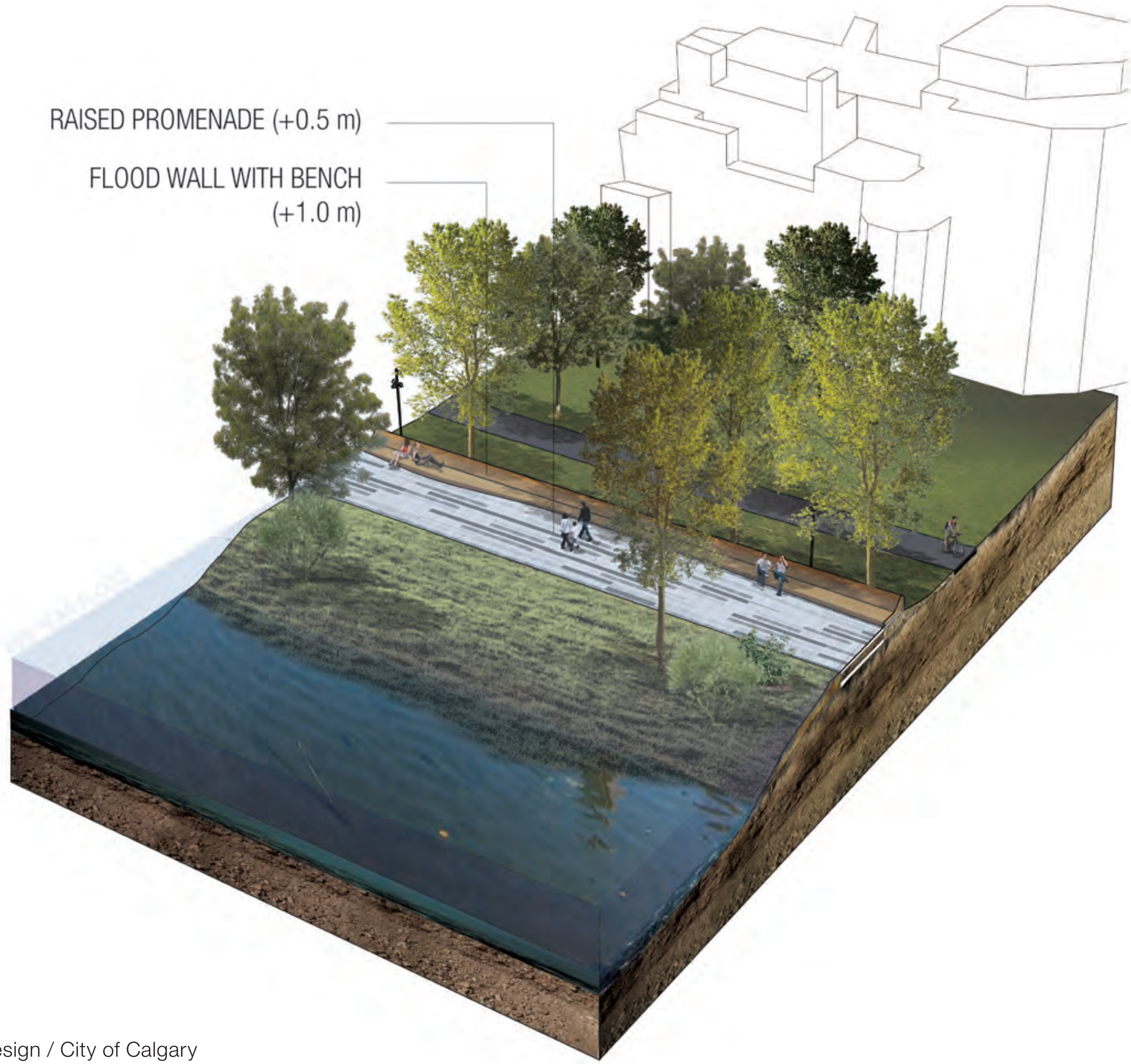
Barrier Illustration - Bowness - South - 20 Year



Barrier Illustration - Bowness - South - 100 Year

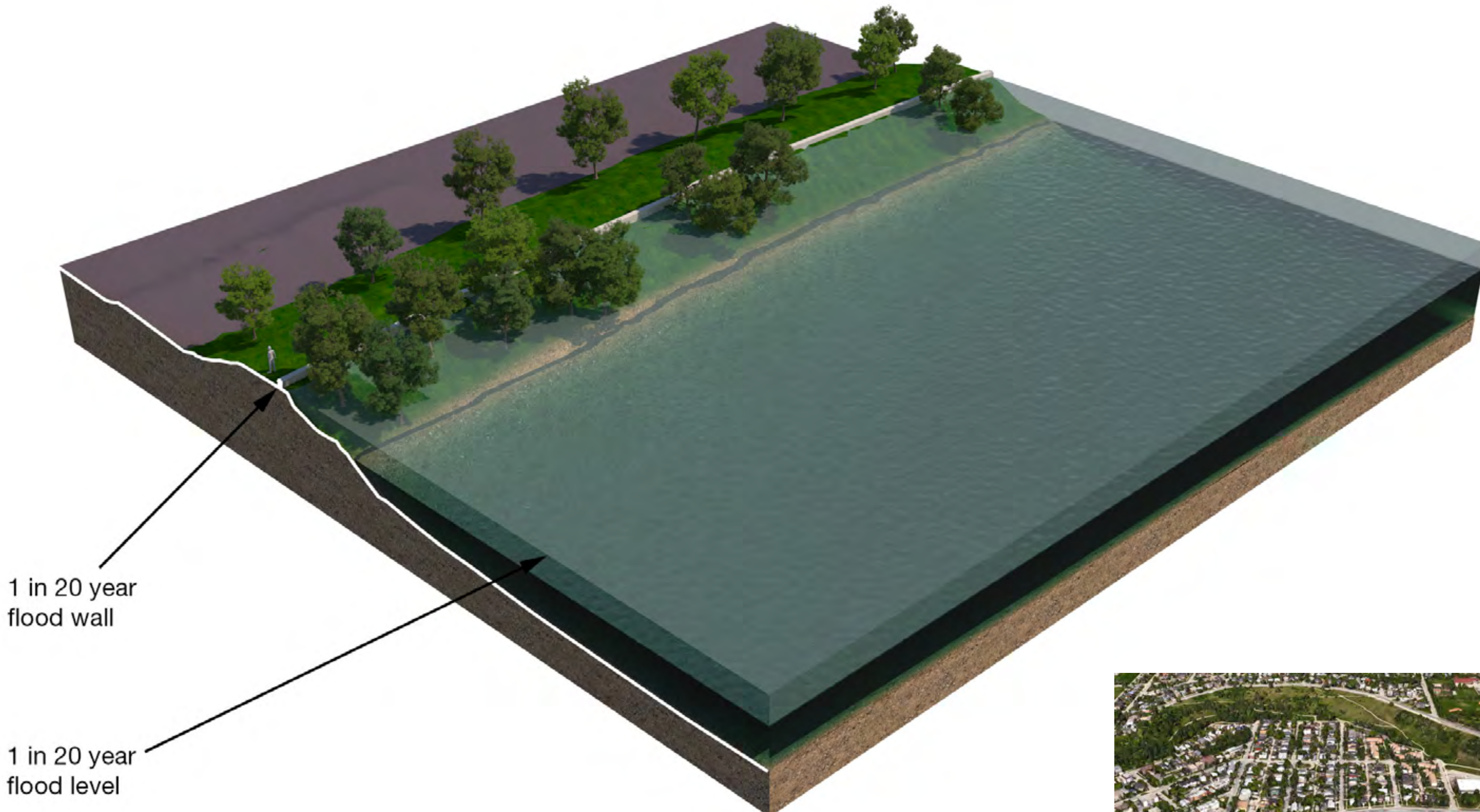


Barrier Illustration - Eau Claire

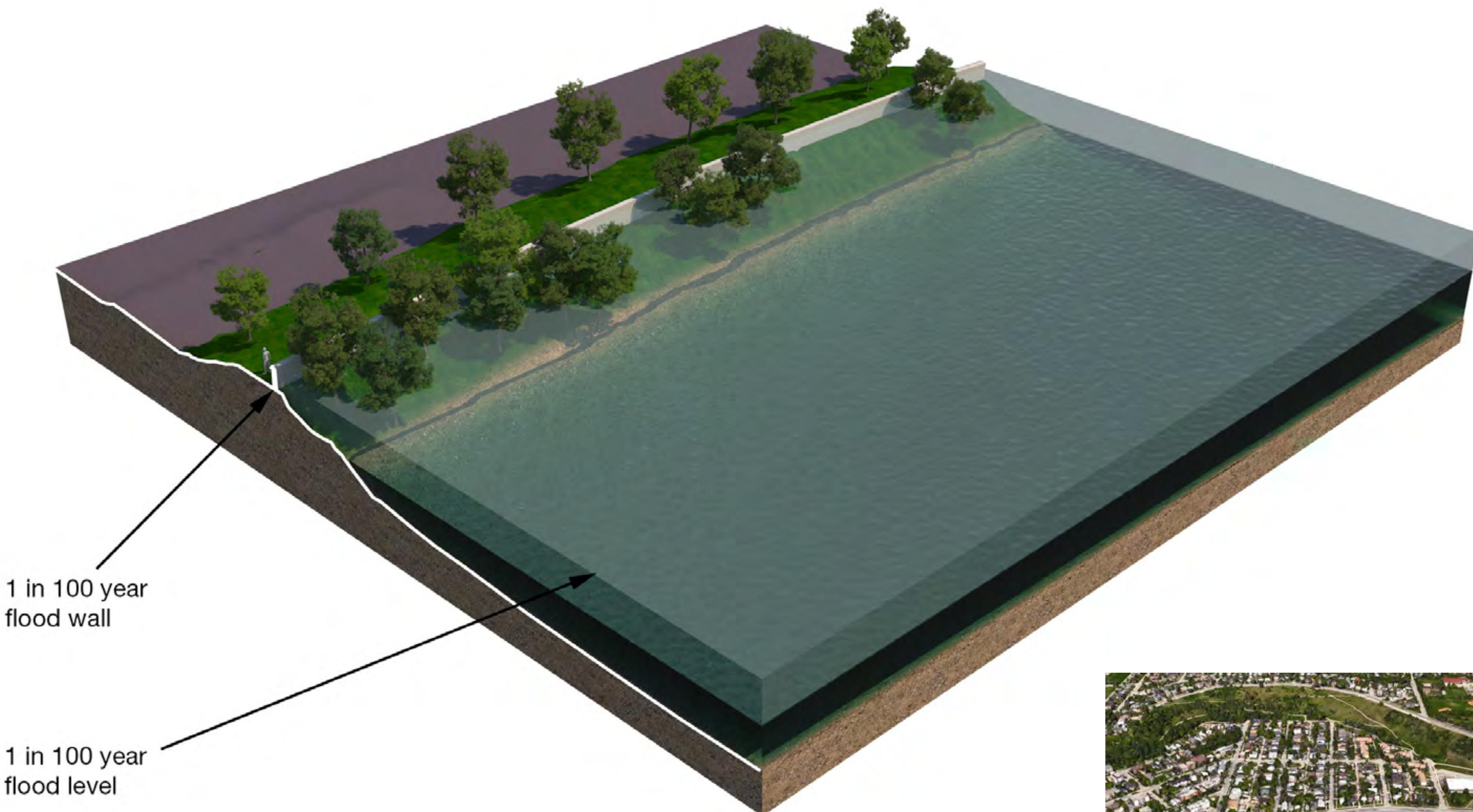


Source: O2 Planning + Design / City of Calgary

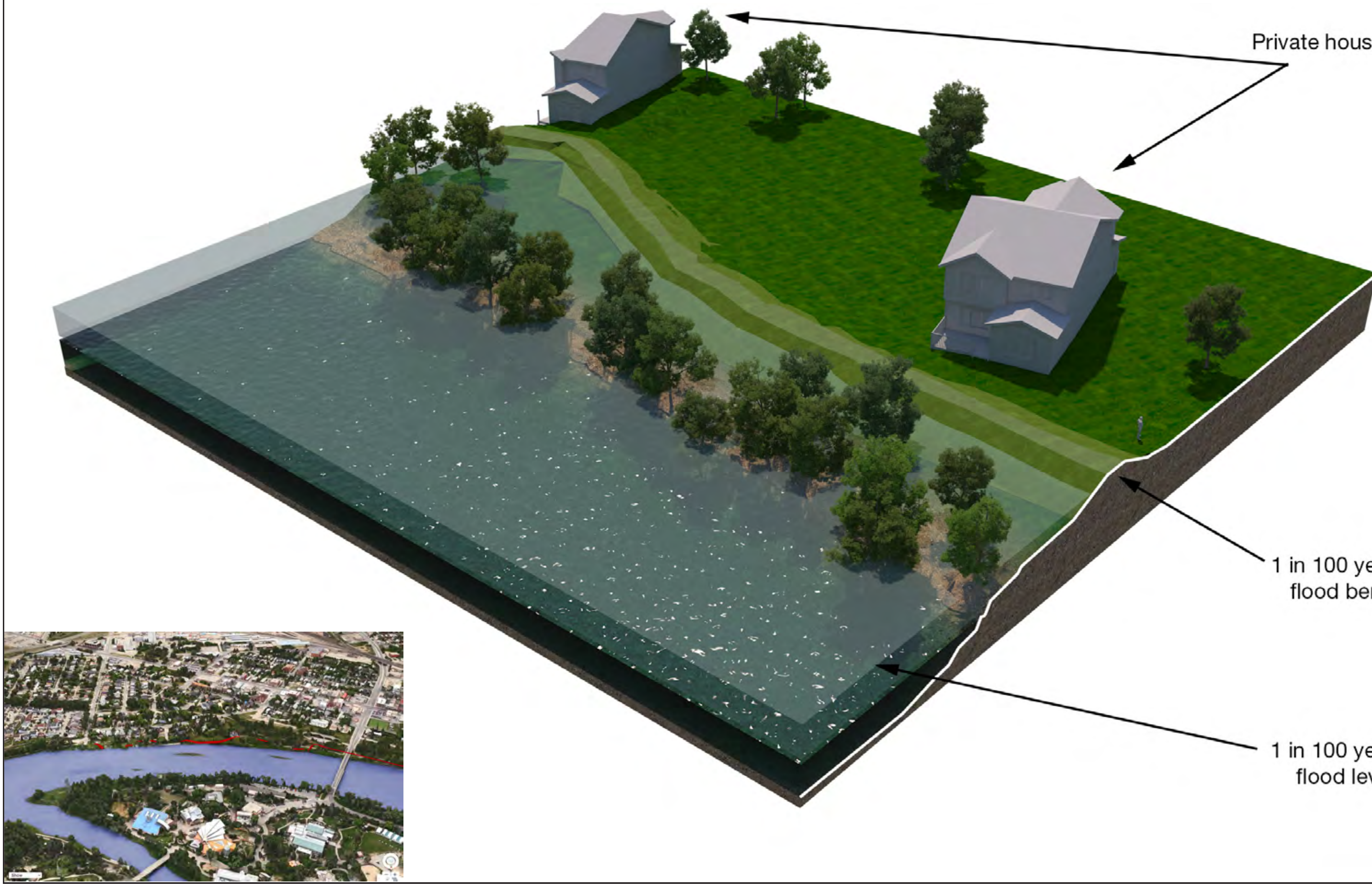
Barrier Illustration - Sunnyside - 20 Year



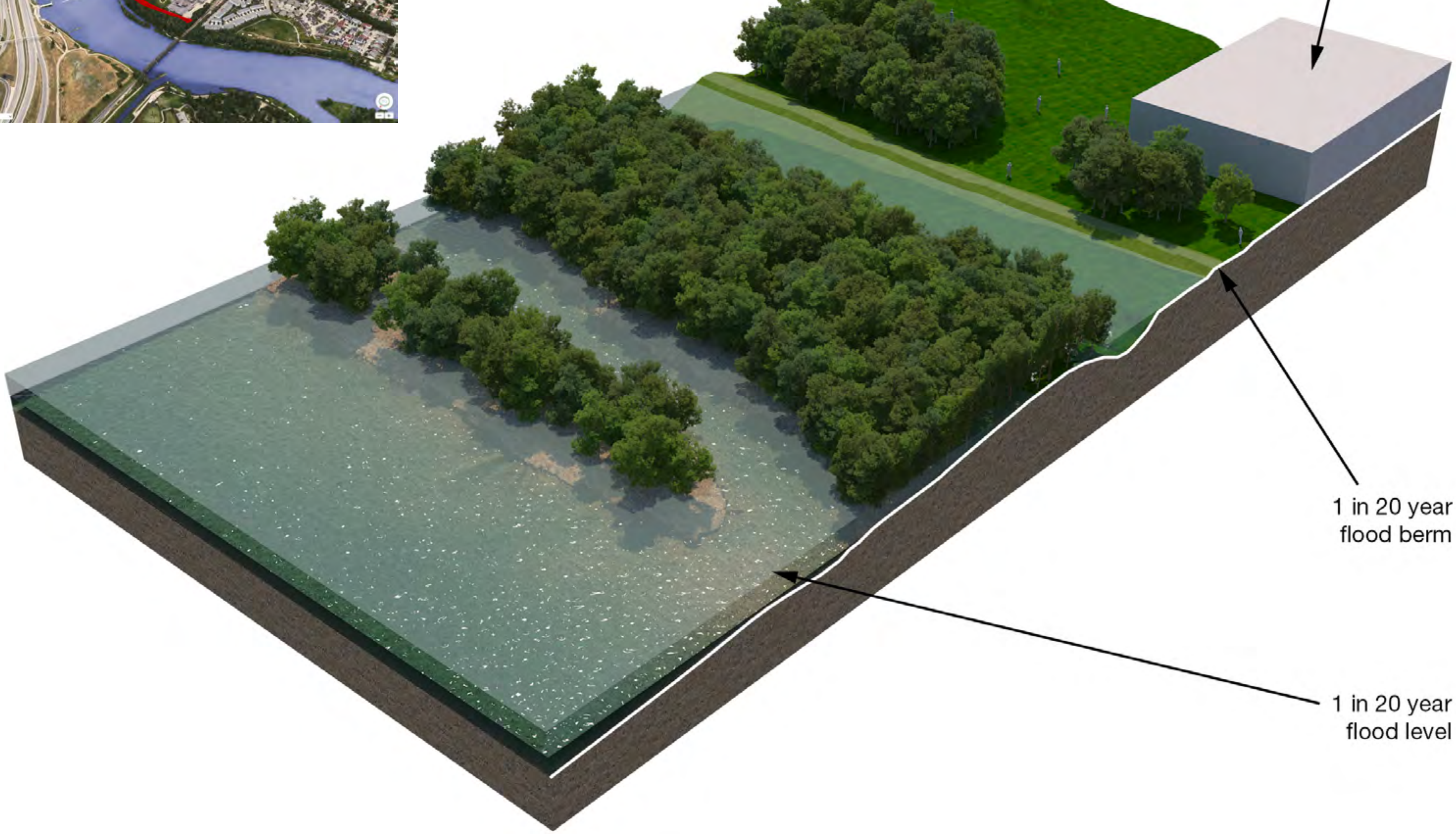
Barrier Illustration - Sunnyside - 100 Year



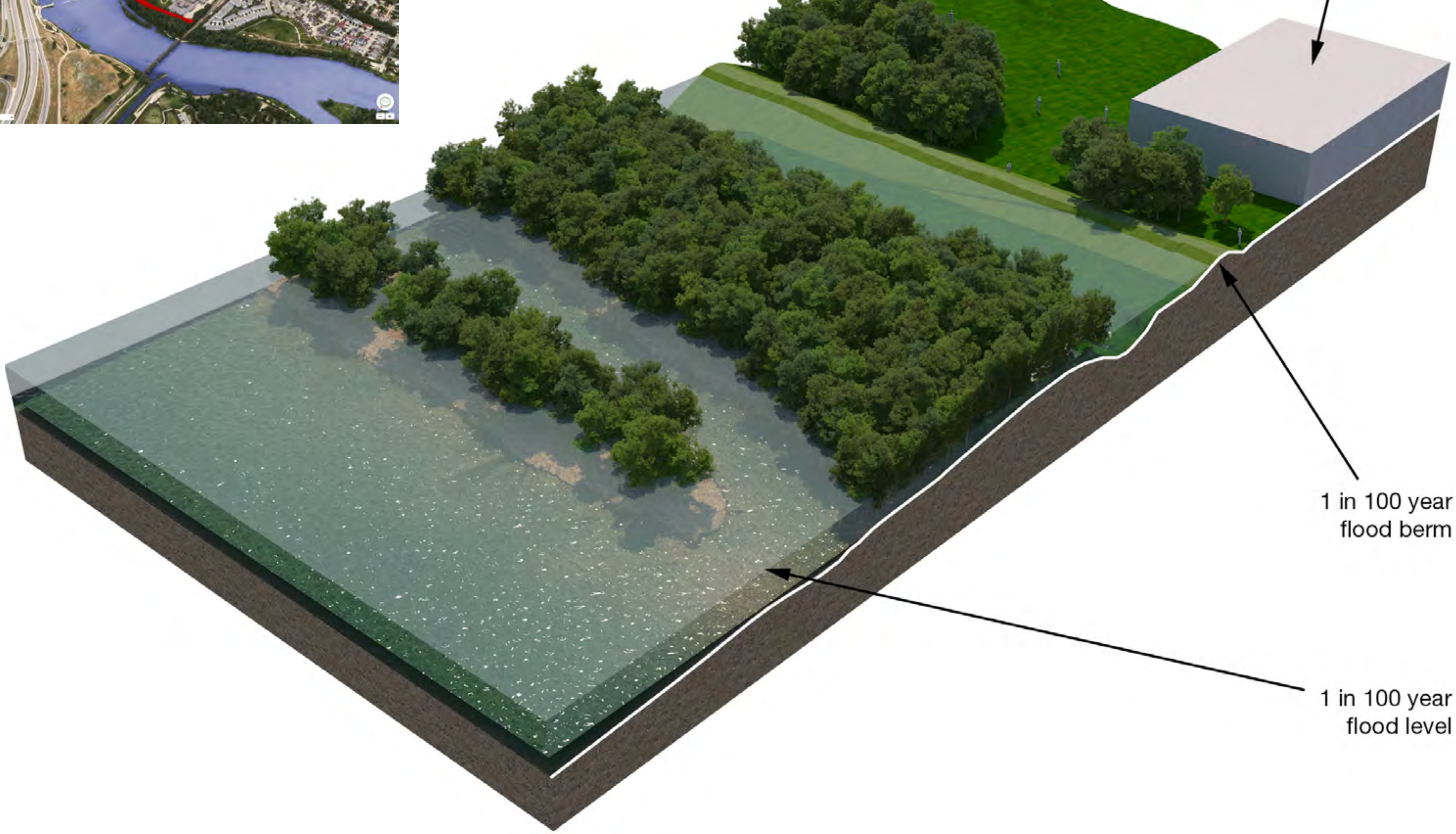
Barrier Illustration - Inglewood - 100 Year



Barrier Illustration - Fish Hatchery - 20 Year



Barrier Illustration - Fish Hatchery - 100 Year



Barriers for Scenarios 7 to 9

Structure	Community	Average Height	Max Height	Total Length	Buyouts
Scenario 7					
Bowness North	Bowness	1.5	3.3	1,500	Y
Bowness South	Bowness	1.5	3.2	2,000	Y
Sunnyside Op1	Hillhurst, West Hillhurst, Sunnyside	0.6	1.5	1,600	N
Fish Hatchery	Inglewood	1.1	1.4	800	N
Scenario 7a					
Bowness North	Bowness	1.5	3.3	1,500	Y
Bowness South	Bowness	1.5	3.2	2,000	Y
Sunnyside Op1	Hillhurst, West Hillhurst, Sunnyside	0.6	1.5	1,600	N
Fish Hatchery	Inglewood	1.1	1.4	800	N
Scenario 8					
Bowness North	Bowness	1.5	3.3	1,500	Y
Bowness South	Bowness	1.5	3.2	2,000	Y
Sunnyside Op1	Hillhurst, West Hillhurst, Sunnyside	0.6	1.5	1,600	N
Downtown - Raised Pathway	Eau Claire, Chinatown, Downtown East Village	1.1	2.3	2,600	Y
Fish Hatchery	Inglewood	1.1	1.4	800	N
Scenario 8a					
Bowness North	Bowness	1.5	3.3	1,500	Y
Bowness South	Bowness	1.5	3.2	2,000	Y
Sunnyside Op1	Hillhurst, West Hillhurst, Sunnyside	0.6	1.5	1,600	N
Downtown - Raised Pathway	Eau Claire, Chinatown, Downtown East Village	1.1	2.3	2,600	Y
Fish Hatchery	Inglewood	1.1	1.4	800	N
Scenario 9					
Bowness North	Bowness	1.9	3.9	1,700	Y
Bowness South	Bowness	1.6	3.3	2,200	Y
Sunnyside Op1	Hillhurst, West Hillhurst, Sunnyside	1.1	2.7	2,200	N
Downtown - Raised Pathway	Eau Claire, Chinatown, Downtown East Village	1.1	2.3	2,600	Y
Inglewood	Inglewood	0.7	2	1,300	N
Fish Hatchery	Inglewood	1.6	2.3	1,000	N


NO EXIT

SUMMARY AND RECOMMENDATIONS

5

5 Summary and Recommendations

5.1 Damage Estimates

Unmitigated flood damages within Calgary are significant, approaching $5.2 billion for the 1:200 flood year event, with average annual damages estimated at $168 million. Groundwater accounts for a large portion of flood damages, approximating 22% of the average annual damage amount.

The existing mitigation measures within the city provide considerable benefit compared to the unmitigated condition, particularly for more frequent flooding. Damages for the 1:200 year event are estimated at $4.7 billion and the average annual damages are $116.6 million. Benefits provided by all scenarios assessed area measured from this existing baseline amount.

5.2 Groundwater

Areas outside the surface flood inundation extents can be subjected to basement flooding due to sewer backup or groundwater seepage through basement cracks. Sewer backup can be caused by higher groundwater pressures and hydraulic connection with the fluid in the sanitary system where the sewer may be hydraulically connected with surface water. Therefore, potential groundwater flood damage can be influenced by both surface and groundwater flood levels.

The Bow and Elbow River channels in Calgary are underlain by a permeable alluvial aquifer. The groundwater levels in the alluvial aquifer may rise as the river levels rise during river floods.

Modelling of groundwater flood levels was conducted in this study to generate information to support groundwater flood damage modelling. In consideration of the overall characteristics of the alluvial aquifer, a simplified relationship of maximum groundwater level versus distance from the edge of surface inundation was developed for application throughout the study domain. This relationship was used to estimate or approximate the maximum groundwater table rise within the alluvial aquifer for the various flood return periods.

As it relates to the "adjacent-to" area, the area adjoining the flooded surface area in which basements may be flooded by backed up sanitary sewers, the modelled groundwater profiles were employed to determine basement damages from groundwater beyond the area of surface inundation. A further groundwater profile was modelled to take into account groundwater propagation beneath the barriers and to account for damage to basements due to groundwater flooding in these areas.

Finally, groundwater surfaces were also modelled for upstream options which would result in an extended duration of flood hydrographs within the channel as floodwaters were released from upstream reservoirs.

The groundwater profiles were estimated based on limited amounts of groundwater flow modelling, geological and groundwater level data, and groundwater damage data of actual flood events and it is the contention of the study consultants that groundwater damages are, in all likelihood, being conservatively estimated. Accordingly, it is felt that more work is required in this area as a means of accurately determining the groundwater profiles and potential impact, both during and after flood events. Recommended studies include additional efforts to refine the groundwater modelling approach and to collect additional field data to support the model refinement and calibration, as well as a comprehensive survey of floodplain residents to determine incidence of basement damage and current floodproofing practices including employment of sump pumps and backflow preventers.

5.3 Flood Mitigation Options

An array of flood mitigation options were considered for implementation as components of comprehensive mitigation scenarios. These included:

- new flood storage facilities along with updated operating rules to the existing hydro facilities and reservoirs in the Bow River Basin;
- permanent barriers along the Bow River;
- permanent barriers along the Elbow River;
- stormwater and drainage improvements;
- groundwater flood control measures at select locations;
- temporary flood barriers at various locations as part of the Emergency Response Plan;
- selective buy-out of flood-affected houses;
- flood insurance; and
- a variety of contingency measures along with modifications to the floodplain regulations and grant programs related to the installation of sump pumps and backflow preventers.

Thirteen flood mitigation scenarios were developed and evaluated, each with multiple individual components, some common to several. All were based on a 1:200 year design flood standard.

5.4 Triple Bottom Line Evaluation

Traditional economic analyses of flood mitigation alternatives have generally assumed a straightforward objective of maximizing the net benefits (total benefits minus total costs) that accrue to a project. Society however, has other goals besides economic efficiency. These goals or objectives are the results of outcomes that society desires and have more recently been described as Triple Bottom Line objectives, which include considerations of economic, environmental and social impacts. The purpose of Triple Bottom Line evaluation is to account for these various goals in the evaluation process. For the purposes of this study, the criteria, objectives and weightings were selected by assessing priorities identified by community engagement, Community Advisory Group, City subject matter expertise, the IBI Group draft evaluation criteria and the City's sustainability appraisal tool.

Criteria were subdivided into four basic categories:

1. Social Criteria: Community Wellbeing
2. Environmental Criteria
3. Scenario Implementation
4. Economic Criteria

The subsequent scoring of scenarios in relation to the established Triple Bottom Line criteria assisted in prioritizing key structural and non-structural investments and actions to increase flood resiliency. This approach also gave full voice to community input in terms of defining values and preferences with respect to flood mitigation options.

5.5 Evaluation of Flood Mitigation Scenarios

The baseline case involved the evaluation of existing improvements and modifications that were initiated after the 2013 flood. This includes historic dykes, new barriers and stormwater improvements. With these mitigation improvements in place there is a reduction of some $51 million in average annual damages from $168 million to $117 million.

In terms of the Triple Bottom Line scoring and ranking of the 13 scenarios, Scenario 7 achieved the highest overall score and was first-ranked. Scenario 7 involved the SR1 project along with one new Bow River upstream storage reservoir. It was supplemented with barriers at three locations on the Bow River as required to bring a uniform 1:200 year flood protection level. The combination of structures upstream of the City of Calgary scored very highly with respect to social and environmental criteria as it had the least impact on communities and river aesthetics and access within the City itself. It has the greatest ability to protect riparian health and species habitat within the City as well as providing water supply security by promoting efficient, sustainable water management and thereby allowing the region's water supply to meet the current and future needs of a growing city and region of users (municipalities and irrigation districts). From a purely economic standpoint it achieves a benefit/cost ratio of 1.41 with the highest benefits in terms of average annual damages averted at $90.6 million and the second lowest residual average annual damages at $26 million.

Scenario 7 maintains the first rank if the percent weight for the social or environmental criteria is doubled. Scenario 7 is ranked close second if the percent weight is doubled for the economic or implementation criteria, while Scenario 1 is ranked first. This shows that Scenario 7 is relatively robust as a favored or preferred scenario.

A further scenario was developed. It is referred to as 8a and is an illustration of Scenario 8 without the construction of the upstream reservoir on the Bow River. Essentially, this could be considered an interim scenario in consideration of the time it will take to design, gain approval and construct the Bow River reservoir component.

5.6 Recommendations

5.6.1 Non-Structural Options

5.6.1.1 Contingency Measures

Contingency measures are an essential part of the non-structural flood mitigation approach because they provide a flexible, low-cost option that is relatively fast and easy to implement, and is adaptable to local conditions. Many of the specific recommendations offered in Section 3.7 are centred on the formalization and implementation of a clear, effective, and up-to-date warning plan; keeping citizens safe and informed, particularly those in the flood hazard area; defining roles in the event of a flood; and creating connections and partnerships to enhance flood preparedness.

5.6.1.2 Land Use Regulations

Based on the principle outlined in the 2014 Floodway Development Regulation Discussion Paper that, "it is most effective to keep people and property away from the flood water, rather than attempting to keep the flood water away from the people and property", development in the floodplain should be limited as much as possible (Floodway Development Regulation Task Force, 2014). Through a combination of land use regulations and property level mitigation, over time the City of Calgary has the ability to drastically reduce the amount of basement damage due to flooding and related events. By implementing land use regulations that eliminate the development of below grade space, and requiring sump pumps and sewer backflow preventers, in addition to bylaws already in place, the City could reduce or eliminate basement damages in the flood hazard area over time.

5.6.1.3 Property Level Mitigation/Floodproofing

Property level flood mitigation practices encourage property owners to undertake floodproofing measures at an individual, property-level scale. They have shown to be cost-effective and also keep flood readiness front of mind.

In order to alleviate flooding and seepage in basements in the flood hazard area, it is recommended that The City of Calgary initiate a program to encourage the voluntary installation of sump pumps and backflow preventers for existing residents and businesses within the flood hazard area while making this requirement mandatory for significant renovation and redevelopment initiatives.

Other potential options for property level floodproofing include elevation of main floors, removal of basements and installation of seals and closures for commercial and larger buildings where appropriate.

5.6.1.4 Flood Insurance

Risk due to hazards such as flooding are best reduced using a combination of mitigation strategies, where the responsibility is spread among stakeholders. The viability of insurance as a flood mitigation risk is challenged by a lack of randomness and the mutuality of flood losses resulting in adverse selection. Providing flood insurance does not reduce flood damages, however, after applying other cost-effective measures, it may be an appropriate mechanism to help redistribute residual risks and, if implemented effectively, may discourage risky development in the floodplain.

Information from the industry suggests that the majority of homeowners at risk do not have flood coverage and that coverage decreases as risk increases due to the high cost. Insurers consider the estimated annual loss and add profit and expenses. As a new product, loading on flood insurance is relatively high with reports that the average amount is between 1.5 and 2 times the annual loss. Hypothetical insurance premiums were calculated based on these loading factors and annualized damages. The average annual full-coverage premium for all residential houses within the 1:1000 year risk area would be between $4,650 and $6,200 but vary greatly with risk. Within the 1:50 year risk area, it would average between $15,000 and $20,000.

For all possible insurance options, the required premium would be a perpetual cost. It would also likely be a perpetually increasing cost as the quantity and value of at-risk properties increases. Given the costs and level of uncertainty, insurance for high risk of flood damages is not a viable option for property owners. It may remain an option for individual purchase once the risk has been mitigated to an acceptable level through structural or regulatory options. In other words, insurance should not be relied upon to achieve the acceptable level of protection.

5.6.2 Structural Options

It is recommended that The City pursue implementation of Scenario 7 which entails water storage facilities along both the Bow and Elbow Rivers upstream of the city. Development of these facilities should include consideration of multi-functional aspects including recreation and water supply in addition to flood mitigation as a means of increasing the benefits of these facilities. Scenario 7 will benefit from the addition of groundwater control for the Sunnyside community.

In the absence of an upstream reservoir on the Bow River, Scenario 9 should be considered for implementation.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Appendices

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APPENDIX A:
SUMMARY OF JUNE 2013 FLOOD EMERGENCY RESPONSE AND INITIAL RECOVERY EFFORTS

SUMMARY OF JUNE 2013 FLOOD EMERGENCY RESPONSE AND INITIAL RECOVERY EFFORTS

This report summarizes The City of Calgary's emergency response and initial recovery efforts related to the June 2013 flood. The activities outlined occurred during the 14 days when The City's second-ever State of Local Emergency (SOLE) was declared, beginning June 20 and ending on July 4.

CALGARY EMERGENCY MANAGEMENT AGENCY

The Calgary Emergency Management Agency (CEMA) coordinated The City's response to the flood, overseeing the efforts of 29 Business Units, 12 external members, seven invited partners and approximately 7,000 City staff who assisted in emergency response and initial recovery activities.

Under the terms of the provincial Emergency Management Act (R.S.A. 2000 c E-6.8) and The City of Calgary Emergency Management Bylaw (#23M2008), CEMA is designated as the civic body responsible for the coordination of disaster planning, response and recovery within The City of Calgary. The City has designated the Fire Chief as the Director of CEMA.

The Alberta Emergency Management Act allows The City to procure assets and resources to prevent, combat or alleviate the effects of an emergency or disaster, restore essential facilities, distribute essential supplies, and provide, maintain and coordinate emergency medical, welfare and other essential services.

The Municipal Emergency Plan (MEP) is activated when an event requires coordinated, active management of multiple agencies or centralized decision-making to mitigate impact. It outlines policies, operations, and roles and responsibilities for the Corporation and CEMA members when the Municipal Emergency Plan is activated. The plan also identifies when and how a SOLE may be declared.

Through its Comprehensive Emergency Management Model, CEMA coordinates the efforts of its staff, City Business Units and external members and partners in the non-emergency and emergency phases of emergency management: risk assessment, mitigation, preparedness, response, recovery and rehabilitation. This model, refined in Calgary, has been adopted by the Conference Board of Canada for use by its Council on Emergency Management and has been incorporated into two ISO technical standards.

The phases of the model have been used to outline the key activities that took place in preparation for, and in response to, the June 2013 flood.

PHASE 1: RISK ASSESSMENT

Each year, CEMA produces a Corporate Hazard Identification and Risk Assessment (HIRA) that identifies the human-caused, natural, and technological hazards with the potential to impact The City of Calgary and its communities. By assessing the probability and impact of various events, the HIRA informs The City's mitigation activities, emergency response planning and business continuity planning.

The HIRA has identified flooding as a high probability and high impact risk for Calgary. In June 2005, the Bow River achieved a one in 20-year return peak flow rate and the Elbow River reached a one in 40-year return peak flow rate. In June 2013, the Bow River reached an approximate one in 100-year return peak flow rate while the Elbow River, upstream of the Glenmore Dam, achieved an approximate one in 500-year return peak flow rate.

Each June, regular snowmelt and rainfalls typically result in saturated ground throughout the watersheds. In June 2013, these saturated soil conditions were exacerbated by more than 200mm of rainfall in the Bow River watershed and close to 300mm in the Elbow River and High River watersheds between June 19 and 22. This rainfall contributed to rapid melting of a relatively high snow pack still in the watersheds, and the convergence of these three events resulted in the massive flooding that occurred in Calgary and throughout southern Alberta.

PHASE 2: MITIGATION

Each year, events identified in the HIRA as high probability and high impact inform the planning of CEMA and other City Business Units. As a result, Business Units have implemented various flood mitigation strategies over the years to reduce the impact of potential flood events on citizens, businesses and City infrastructure. Through astute reservoir management, the Elbow River water flows downstream of the Glenmore Reservoir were reduced from an approximate one in 500-year return peak flow rate to a flow equivalent to an approximate one in 100-year event. This helped mitigate damage to downstream communities and allowed time for their evacuations.

Following the 2005 flood, Calgary Disaster Services along with other Business Units developed 74 recommendations to improve The City's preparedness and response specific to flood events. With the support of Council, the majority of the recommendations, which spanned 10 Business Units, were completed by 2008 with a few continuing in implementation through the 2009-2011 business planning cycle.

During the 2013 flood, the actions resulting from those recommendations served to reduce flood damage to certain areas, improve the accuracy of evacuation planning and enhance emergency response and recovery coordination.

PHASE 3: PREPAREDNESS

Maintaining an ongoing state of preparedness

To ensure continuous improvement in The City's emergency management planning and response, a review of the MEP is completed after most activations of the plan. CEMA refines roles, responsibilities, coordination and communications outlined in the plan to ensure effective, timely management of future events.

CEMA uses an "all hazards" approach to managing incidents and maintains a number of key emergency response plans designed to provide key operational information during the initial stages of a variety of emergency scenarios, including flooding.

CEMA leads a range of training and mock disaster exercises throughout the year involving City Business Units and external members. Since the opening of the new Emergency Operations Centre (EOC) in October 2012, 312 agency members have received emergency management training and CEMA led two flood-related exercises in addition to exercises focused on other man-made and natural disasters.

CEMA also works within Calgary's communities to educate citizens on how to prepare for a variety of emergencies. The Household Emergency Action Plan provides direction on what individuals should do when they encounter particular emergency situations and what information and supplies they need to sustain themselves for 72 hours. The annual Disaster Alley event brings together CEMA and its agency members to provide demonstrations, educational sessions and materials to help citizens prepare for emergencies. The 2013 Disaster Alley event held at McMahon Stadium provided emergency preparedness information to 5,000 citizens.

Monitoring conditions prior to flooding
Each year, CEMA monitors dozens of potentially threatening severe weather events. Regular seasonal flood monitoring procedures were operating within The City of Calgary throughout the months of May and June in 2013, which involved both Water Services and CEMA. The Water Emergency Operations Centre (H2OC), which oversees issues that affect public health and safety with respect to water, wastewater and stormwater service, had been activated and de-activated as deemed necessary throughout the season.

On June 17, Environment Canada issued a weather advisory indicating 50mm to 75mm of rainfall was expected between June 19 and 21, with some areas of the foothills expected to receive 100mm. On June 19, Environment Canada adjusted their estimates to 100mm to 150mm of rainfall. On the same day, Transalta Utilities, which manages several dams upstream on the Bow River, provided water flow estimates of 235 to 292 cubic metres per second (CMS) from its Bearspaw dam.

Based on data from its extensive monitoring program, Water Services commenced lowering of water levels in the Glenmore Reservoir on the evening of June 16 to accommodate for rainfall in Calgary and the watersheds. The H20C was partially activated on June 19 based on the Environment Canada and Transalta Utilities estimates. Updated forecasts from Alberta Environment and Environment Canada indicated the potential for flooding within Calgary city limits early in the morning of June 20. In addition, upstream municipalities and communities began reporting emergency situations.

At 5:50AM on June 20, Environment Canada issued a flood watch for the Elbow River upstream of the Glenmore Dam. At 8:45AM, it issued a flood warning for the Bow and Elbow rivers. CEMA personnel staffed the Municipal Emergency Operations Centre (EOC) at 6:00AM and alerted Agency members to attend the EOC at 8:11AM, the MEP was activated at 8:28AM and a SOLE declared at 10:16AM.

The City was challenged with ensuring timely evacuations of communities due to rapid and significant changes in water flow estimates provided by Transalta Utilities. Over the course of 12 hours starting the morning of June 20, Transalta Utilities' water flow estimates for the Bow River increased from 400CMS to 1,700CMS. In several instances, there was very little time between notification and actual changes in flows, which placed additional pressure on resources, planning and evacuations.

Ultimately, 200mm of rain fell in the Bow River watershed and close to 300mm in the Elbow River watershed. During the peak of the flood, the Bow River reached 1,750CMS, an approximate one in 100-year return peak flow rate, and the Elbow River reached 1,240CMS above the Glenmore Dam, an approximate one in 500-year return peak flow rate.

Preparing for flooding

As the likelihood for widespread flooding became evident, CEMA activated the MEP at 8:28AM on June 20. This included the opening of the EOC from June 20 to July 7. The EOC is the central hub of an extensive network of communication and control centres that assist participating agencies with the management of large-scale emergencies and disasters. The EOC is opened when the emergency may have citywide impact or requires coordination of resources to assist on-scene commanders and ensure the rest of the city is adequately serviced and protected. Information from field staff, other levels of government, external agencies and the public regarding ongoing events is transmitted to and from the centre.

Table 1 lists the CEMA members and partners in attendance at the EOC to assist with emergency response and initial recovery efforts during the 2013 flood.

Table 1: CEMA Members and Partners at EOC During 2013 Flood

City Business Units		External Members	Invited Partners
• City Auditor's Office	• City Clerk's Office	• Alberta Emergency Management Agency	• Building Owners and Managers Association
• Development & Building Approvals	• City Manager's Office	• Alberta Health Services	• Calgary Search and Rescue
• Law	• Assessment	• Alberta Health Services -EMS	• Canadian Red Cross
• Land Use Policy & Planning	• Transportation Infrastructure	• Alberta Environment and Water	• The Salvation Army
• Roads	• Calgary Transit	• ATCO	• Calgary Airport Authority
• Transportation Planning	• Waste & Recycling Services	• Telus	• Canadian Pacific Railway
• Water Resources	• Water Services	• Calgary Catholic School District	• Department of National Defence
• Environmental & Safety Management	• Community & Neighbourhood Services	• Calgary Stampede	• Shaw Cable
• Recreation	• Parks	• Calgary Zoo	• Transalta Utilities
• Calgary Fire Department	• Animal & Bylaw Services	• Calgary Board of Education	
• Office of Land Serving & Housing	• Human Resources	• Greater Southern Separate Catholic Francophone Education Region	
• Information Technology	• Infrastructure & Information Services	• Greater Southern Public Francophone Education Region	
• Corporate Properties & Buildings	• Fleet Services	• Energy Resource Conservation Board	
• Customer Service & Communications	• Finance & Supply	• ENMAX	
• Calgary Police Service		• Environment Canada	

Due to the potential widespread impact and magnitude of the flooding, a State of Local Emergency (SOLE) was declared at 10:16AM on 2013 June 20. During a SOLE, The Director of

CEMA can allocate funds as necessary to ensure appropriate, timely response and recovery efforts, conscript resources as required and assign additional authorities to emergency response personnel.

As water flow estimates provided by Transalta Utlities continued to increase, CEMA relied upon inundation maps in the Flood Emergency Reference Manual to identify communities that may be impacted. These maps proved to be extremely accurate and a vital resource for mitigation and evacuation planning. CEMA was challenged to quickly produce mapping in the EOC that identified specific evacuation zones that could easily be shared with field staff conducting the evacuations. As indicated by the Flood Emergency Reference Manual, 16 temporary berms were constructed throughout the city to help protect communities and infrastructure. Sandbags and flood tubes were also used in areas throughout the city to help divert water from homes and businesses. Efforts were reprioritized as water flow updates were received from Transalta Utilities.

PHASE 4: RESPONSE

Ensuring public safety
In addition to the municipal EOC, other tactical operations centres activated over the course of the event to direct the efforts of their field staff, serve as a central point for collection of information relevant to their individual operations and provide information to the EOC. In addition to the H2OC, the Police Tactical Operations Centre, Fire Department Tactical Operations Centre, Enmax Electrical Event Command Centre and Roads Operations Centre all activated to provide support to the EOC.

Community evacuations took place throughout the day on June 20. As communities were identified for evacuation and maps prepared, CEMA utilized uniformed staff from Business Units, including police officers and firefighters, and external members to go door-to-door in many communities to notify residents to evacuate. These efforts were supported by broad-based communications efforts, including press releases and posting of information on the City web site and social media. Through authority granted by the Alberta Emergency Management Agency, CEMA used the Alberta Emergency Alert System in Calgary to interrupt local media broadcasts and alert Calgarians to the need to evacuate along the rivers.

Within 24 hours of the evacuation notice, the Calgary Fire Department performed more than 400 rescues of citizens who could no longer safely escape their home and initiated shelter-in-place directives for others who could not be removed.

As evacuations began, plans were developed in the EOC for Enmax to conduct staged de-energizing of communities to ensure public safety throughout the flooding. At the height of the flood, 39,837 metred customers and five LRT stations were affected.

Over 800 kilometres of roadways were closed during the flood, including 20 bridges across the city. In addition, 93 kilometres of pathways and 30 parks were closed. Transit modified routes in flood-affected areas as the event progressed and roads and bridges were closed. Most city schools, with the exception of some high schools in non-flood areas that were holding diploma exams, were closed from June 21 to June 26 to ensure the safety of students and staff.

Approximately 160 firefighters from Edmonton were brought in to supplement Calgary's response to the flood and to allow the Calgary Fire Department to maintain adequate fire and rescue response coverage across all parts of the city, including those unaffected by the floods.

The Canadian military arrived on June 21 to assist with river bank stabilization and sandbagging efforts. Canada Task Force 1 (Vancouver) and Canada Task Force 2 (Calgary), nationally recognized urban search and rescue teams of over 60 persons each, assisted with performing wide-area searches, pumping water from facilities and homes and conducting rapid damage assessments.

CEMA and its agency members managed the full or partial evacuation of 32 communities, representing approximately 80,000 citizens[1], within a 15-hour period. Citizens were safely evacuated or provided shelter-in-place instructions with one fatality reported as a result of flood. By comparison, during the 2005 flood, 1,500 citizens were evacuated.

Over the course of EOC operations, CEMA also helped coordinate response to several additional significant public safety events that would have resulted in the EOC opening on their own, including a gas leak in an Inglewood condominium complex, a CP Rail train derailment on the Bonnybrook Bridge, Canada Day events and the Stampede Parade.

Protecting critical infrastructure and Calgary's water

During the flood, City staff and members of Canada Task Force 2 helped pump water and deploy sandbags to prevent water from entering key Telus sites and Enmax vaults in order to protect critical telecommunications and electrical systems. These efforts were essential in ensuring emergency facilities could continue to operate and 9-1-1 services remained available.

As a result of the proactive de-energization of electrical substations in advance of flood waters reaching them, significant damage was avoided. This prevented the long-term loss of these substations as well as electrical equipment in flood-affected buildings.

Calgary Transit evacuated 350 buses from its Victoria Park garage in advance of floodwaters reaching the building. The loss of those vehicles would have impacted Transit services and potentially resulted in the need for replacement of these buses.

Finally, as a result of measures undertaken since the 2005 flood, Water Services was able to protect and maintain Calgary's drinking water supply throughout the 2013 flood. Water use restrictions were put in place to help ensure demand did not exceed system capacities.

Maintaining core services to citizens

ENMAX redirected substation services in flood-affected areas to other substations to allow as many citizens as possible in non-flood zones to remain with power and support critical infrastructure.

Transit services in non-flood affected areas ran as usual with no cancelled routes in these areas. Transit services in flood-affected areas were detoured, altered and cancelled as evacuation zones increased, and route information was constantly updated through the Transit web site and Twitter feeds.

Some non-essential City services were placed on hold during the floods to allow City staff to respond effectively to the emergency situation. Due to the elevated public safety and animal-sheltering role taken on by Animal & Bylaw Services, the intake of citizen complaints was temporarily suspended during the peak of the flood, except for those that posed an immediate danger to the public. The City's blue cart recycling program was suspended for almost two

[1] As of 2013 October 2 (Source: CEMA)

weeks due to the re-prioritization of workforce and equipment that normally provides this service. Regular garbage collection was not affected by this disaster, other than those areas that became inaccessible due to the flood.

Preserving essential communications
Throughout the flood, The City's 9-1-1 telephone lines remained available to allow citizens to access emergency assistance. In preparation for expected higher call volumes due to flooding, Public Safety Communications temporarily increased staffing levels by 25 per cent. Call volumes increased upwards of 85 per cent over the first two days of the flood, and remained about 35 per cent higher for the six following days. Due to flooding of a neighbouring emergency call centre, 9-1-1 calls from the Foothills Regional Emergency Services Commission were also redirected to Public Safety Communications for a period of time during the flood.

The City's 3-1-1 service served as a critical source of help for the public. Due to flood waters entering the Municipal Building on June 20, The City's 268 exchange phone lines were damaged leaving all of these numbers unavailable, including the 3-1-1 line. 3-1-1 service was down for less than an hour until the back-up system was implemented, which provided access to 12 lines. The following day, 3-1-1 had 48 lines operational with reduced functionality. 3-1-1 handled an estimated 100,000 calls in the first two weeks of the flood including almost 13,000 flood-related service requests, such as calls for assistance with water pumping, property damage assessments and sewage backup.

As a result of the 2005 floods, plans were developed to move The City's servers and key technology infrastructure from the basement of the Municipal Building to the municipal EOC to ensure continuity of operations in the event of future disasters. Much of this work had been completed prior to the 2013 flood.

During the 2013 flood, The City's web site became the hub of flood-related information, logging over 1.1 million site visits. Issues with the network infrastructure resulted in the site crashing the afternoon of June 20. Information Technology, which tripled its on-call staff to assist the EOC and the other tactical operations centres, worked quickly to redirect citizens to The City's blog.

Over 140 media releases were issued and the Director of CEMA, His Worship Mayor Nenshi and other Business Unit and external member representatives held regular media briefings. Information was also shared through social media outlets to ensure citizens remained up to date on developments.

PHASE 5 AND 6: RECOVERY AND REHABILITATION

The original SOLE expired on June 27. Due to the magnitude and ongoing impacts of the flood event, the Director of CEMA requested and received an extension to the SOLE. This allowed The City to continue to provide immediate access to resources and an expedited approval process to assist affected citizens, businesses and critical infrastructure. Through the SOLE, the Director of CEMA worked in close concert with the City Manager and His Worship Mayor Nenshi to collaboratively identify areas of resource need and expenditures.

The SOLE was lifted on July 4, 14 days after it was originally declared. During the SOLE, EOC recovery efforts maintained the same level of intensity and resources as in the response in order to expedite Calgarians returning to their residences and businesses and the restoration of City Services.

The CEMA Emergency Social Services (ESS) program is a planned emergency response program intended to meet the immediate physical and psychological needs of individuals impacted by emergencies or disasters. CEMA ESS plays a significant role in initial recovery efforts and is specifically intended to assist citizens displaced by emergencies or disasters by facilitating access to temporary lodging and other necessary social services.

Establishing reception centres for evacuees

Hours before evacuations commenced, CEMA ESS had fully mobilized and started formulating plans for how to assist displaced citizens. Five reception centres opened within about 12 hours of the declaration of SOLE. As the number of evacuation zones increased, so did the number of reception centres with a total of nine centres and four dormitories being opened by June 21. In one of the shelters, Shaw provided large screen televisions and free Wi-Fi service to allow evacuees access to information regarding the flood, community re-openings and recovery efforts.

Additional City staff from a range of Business Units were used to help staff the centres, which provided much-needed manpower, however required a significant amount of just-in-time training to ensure these staff had the knowledge and information required. There were approximately 3,800 citizens registered into the CEMA ESS system, with shelter for 2,800 people and 68,000 meals provided.[2]

CEMA ESS worked with Alberta Health Services to ensure medical care was provided to evacuees as needed, and also coordinated with other external members to ensure the other physical and emotional needs of citizens at the centres were met. CEMA ESS worked with Community & Neighbourhood Services to develop a Housing Cohort plan after the first few days of initial emergency sheltering to better manage the differing needs of evacuees. This allowed for further medical assessment and support, identification of appropriate housing environments, consolidation and alignment of resources and provision of information and transportation when evacuees were able to return to their homes. CEMA ESS continued to support evacuees until July 10 when responsibility for evacuees was transferred to Community & Neighbourhood Services, which managed the Interim Housing program.

Assisting vulnerable populations

The City assisted ten non-profit agencies and seniors' residences with evacuating and finding accommodations for their program participants. These non-profit agencies, located in the downtown core, East Village and Bowness, assist individuals struggling with poverty, homelessness and addiction. While some of these agencies had well developed emergency response plans to guide their actions during a disaster, others did not, which placed a larger burden on the ESS system to ensure these individuals were sufficiently supported.

Transit dispatched buses to transport the large groups needing to leave these facilities as well as 144 Access Calgary vehicles to transport over 500 people in wheelchairs in flood-affected areas to safe facilities. Transit staff also assisted with the safe loading and unloading of seniors at care centres.

CEMA ESS worked with reception centre staff and external partners to identify appropriate, accessible facilities that could house these individuals. Additional medical and emotional support services were coordinated and provided as necessary to ensure the continued health and safety of these citizens.

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[2] As of 2013 October 16 (Source: CEMA)

Providing support and relief to impacted citizens
Intensive recovery efforts to return citizens to their homes and businesses occurred in parallel with emergency response activities.

CEMA coordinated a staged re-entry of citizens back into their communities as floodwaters receded and areas were deemed safe. Nine Community Support Centres were established in flood-impacted communities to provide returning residents with information on how to assess if their property was safe for re-entry. The Centres provided locations for residents and volunteers to meet with members from the Calgary Fire Department, Development and Building Approvals, Calgary Police Service, Alberta Health Services, Enmax and ATCO. Residents could also request additional assistance in performing assessments from teams of Enmax, ATCO, City and Fire inspectors. Additionally, the Centres acted as logistics centres providing bottled water, gloves, masks, flood restoration documents and other equipment and materials to assist with re-entry. Schools and other community facilities were used as designated areas for food distribution, provincial debit card distribution and volunteer muster points.

Re-energizing of communities began just after noon on June 21 as areas were assessed safe for resumption of electrical service. Within nine days of the declaration of the SOLE, the citywide electrical grid was restored and all communities were re-opened for residents to access and assess their properties.

Initial recovery efforts focused on remediating homes by removing water and waste as quickly as possible. Members of Canada Task Force 1 and 2 pumped water from homes and within six days of the SOLE declaration, 95 per cent of residential pumping requests were completed.

Schools and other community facilities were designated as drop-off points for flood-related debris. In addition, Waste & Recycling Services, supported by a number of independent local businesses, reallocated resources and schedules to remove garbage and waste from flood-affected areas. Landfill hours were extended and landfill tipping fees were waived for commercial and residential customers clearing flood-related debris. In total, over 98,000 tonnes of flood-related waste were removed from Calgary communities.

Additional efforts were made to provide relief to citizens impacted by floods. The City offered free day camps were provided to families affected by floods with over 200 children participating. In addition, on-street parking bans were lifted for non-flood areas to accommodate the use of trailers and recreational vehicles to temporarily house flood victims.

Mobilizing community volunteers
On June 24, there was a volunteer drive at McMahon Stadium to assist those impacted by the flood. Six hundred volunteers were needed to assist with clean up in several communities, and 6,000 people showed up to offer their help. Over the following days and weeks, volunteers were directed to Community Support Centres where they were provided information on the exact streets and homes requiring assistance. These Community Support Centres registered more than 3,100 volunteers and received over 3,000 requests for help and supplies.

Supporting the timely, safe resumption of businesses
To allow for emergency response and initial recovery efforts to take place, City businesses located downtown were encouraged to allow employees to work from home during the initial days of the flood. A phased reopening of downtown began on June 24 as The City worked in concert with Enmax to coordinate a staged reenergizing of the downtown core. Within eight days of the SOLE declaration, the core's electrical grid was fully restored.

Within six days of the SOLE declaration, 100 per cent of all roads in the core were swept clean. Within eight days, following the completion of residential pumping requests, The City increased its water-pumping services for businesses. In addition, teams of inspectors, comprised of ATCO gas representatives, Enmax representatives, gas and plumbing inspectors, building inspectors, fire inspectors and health inspectors, were deployed to assess businesses for re-entry. Within nine days, 300 metres of new road was laid on Macleod Trail beside the Stampede Grounds and it was re-opened to support downtown commuters.

Of the approximately 18,000 homes and businesses assessed by inspection teams, 29 remain structurally compromised[3]. Of the 4,000 businesses directly affected by the flood, just 25 remain closed with only 12 not expected to reopen[4].

Assessing and repairing key City infrastructure

Within six days of the SOLE declaration, 85 per cent of roads in flood areas were re-opened and 100 per cent of downtown roads were swept clean. Within two weeks, all vehicular bridges in the city had been inspected and re-opened.

To support the quick resumption of LRT service, over 34 million litres of water were removed from the CP, Cemetery Hill and 42nd Avenue tunnels, two tunnels were repaired and 100 metres of new track were fully rebuilt by the Erlton station within 13 days of the SOLE declaration.

Within two weeks of the SOLE declaration, 94 per cent of pathways, 83 per cent of downtown parks and 53 per cent of parks in flood-affected areas were also re-opened.

During the flood event, the Bonnybrook Wastewater Treatment Plant was completely inundated, resulting in significant damage to equipment. Recovery and repair efforts were initiated by Water Resources and Water Services during the SOLE as soon as water levels receeded. By the middle of July, the Bonnybrook WWTP was operating within regulatory compliance requirements.

The flood affected 48 per cent of workspaces managed by Corporate Properties and Buildings, including five administrative buildings and four fire stations located in and around the downtown area. Damage assessments of City buildings were started within 48 hours of the SOLE to allow remediation and repair work to begin immediately.

Seven public facilities were impacted by the flood, including fitness and aquatic centres, pools and golf courses. Six reopened within four days of the SOLE declaration.

Maintaining City operations vital to residents and businesses

CEMA was in the process of working with City Business Units to establish more formal and consistent Corporate-wide business continuity plans prior to the flood. Many Business Units were able to quickly and seamlessly adapt their operations to the loss of personnel and workspaces, however more work is required to ensure similar results in all Business Units and apply lessons learned from the flood. Moving forward, CEMA has identified an opportunity to engage Business Units to develop comprehensive business continuity plans that align with other Business Units using the same guidelines and templates.

[3] As of 2013 October 3 (Source: CEMA)
[4] As of 2013 September 19 (Source: CEMA)

Human Resources and Corporate Properties took the lead in staff reassignment and relocation planning during the flood to identify skill sets that could be utilized elsewhere and workspace alternatives for City staff displaced from flood-affected buildings. Staff were assigned to other buildings or worked from home to ensure City business could resume as quickly as possible. Within 15 days of the SOLE declaration, 95 per cent of City sites were connected to the network and phone service.

As a result of the Municipal Building being flooded, temporary service centres were opened in each quadrant of the city beginning June 25 to allow citizens to pay property taxes, which were due during the flood, and receive help with permit applications. Intensive efforts were made to repair the damage caused to the Municipal Building to allow staff to safely return as soon as quickly as possible.

All recreation facilities were closed for two days at the height of the flood as staff were reassigned to assist at reception centres. By June 23, four aquatic and fitness centres were reopened to provide recreational opportunities for Calgarians. Within four days of the SOLE declaration, all remaining facilities were re-opened, with the exception of one damaged aquatic and fitness centre, one athletic park and the two facilities still in use as reception centres.

Outside of flood-affected areas, bus schedules remained as usual with no change to schedules. In flood-affected areas, some routes were detoured or cancelled to ensure safety of citizens and staff. Within eight days of the SOLE declaration, Transit had all bus routes back in service, and within 13 days all LRT service was restored. Restoration of LRT service was considered a major milestone considering the section of track that had to be fully reconstructed, the number of flooded underground tunnels and the amount of flood debris in affected areas.

To ensure citizens could continue to have access to safe drinking water, water use restrictions were put in place for City, business and residences between June 22 and 29 to reduce the burden on water treatment plants.

Fostering community spirit and pride
In support of the reopening of Calgary to residents and visitors, Canada Day activities and fireworks took place just 11 days after the SOLE declaration. Due to flood damage in Prince's Island Park, this event, which also marked the re-opening of the city's core, took place at other designated event locations throughout the downtown.

City staff and external partners worked diligently to ensure roads, LRT stations and bus routes were reopened to support the start of the 2013 Stampede on July 5. Fifteen days after the SOLE declaration, the Stampede kicked off with its annual parade through downtown. The parade route as well as Stampede events and schedules were modified to accommodate for facilities unavailable due to flooding.

Establishing continuity in Calgary's recovery
While emergency response and initial recovery efforts prevented and mitigated damages to some of Calgary's critical infrastructure and communities, hundreds of residents are still dealing with the impact of damages to their homes and businesses. The City continues to oversee the rebuilding of roadways, pathways, parks, facilities and amenities.

The focus of this report is on the emergency response and initial recovery efforts that occurred during the 14 days of the SOLE declaration. On June 22, the Recovery Operations Centre Steering Committee, consisting of members of The City's Administrative Leadership Team, was established to begin planning for Calgary's long-term recovery. The Recovery Operations Centre Steering Committee created the Flood Recovery Task Force to oversee the long-term community restoration, rehabilitation and resiliency of the city. The Recovery Director will provide all further reporting of recovery efforts to Council.

The Municipal Emergency Plan remains activated as of 2013 October 30 to allow the Recovery Operations Centre Steering Committee to maintain its structure in leading recovery and restoration efforts for The City.

NEXT STEPS

CEMA has undertaken efforts to evaluate The City's response to the June flood to ensure all opportunities to improve preparedness, mitigation, response and recovery in future disaster events are considered.

CEMA conducted an internal review of its response and initial recovery efforts from an emergency management perspective and has identified opportunities for improvement. CEMA also led a Corporate-wide debrief where all Business Units and Agency members were invited to identify strengths, challenges and opportunities for improvement in the City's coordinated response. In addition, CEMA has retained the Conference Board of Canada to conduct an independent assessment of its emergency management and response efforts as they relate to best practice. The Conference Board has started its work and will have the report completed in the second quarter of 2014.

The Conference Board of Canada findings, along with those from the Corporate and CEMA debriefs, will be presented to Council, including recommendations that may have budget implications, no later than June, 2014. The recommendations and direction from Council will guide future disaster planning and emergency management objectives for The City. The Recovery Operations Centre Task Force will be continuing working for some time and are reporting to Council on restoration efforts separately.

2013 JUNE FLOOD EMERGENCY RESPONSE AND INITIAL RECOVERY EFFORTS

EXECUTIVE SUMMARY

This report summarizes The City of Calgary's emergency response and initial recovery efforts related to the 2013 June flood. The activities outlined occurred during the 14 days when The City's second-ever State of Local Emergency (SOLE) was declared, beginning 2013 June 20 and ending on 2013 July 4.

The Calgary Emergency Management Agency (CEMA) and its agency members managed the full or partial evacuation of 32 communities, representing approximately 80,000 citizens within a 15-hour period. Citizens were safely evacuated or provided shelter-in-place instructions with one fatality reported as a result of flood. At the height of the flood, nine reception centres and four dormitories were opened. These centres registered approximately 3,800 citizens, sheltered 2,800 people and provided 68,000 meals.

Intensive recovery and business continuity efforts were started in parallel with emergency response activities. Following the initial recovery efforts that took place under the SOLE, the Flood Recovery Task Force, which reports to the Recovery Operations Centre Steering Committee, assumed responsibility for longer term community restoration and rehabilitation in the city. The Recovery Director will provide further reporting of recovery efforts to Council.

Following the flood, CEMA conducted both Corporate-wide and CEMA team debriefs. While the emergency response and early recovery efforts demonstrated the strength of CEMA's Comprehensive Emergency Management Model and supporting emergency response plans, these debriefs provided an opportunity to identify successes to leverage in the future as well as areas for improvement. One such opportunity includes the development of a Corporate Business Continuity policy to capitalize on momentum and provide a consistent approach to corporate business continuity planning and resiliency that recognizes interdependencies and areas for efficiencies. CEMA has also retained the Conference Board of Canada to conduct an independent assessment of The City's emergency management of the flood. This report will be completed in the second quarter of 2014.

ADMINISTRATION RECOMMENDATION(S)

That the Emergency Management Committee recommend that Council:

1. Receive this report for information; and

2. Direct Administration to report back to Council, through the Emergency Management Committee, with results from 2013 flood debriefs conducted by Administration, as well as the results of the Conference Board of Canada assessment, no later than 2014 June.

RECOMMENDATION OF THE EMERGENCY MANAGEMENT COMMITTEE, DATED 2013 DECEMBER 06:

That the Administration Recommendation contained in Report EMC2013-0822, be approved.

2013 JUNE FLOOD EMERGENCY RESPONSE AND INITIAL RECOVERY EFFORTS

PREVIOUS COUNCIL DIRECTION / POLICY

On 2006 February 13, Council approved report DS2006-04, "2005 Flood Policy and Procedures Changes Report" which included 74 recommendations to enhance emergency management within the city of Calgary. All of the recommendations were adopted.

On 2013 July 2, the Priorities and Finance Committee approved report PFC2013-0578, "Flood Status Update" which provided initial cost estimates for The City's emergency flood response.

On 2013 September 16, Council approved report PFC2013-0646, "2013 Flood Recovery Task Force Update Report" which outlined the framework for long-term community recovery across the city.

BACKGROUND

In 2013 June, Calgary experienced the largest flood in recent history. The Bow River reached an approximate one in 100-year return peak flow rate while the Elbow River, upstream of the Glenmore Dam, reached an approximate one in 500-year return peak flow rate. Storage in the Glenmore Reservoir mitigated downstream flow on the Elbow River to a one in 100-year return-peak flow rate. Overland flooding affected residential homes, businesses, electrical facilities and City infrastructure. CEMA coordinated The City's overall response to the floods from the municipal Emergency Operations Centre (EOC), overseeing the efforts of 29 Business Units, 12 external members, seven invited partners and approximately 7,000 City staff that assisted in emergency response and initial recovery activities (Attachment 1 provides a detailed summary of key emergency response and recovery activities).

The health and safety of Calgarians remained safeguarded as a result of The City's coordinated response, CEMA's Comprehensive Emergency Management Model, mitigation efforts undertaken following the 2005 flood and the collaborative efforts demonstrated by citizens and businesses within Calgary. Throughout the flood, Calgary's drinking water remained safe for consumption and The City's 9-1-1 telephone lines remained available to allow citizens to access emergency services. In addition, Calgary's emergency services and CEMA members managed and responded to several additional significant emergency events during the SOLE that would have normally merited an activation of the EOC on their own.

In the EOC, recovery efforts were started in parallel with emergency response activities and concentrated resources to support the resumption of normal day-to-day activities for citizens and businesses as quickly as possible. Within four days, citizens from 26 of the 32 full or partially evacuated communities, which represented approximately 50,000 people, were permitted to return to their homes to assess damages and begin clean up. Within six days, 95 per cent of residential pumping requests were completed, 85 per cent of roads in flood areas re-opened and 100 per cent of downtown roads were swept clean. Within nine days, all communities were provided re-entry, the city-wide electrical grid was restored and 300 metres of damaged road were rebuilt along Macleod Trail. Within thirteen days, millions of gallons of water were removed from LRT tunnels and 100 metres of new LRT track were laid beside the Stampede Grounds.

Of the approximately 18,000 homes and businesses assessed by inspection teams, 29 remain structurally compromised (as of 2013 October 3). Of the 4,000 businesses directly affected by the flood, 25 remain closed with 12 not expected to reopen (as of 2013 September 19).

INVESTIGATION: ALTERNATIVES AND ANALYSIS

CEMA has undertaken efforts to evaluate The City's response to the June flood to ensure all opportunities to improve preparedness, mitigation, response and recovery in future disaster events are considered.

CEMA and Corporate Debriefs

CEMA conducted an internal review of its response and initial recovery efforts from an emergency management perspective and has identified areas of strength and opportunities for improvement. On 2013 September 19, CEMA held a Corporate-wide debrief of the flood response to identify opportunities to improve The City's coordinated response to future emergency and disaster events. About 120 staff from every City Business Unit and 16 external members and partners participated.

As a result of these debriefs, a number of preliminary actions have been identified for follow up to guide improved response for future events. One specific area for immediate action is to have formal and consistent Corporate-wide business continuity plans. During the flood, many Business Units were able to quickly and seamlessly adapt their operations to the loss of personnel and workspaces, however more work is required to ensure similar results in all Business Units and apply lessons learned. Moving forward, CEMA has identified an opportunity to engage Business Units to develop comprehensive business continuity plans that align with other Business Units using the same guidelines and templates.

Third-Party Review

CEMA has also retained the Conference Board of Canada to review The City's emergency response to the 2013 flood. The Conference Board of Canada, in consultation with The City Auditor's Office, will evaluate The City's response against emergency management best practices and standards, and provide its results and recommendations in the second quarter of 2014. These findings, along with those from the Corporate and CEMA debriefs, will be presented to Council no later than 2014 June. This report will also include recommendations for incorporating findings into the 2015-2018 Business Plan and Budget Cycle. The recommendations and direction from Council will guide future disaster planning and emergency management objectives for The City. The Recovery Operations Centre Task Force remains in place and will report directly to Council on restoration efforts.

Stakeholder Engagement, Research and Communication

Membership of CEMA is comprised of 19 City Business Units, 12 external members and a range of organizations that work in collaboration with CEMA at the invitation of the Director. These include non-governmental organizations, faith-based entities, government agencies, private companies and subject matter experts.

Regular training and mock disaster exercises throughout the year provide opportunities for members to identify potential gaps in response planning, enhance coordination, and refine member operations to prepare for a range of emergency scenarios. Members are also fully engaged in developing and maintaining the various emergency response plans of The City.

During the 2013 flood, Council was very supportive of the operational and communications needs of the EOC. Council members observing the emergency response in the EOC, as well as those inquiring on progress, worked to ensure their communications to constituents were aligned with, and supported, the direction and messaging being provided by the EOC.

On October 29, in response to a Calgary Police Commission request, CEMA made a presentation to the Calgary Police Commission on its Comprehensive Emergency Management Model and the pillars of emergency management. This overview included discussion of emergency management authority and legislation as set out by the Alberta Emergency Management Act, and the resulting roles and responsibilities of internal and external agency members, the Mayor and Council. As a result of the presentation and discussion, CEMA and the Calgary Police Service will be meeting to further discuss operational opportunities to work together and to clarify roles.

The Recovery Operations Committee Task Force has reviewed this report and CEMA will continue to work closely with the Task Force to share lessons learned.

Strategic Alignment
This report and The City of Calgary's response to the 2013 June flood aligns with Council's Fiscal Plan for Calgary 2012-2014: *"Ensuring every Calgarian lives in a safe community and has the opportunity to succeed."*

Social, Environmental, Economic (External)
Social
Although Calgary only had about 15 hours to conduct evacuations of areas affecting approximately 80,000 citizens, the emergency response to the 2013 flood protected the health and safety of Calgarians through a series of staged, managed and deliberate evacuations. Consideration was also provided for Calgary's most vulnerable populations, including seniors and those struggling with poverty, homelessness and addiction.

Intensive initial recovery planning and activities occurred in parallel to response efforts to support the quick and safe re-entry of citizens and businesses into their homes and communities. This closely integrated approach between response and recovery allowed citizens with damage to their homes to quickly begin remediation and restoration. Citizens with little or no damage to their homes were able to quickly resume normal activities and recommence the vital work and commerce activities in the city.

Environmental
Environmental and climate change factors are influencing the frequency and magnitude of events on a worldwide basis. The nature and scale of events expected to impact the city of Calgary are changing and expanding. CEMA's annual Hazard Identification and Risk Assessment (HIRA) is designed to identify these potential events to allow CEMA and City Business Units to incorporate mitigation activities into annual business and continuity planning.

This type of mitigation planning, combined with additional measures undertaken since the 2005 flood, such as development of the Water Emergency Operations Centre (H2OC) and improvements to the water treatment plants, allowed The City to mitigate the flood magnitude on the Elbow River downstream of the Glenmore Dam, and maintain the safety of its drinking water during and following the flood.

Economic (External)
Due to recovery efforts being coordinated and executed with the same intensity and resources as the response efforts in the EOC, The City was able to support the timely resumption of business activity in the city, particularly within the severely affected downtown core.

Early stage business continuity planning by Business Units ensured essential services to citizens and businesses, such as applications for permits, were available and others were restored as quickly as possible.

Financial Capacity
Current and Future Operating Budget:
Costs associated with the Conference Board of Canada Report are estimated to be approximately $50,000. There are no additional operating impacts at this time. Any further operating budget impacts as a result of the ongoing review will be identified in the 2014 June report and will be referred to the 2015-2018 business plan and budget cycle.

Current and Future Capital Budget:
There are no capital budget implications at this time. Any further capital budget impacts as a result of the ongoing review will be identified in the 2014 June report and will be referred to the 2015-2018 business plan and budget cycle.

Risk Assessment
During the 2013 flood, the Bow and Elbow rivers reached approximate one in 100-year and one in 500-year return peak flow rates, respectively. This is not intended to indicate such events will only occur once every 100 or 500 years; rather, it is an indication of the likelihood of such events occurring in a given year. The probability of a 100-year event occurring in any given year is one per cent, while the probability of a 500-year event occurring in a year is 0.2 per cent.

Environmental and climate change factors are influencing the magnitude of events on a worldwide basis. Through its annual HIRA, CEMA works to identify those events most likely to occur in Calgary and with the potential for the largest impact. Based on the flooding occurrences in 2005 and 2013, CEMA is consulting with subject matter experts to continue to assess the likelihood of these types of events in the future.

The City has directed the development of an external Expert River Flood Mitigation Advisory Panel to review flood issues and make recommendations for future mitigation strategies. Recommendations are anticipated by spring 2014 and will be integrated within the 2015-2018 Business Plan and Budget Cycle.

2013 JUNE FLOOD EMERGENCY RESPONSE AND INITIAL RECOVERY EFFORTS

REASON(S) FOR RECOMMENDATION(S):
Initiatives and actions resulting from flood debrief activities as well as an independent third-party review of the emergency response to the 2013 June flood will contribute to improved Corporate preparedness and emergency management of future large-scale emergency events.

ATTACHMENT(S)
Summary of 2013 June Flood Emergency Response and Initial Recovery Efforts

B

APPENDIX B:
EMERGENCY OPERATIONS COSTS AND INFRASTRUCTURE DAMAGES

2013 Flood - Financials ($'000s)

	Advances Received	2013	2014	2015	Future Years	Total
Operating						
Emergency Operating Costs Incurred		$43,300				$43,300
Recovery Operating Costs Incurred			$4,586	$1,122		$5,708
(These are incremental flood emergency / recovery costs over & above the base budget. These are the costs being submitted through the DRP & MSCG program to the Province)						
Recovery Task Force		$314	$1,661	$1,037		$3,012
(One Time budget & 7 FTEs in 2013 & 2014; Operating budget for 6 FTEs in 2015 to support recovery)						
Municipal Staffing Capacity Grant (PFC2014-0316) – FSR Funding Approved		$1,000	$2,600	$4,230	$70	$7,900
2014 / 2015 Flood Readiness Supply Grant Approved			$7,685			$7,685
Property Tax Relief Program (C2014-0334) Grant Approved			$2,094	$326		$2,420
City of Calgary/Canadian Red Cross Society Permit Pilot Program – Budget Approved One time budget for 2014 (NM2014-18)			$310			$310
One time budget for 2015 (PFC2014-0948)				$50		$50
One-time Operating Resilience Budget (PFC2014-0316)			$1,110			$1,110
Capital						
Capital (Infrastructure) Budget - Originally approved in 2013		$182,423	$134,203		$128,521	$445,147
Capital (Infrastructure) Budget (Excluding Resilience) as at May 31, 2015		$101,180	$92,210	$168,390	$47,867	$409,647
Capital (Infrastructure) Expenditures (Excluding Resilience) as at May 31, 2015		$101,180	$92,210	$6,572		$199,962
Capital – Resilience Projects – Budget approved			$16,025			$16,025
- (PFC2014-0316) Budget approved $15.675M						
- (C2014-0774) Budget approved for Roads Resilience Projects $350K						
- Calgary Parking Authorities - Budget Relinquishment			($325)			(325)
Capital - Resilience Projects - Expenditures as at May 31, 2015			$3,618	$1,179		
Flood Recovery Erosion Control Program - Grant Approved			$52,105			$52,105
Disaster Recovery Program (DRP) Financial Submissions Summary						
Emergency & Recovery Operations Cost Submitted for reimbursement - May 31, 2015		$18,580	$18,114	$2,731		$39,425
Infrastructure Project Costs submitted for reimbursement – May 31, 2015		$676	$4,707	$1,606		$6,989

2013 Flood - Financials ($'000s)

	Advances Received	2013	2014	2015	Future Years	Total
Funds Received as of May 31, 2015						
Province of Alberta DRP – Emergency Operations Cost Reimbursement			$32,372	$1,295		$33,667
Province of Alberta DRP - Advance for Infrastructure Project Costs + Interest	$63,033	$219	$277			$63,529
Insurance – Advance	$50,000					$50,000
Insurance – Talisman Centre			$437			$437
2014/2015 Flood Readiness Supplies Grant Program + Interest			$7,770	$27		$7,797
Flood Recovery Erosion Control Program - Grant Received + Interest			$52,657	$299		$52,956
Municipal Staffing Capacity Grant + Interest			$3,607	$1,338		$4,945
Property Tax Relief Program Grant Received			$2,094	$326		$2,420
Flood Mitigation Study – Bypass Tunnel			$250			$250
Total	**$113,033**	**$219**	**$99,464**	**$3,285**		**$216,001**

2013 Flood - Financials ($'000s)

Fiscal Stability Reserve Balance As at 2015 May 31 ($'000s)	Projected
Tax supported	
Approved 2013 November 25 (C2013-0668)	$100,000
PFC2014-0279 Resiliency Report	
Flood Mitigation Project for Calgary Zoo	(1,200)
• funding for Calgary Zoo cleanup expenses and preliminary design that are not eligible for DRP or insurance	(795)
PFC2014-0316 Resiliency Report	
Community Resiliency Projects	
• Capital Projects	(9,085)
Infrastructure/Operations: Flood Resiliency Projects	
• Capital Projects	(6,590)
• Roads Capital Resiliency Project (PFC2014-0774)	(350)
• Calgary Parking Authorities - Capital Resiliency Budget Relinquishment	325
NM2014-18 City of Calgary and Canadian Red Cross Society Permit Pilot Program for 2014	(15)
PFC2014-0948 City of Calgary and Canadian Red Cross Society Permit Pilot Program for 2015	(50)
$100M FSR Balance Remaining	**$82,240**
Other FSR funding provided for flood related items	
Funding for Flood Recovery Task Force 2013 (PFC2014-0634)	(650)
Funding for Flood Recovery Task Force 2014 (PFC2014-0634)	(1,300)
Shouldice Athletic Park Turf Replacement (C2013-0668)	(300)
Insurance premium increase (2014 Budget Adjustment Cycle)	(2,500)
Additional Insurance Premium (PFC2014-0169)	(250)
Legal Division Resilience (2014 Budget Adjustment Cycle)	(35)
PFC2014-0316 Resiliency Report	
Community Resiliency Projects • One-Time Operating Expenditure (2014 Approved budget $460K)	(145)
Infrastructure/Operations: Flood Resiliency Projects • One-Time Operating Expenditure (2014 Approved Budget $650K)	(240)
Municipal Staffing Grant for staff and consulting - projected costs ($7.9M approved less $4.93M grant received)* *Recoverable from the Province	(2,970)
PFC2014-0171 Flood Hazard Area Policy & Bylaw Review	(172)
Interim financing for Capital Infrastructure Projects in 2014	(12,692)
Other FSR funding provided to-date	**(21,254)**

Capital Budget - Flood Related Projects
Budget & Expenditures as at May 31, 2015

(in $'000s)

PRG	Activity	DESCRIPTION	(A) = (B)+(C)+(D) Total Budget (2013 - 2018)	(B) 2015 Budget	(C) Future Years Budget	(D) Total Expenditures in 2013 and 2014	2015 Expenditures as at 2015 May 31
		<u>PARKS</u>					
932	793230	Pathways	19,027	5,825	9,267	3,935	478
932	793240	Major Parks (Prince's Island and Bowness Park)	8,179	1,084		7,095	348
932	793220	Other Parks (excl. Bowness & Prince's Island Park)	18,158	5,580	5,980	6,598	21
932	793210	Parks Buildings	4,203	255	200	3,748	604
932	798050	Flood Resiliency	2,340	2,063	250	27	577
		Total Parks Including Resiliency	**51,907**	**14,807**	**15,697**	**21,403**	**2,028**
		<u>RECREATION</u>					
933	793301	Maple Ridge Golf Course Pumphouse	1,350	1,163		187	(15)
933	793302	Shaganappi Golf Course Pumphouse	1,700	1,491		209	15
933	793304	Shouldice Athletic Park Turf Replacement	12,000	5,131	6,500	369	36
933	793303	Stanley Park Outdoor Pool	2,000	796		1,204	1
933	798100	RC-Shouldice Flood Ctrl Plng	100	85		15	-
		Total Recreation Including Resiliency	**17,150**	**8,666**	**6,500**	**1,984**	**37**
		<u>Animal & Bylaw Services</u>					
934	793401	ABS Equipment For Centre City	250	244		6	
		Total Animal & Bylaw Services (No Resiliency)	**250**	**244**	**-**	**6**	**-**
		<u>FIRE</u>					
935	793506	Calgary Fire Department Boat Launch Repairs	545	84		461	6
935	793501	Building Infrastructure Flood Mitigation	900	900		-	
935	793503	Emergency Units Repair & Replacement	550	478		72	
935	793504	Replacement of Flood Damaged Equipment	240	203		37	
935	793502	Replace Flood Damaged Personal Protective Equip	200	200		-	
935	793505	Urban Search & Rescue Equip. Replace/Purchase	360	93		267	

Capital Budget - Flood Related Projects
Budget & Expenditures as at May 31, 2015

PRG	Activity	DESCRIPTION	(A) = (B)+(C)+(D) Total Budget (2013 - 2018)	(B) 2015 Budget	(C) Future Years Budget	(D) Total Expenditures in 2013 and 2014	2015 Expenditures as at 2015 May 31
935	798201	FI - Pandemic Supply Top up	100	65		35	11
935	798210	FI - Community Support Centres	1,250	1,248		2	
935	798211	FI - Alert and Warning Notific	1,000	1,000			
935	798212	FI - Fire Station in a Box	140	102		38	
935	798213	FI - Critical Equipment and PP	150	150			
935	798214	FI -Towing and Recovery Vehicl	550	550			
		Total Fire Including Resiliency	**5,985**	**5,073**	**-**	**912**	**17**
		CORPORATE PROPERTIES & BUILDINGS					
937	793701	Muni/Admin/ATC/EMS #3 Buildings	24,478	9,644		14,834	711
937	793703	Furniture & Related Equipment Flood Recovery	980	676		304	48
937	798300	CP-Seal Cracks	150	124		26	
937	798301	CP-Channel Water	550	75		475	40
937	798302	CP-Relocate Electrical Switch	600	168		432	1
937	798303	CP-Emergency Service Counter P	150	150			
937	798304	CP-Disaster Response Resources	45	12		33	2
937	798305	CP-Sump Pumps-Backup Generator	200	139		61	134
		Total Corp. Prop. & Buildings Including Resiliency	**27,153**	**10,988**	**-**	**16,165**	**936**
		FLEET					
939	793910	Fleet Replacements	1,120			1,120	
		Total Fleet (No Resiliency)	**1,120**	**-**	**-**	**1,120**	**-**
		INFORMATION TECHNOLOGY					
941	414200	Telephone Restoration	4,100	1,572		2,528	59
941	414202	Network / Hardware Replacement	3,500	1,014		2,486	
941	414201	Business Continuity	2,483			2,483	

Capital Budget - Flood Related Projects
Budget & Expenditures as at May 31, 2015

PRG	Activity	DESCRIPTION	(A) = (B)+(C)+(D) Total Budget (2013 - 2018)	(B) 2015 Budget	(C) Future Years Budget	(D) Total Expenditures in 2013 and 2014	2015 Expenditures as at 2015 May 31
941	414203	Network Restoration	361			361	
		Total Information Technology (No Resiliency)	**10,444**	**2,586**	**-**	**7,858**	**59**
		<u>Office of Land Servicing & Housing</u>					
943	798600	OLSH-Flood Resiliency	55	48		7	5
		Total Office of Land Servicing & Housing Resiliency	**55**	**48**	**-**	**7**	**5**
		<u>CALGARY HOUSING COMPANY</u>					
944		CHC-Flood Resiliency	-	-			
		Total Calgary Housing Company Resiliency	**-**	**-**	**-**	**-**	**-**
		<u>LAW - CORPORATE SECURITY</u>					
955	799200	LA-Flood Resiliency	270	265		5	95
		Total Corporate Security Resiliency	**270**	**265**	**-**	**5**	**95**
		<u>INFRASTRUCTURE & INFORMATION SERVICES</u>					
942	794201	High Accuracy Airborne Laser (HAAL)	375	375			
942	794202	Flood Recovery Program Management System	106			106	
		Total Infrastructure & Info Serv (No Resiliency)	**481**	**375**	**-**	**106**	**-**
		<u>CALGARY TRANSIT</u>					
947	794701	Victoria Park Garage	2,072			2,072	
947	794705	Erlton / Victoria Park LRT	1,495	704		791	194
947	794710	South LRT Corridor Recovery	8,633	1,688		6,945	505
947	798800	CT-ACIVR Network	250	198		52	3
947	798801	CT-AC Phone Backup System	300	294		6	
947	798802	CT-AC Internal Mobile Backup	25	25			
		Total Calgary Transit Including Resiliency	**12,775**	**2,909**	**-**	**9,866**	**702**

Capital Budget - Flood Related Projects
Budget & Expenditures as at May 31, 2015

PRG	Activity	DESCRIPTION	(A) = (B)+(C)+(D) Total Budget (2013 - 2018)	(B) 2015 Budget	(C) Future Years Budget	(D) Total Expenditures in 2013 and 2014	2015 Expenditures as at 2015 May 31
		ROADS					
948	794821	RD: 5 Trafford Crescent NW	6,000	5,856		144	2
948	794816	Slope Stability Projects	600	(690)		1,290	
948	794817	RD: Hill Rd/ Child Avenue	-	(42)		42	
948	794822	RD: Klippert Gravel Pit Road	-	(35)		35	
948	794801	25 Ave / McLeod Tr to 5 St	13,226	12,997		229	
948	794805	RD: Pump House Snow Dump Site	2,309	2,200		109	
948	794826	RD-Centre St Deck Hangers	-	(56)		56	
948	794827	Bank Erosion & Scour Protection	1,300	606		694	48
948	798850	RD-Undergrd SignlDuct Replc	2,075	2,075			28
948	798855	RD-Relocate StreetLight Contrl	-				70
948	798860	RD-Signal Cabinet Retrofit	-				213
948	798865	RD-IBS Bridge Piled Foundation	-				
948	798871	RD-Emergency Access Ramp	350	350			
		Total Roads Including Resiliency	**25,860**	**23,261**	**-**	**2,599**	**361**
		TRANSPORTATION INFRASTRUCTURE					
949	794901	Pedestrian Bridges	4,370	923		3,447	21
949	794902	TR-Ped Bridge-Sandy Beach	3,708	231		3,477	38
949	794903	TR-Ped Bridge-Riverdale Ave	3,806	177		3,629	(42)
949	794905	Macleod Trail North Bound (25th Ave to Victoria Bridge)	818			818	
949	794910	25th Avenue - between Spiller Road and Macleod Trail S.E.	137			137	
949	794915	25th Ave (1st St S.W. and Erlton St S.W.) - Scollen Bridge	1,072	59		1,013	
949	794920	Miscellaneous Road and Transit Repairs	330	77		253	
949		Complete Elbow River Pedestrian Bridge	-				
		Total Transportation Infrastructure (No Resiliency)	**14,241**	**1,467**	**-**	**12,774**	**17**

Note 1

Capital Budget - Flood Related Projects
Budget & Expenditures as at May 31, 2015

PRG	Activity	DESCRIPTION	(A) = (B)+(C)+(D) Total Budget (2013 - 2018)	(B) 2015 Budget	(C) Future Years Budget	(D) Total Expenditures in 2013 and 2014	2015 Expenditures as at 2015 May 31
		UTILITIES (WATER RESOURCES & WATER SERVICES)	Note 2				
952	795271	DR-EP Home Road & 52 Street SE	5,364	800		4,564	11
952	795276	DR-EP Inglewood	6,789	1,596		5,193	25
952	795277	DR-EP Memorial Dr & Sunnyside	5,298	770		4,528	50
952	795278	DR-EP Memorial Dr & 19 St NW	3,556	270		3,286	3
952	795279	DR-EP Enmax Power Station	957	270		687	
952	795280	DR-EP Diamond Cove	4,300	270		4,030	
952	795272	DR-High Priority Erosion Sites	31,215	22,815		8,400	3,719
952	795281	DR-Moderate Priority Erosion Site	17,063	11,135	1,080	221	1,431
952	795292	DR-S Highfield High Priority Erosion Site	9,000	5,270		3,730	379
952	795273	DR-Lift Stations - Drainage	625	520		105	22
952	795274	DR-Stormwater Ponds	2,976	1,405		1,571	
952	795275	DR-Stormwater Outfalls	9,764	7,788	1,080	896	827
952	795283	Carburn Park - Flood Preparedness Grant	500	500		-	
952	795284	DR-Fish Compensation	12,205	7,885	4,320	-	
952	795237	WS-Lift Stations - Wastewater	4,581	3,034		1,547	91
952	795201	WS-River Crossings - Waterworks	15,786	5,813	9,720	253	14
952	795236	WS-Bonnybrook Wastewater Treatment Plant	17,345	4,068		13,277	153
952	795238	WS-River Crossings - Sanitary	15,512	5,777	9,720	15	8
952	795282	DR-4th St SE LS Resiliency	-				
		Total Utilities (No Resiliency)	**162,836**	**79,986**	**25,920**	**52,303**	**6,733**
		CALGARY POLICE SERVICE					
953	428304	Administration Building	4,674			4,674	
953	428000	Vehicle Replacements	416			416	
953	799100	Calgary Police Service Resiliency	4,875	2,471		2,404	

Note 3

Capital Budget - Flood Related Projects
Budget & Expenditures as at May 31, 2015

PRG	Activity	DESCRIPTION	(A) = (B)+(C)+(D) Total Budget (2013 - 2018)	(B) 2015 Budget	(C) Future Years Budget	(D) Total Expenditures in 2013 and 2014	2015 Expenditures as at 2015 May 31
		Total Calgary Police Service Including Resiliency	9,965	2,471	-	7,494	-
		CIVIC PARTNERS					
956	795610	Talisman Centre	20,000	3,772		16,228	567
956	795615	Calgary Zoo Buildings	35,800	10,059		25,741	368
956	795620	Calgary Public Library	8,000	5,526		2,474	
956	795605	Pumphouse Theatre	100	92		8	
956	795601	Calgary Zoo Cleanup	10,900	7,392		3,508	452
		Total Civic Partners (No Resiliency)	74,800	26,841	-	47,959	1,387
		CALGARY PARKING AUTHORITY					
957	425720	Calgary Parking Authority - Civic Plaza Parkade	9,115	60		9,055	
957	425720	Calgary Parking Authority - McDougall Parkade	765			765	
		Calgary Parking Authority Resiliency	175	175			
		Total Calgary Parking Authority Including Resiliency	10,055	235	-	9,820	-
		Total Budget Excluding Resiliency :	409,647	168,390	47,867	188,763	11,198
		Total Resiliency Budget :	15,700	11,832	250	3,618	1,179
		Total Budget Including Resiliency :	425,347	180,222	48,117	192,381	12,377

Note 1: RFP for Roads' Highfield Rd SE project had been approved by DRP engineer from Landlink in the amount of $1.5M; BG12 will be submitted to increase budget.

Note 2 : Future years' budget breakdown provided by Utilities

Note 3 : An adjustment related to payment in 2014 of $4.627M to Calgary Exhibition and Stampede for work done under the Flood Erosion Control Program was made in 2015 as this work was not part of Utilities' Capital Budget. As a result, total expenditures in 2013 & 2014 are shown as $52.3M and $2015 YTD expenditures for Utilities are shown as $6.733M.

C

APPENDIX C:
GROUNDWATER ANALYSIS

April 2016

FLOOD MITIGATION OPTIONS ASSESSMENT

Groundwater Flood Modelling

Submitted to:
The City of Calgary

Report Number: 1531394

REPORT

Golder Associates

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TABLES

FIGURES

1.0 INTRODUCTION

1.1 Groundwater Study Component

The Bow and Elbow River floodplains in Calgary are underlain by a permeable alluvial aquifer. The groundwater levels in the alluvial aquifer may rise as the river water levels rise during river floods. Rising groundwater levels may cause basement flooding in the floodplain areas where there is no overland surface water flooding.

This study (i.e., Flood Mitigation Options Assessment) includes a groundwater component. The overall objective of the component was to generate pertinent groundwater information to support groundwater flood damage modelling in Calgary. The main output from the groundwater component includes the following:

- definition of the maximum extents of the alluvial aquifer where potential groundwater flooding might occur as a result of rising river flood levels; and
- estimation of maximum groundwater levels in the alluvial aquifer which are caused by rising river flood levels.

This report documents the basis, methodology, and results of the groundwater study component, as well as pertinent conclusions and recommendations.

1.2 Definitions of Terms

The following terms are used in this report, and their definitions are provided below:

- *Geologic Conceptual Model or Framework* – The interpreted geologic representation using cross sections, top structure maps, and thickness maps based on the interpolation of data control points and an understanding of the relevant geologic processes which formed the geology in the study area.
- *Hydrogeologic Conceptual Model or Framework* – The superposition of measured hydraulic heads and interpreted potentiometric surfaces, groundwater flow directions and gradients, distribution of hydrogeologic parameters and boundary conditions on the geologic framework.
- *Numerical Flow Model* – Translation of the hydrogeologic conceptual model onto a discretized numerical mesh or grid so the groundwater flow equation can be solved for the hydraulic head distribution subject to appropriate boundary and initial conditions.

1.3 Work Scope

The groundwater study component involved the main activities listed below:

- Reviewed relevant geological data and groundwater flood studies.
- Defined the maximum extents of the alluvial aquifer where groundwater flooding may occur.
- Identified and evaluated alternative groundwater flow modelling approaches, and selected a modelling approach for this study with input from The City.
- Conducted groundwater flow modelling, analyzed the modelling results, and provided the relevant information for estimating the maximum groundwater levels during flood events.

2.0 PREVIOUS STUDIES AND AVAILABLE DATA

2.1 Past Studies on Groundwater Flooding in Calgary

The following papers on groundwater flooding in Calgary were identified by Dr. Ryan and reviewed as part of this study:

- Abboud, J., M.C. Ryan, and G.D. Osborn, 2015. High water in June 2013: More flood than meets the eye. Abstract published in GeoConvention 2015 proceedings.
- Abboud, J., 2014. Groundwater Flooding in a River-Connected Alluvial Aquifer. Unpublished BSc thesis (supervised by Drs. Cathy Ryan and Gerald Osborn). Geoscience, University of Calgary.
- de Bourgraaf, A.J.J., 2014. Delineating the Bow and Elbow River alluvial aquifers heterogeneity. MSc Internship Report for Hydrology and Quantitative Water Management Program, Wageningen University. Supervised in Canada by Dr. Cathy Ryan. 112 p.
- Candel, J., 2014. Groundwater/surface water interactions in relation to flooding in Calgary, Canada. MSc Internship Report for Hydrology and Quantitative Water Management Program, Wageningen University. Supervised in Canada by Dr. Cathy Ryan. 112 p.
- Cantafio, L.J., 2012. Groundwater-surface water interaction, non-point source chloride loading, and flow generation along an urban river. MSc Thesis (supervised by Dr. Cathy Ryan, Geoscience, University of Calgary). 164p.
- Cantafio, L.J. and M.C. Ryan, 2014. Quantifying baseflow and water-quality impacts from a gravel-dominated alluvial aquifer in an urban reach of a large Canadian river. Hydrogeology Journal. 22:957-970. DOI 10.1007/s10040-013-1088-7.
- Herring, T., 2015. Quantifying uncertainty and variability in the interpretation of electrical resistivity tomography images: a practical approach to providing error metrics for features of interest. Unpublished course project (supervised by Dr. A. Pidlisecky, Geoscience, University of Calgary).
- Hugo, K., 2015. Bow River Floods and Groundwater. Presentation made to the 2015 Water Technologies Symposium in Kananaskis, Alberta.

These studies indicate that groundwater flooding occurs when the water levels within alluvial aquifer sediments connected to the river increase due to hydraulic gradients induced by high river water levels. The high groundwater tables may affect basements, underground parking garages and other constructed areas below grade, either directly through structural cracks and openings, or via artificial pathways created by water/ stormwater/wastewater subsurface infrastructure, causing damage to infrastructure and private property.

Abboud et al. (2014) conducted door-to-door surveys of homes affected by groundwater flooding and conducted aerial photographic analyses to differentiate the flood damages caused by surface water and groundwater. The survey results for the Elbow River indicated that approximately 88% of the damaged homes were initially flooded by groundwater and later by overland flow, and 12% flooded exclusively by groundwater.

Candel (2014) used numerical models to simulate groundwater flooding at four locations and compared the modelling results to the continuous measurements of hydraulic head in the alluvial aquifer. The four locations include three along the Bow River within Calgary and one along the Elbow River. The modelling results were used in conjunction with surface overland flooding maps to produce a map of groundwater flooding areas.

Simulated results for the 1:100 year flood at Sue Higgins Park in southeast Calgary reported by Candel (2014), indicate the groundwater level response close to the Bow River (within 10 metres of the river) closely follows the river level change (Figure 1). With a greater distance away from the river, the groundwater response was delayed and muted. Candel (2014) estimated a 25-day lag period at a distance of 650 m from the river, with an increase in hydraulic head of 1.1 m. This groundwater response corresponded to a more than 3.0 m river stage elevation change. For the 2013 flooding event, the simulated groundwater rise was up to 3.1 m compared to the pre-flood level. Candel (2014) used a hydraulic conductivity value of 1.0×10^{-3} m/s (86.4 m/d) that is consistent with the estimate (based on reported values), used by Cantafio (2012). A specific yield (Sy) value in the range of 0.1 to 0.2, typical of unconfined alluvial aquifers, was applied in the model. The simulated change in water level within 50 m of the Bow River was relatively quick and of similar magnitude to the stage change in the Bow River.

Based on one-dimensional analytical modelling, Cantafio (2012) estimated that there would be an almost instantaneous groundwater level response and a water table rise of 70% of the river stage increase. As distance from the river increases, lag time between maximum river stage elevation and maximum groundwater level increases and the water table response becomes muted.

Additionally, Hugo (2015) reported a lag time of one day or less, for the groundwater levels to attain a maximum peak equivalent to 75% of the Bow River peak in 2014 at 280 m. For this calculations Hugo (2015) applied a specific yield of 0.2 and an average transmissivity of 3,000 square metres per day (m^2/d) to estimate the lag time and groundwater response at variable distance from the river.

It is important to note that the results reported by Candel (2014), Cantafio (2012) and Hugo (2015) were preliminary. These studies suggested that additional efforts were required to improve representation of the lateral lithological alluvial aquifer variation, variation in hydraulic conductivity values, bedrock and alluvial aquifer interaction, and river and aquifer interaction.

2.2 Geology and Hydrogeology

The following two reports were reviewed and identified as the most relevant documents for characterizing the hydrogeology of the alluvial aquifer in Calgary:

- Meyboom, P., 1961. Groundwater resources of the City of Calgary and Vicinity. Research Council of Alberta. Bulletin 8. 72 p.
- Moran, S.R., 1986. Surficial Geology of the Calgary Urban Area. Terrain Sciences Department. Alberta Research Council Edmonton. Alberta. Bulleting 53. 46 p.

2.3 Available Geologic Databases

The main sources of available geological information are the ESAR Database, the Alberta Water Well Database, the City of Calgary Database and reports provided specifically for this study, and digitized maps from the Alberta Geological Survey (Meyboom 1961 and Moran 1986).

The information extracted and correlated from the sources noted above has a degree of uncertainty for characterizing the lithological variability that is inherent to any alluvial environment. The uncertainty is dependent upon the number of geologic data control points (boreholes) correlated, the correlation distance between points, and the direction of the correlation examined.

3.0 ALLUVIAL AQUIFER CHARACTERIZATION

3.1 Conceptual Model

According to Moran (1986), during the early Pleistocene, the Bow River cut its level near the current valley floor leaving buried gravel deposits beneath the glacial till. Later, during the glaciation melting, the Elbow and Bow Rivers cut their valleys near the current levels depositing and re-eroding gravels. A summary of the surficial stratigraphy proposed by Tharin (1960) is shown in Figure 2.

The conceptual model used in this study includes the following consideration:

- groundwater flooding will be most prevalent in the more permeable deposits (sand and gravel) within the floodplains (i.e. alluvial aquifer) of the Bow and Elbow Rivers; and
- the more permeable deposits consist of sands and gravels within the area constrained by the bedrock topography of the Paskapoo Formation.

The geologic framework discussed below is based largely on the following:

- ground surface topography and the associated definition of the Bow and Elbow River Valleys and, by inference, definition of the alluvial river-connected aquifer extents illustrated in Figure 3;
- a modified version of the Paskapoo Formation topography from Moran (1986) illustrated in Figure 4;
- the alluvial aquifer thickness distribution map illustrated in Figure 5;
- a post map showing multi-year composite groundwater level data recorded during the period from1993 to 2013, illustrated in Figure 6;
- four stratigraphic cross sections illustrated in Figures 7 to 9, with locations shown in Figure 6.

In the Calgary area, gravel deposits contiguous with the rivers can be saturated, whereas gravel deposits at higher elevation than the river stage are commonly dry (see Figures 7 and 8). In places where the bedrock surface is above the water table, the sands and gravels are at least seasonally unsaturated. During high flow periods (May and June) the Bow and Elbow Rivers become influent (i.e., driving river water into the alluvial aquifers). After the high flows pass, the river levels drop below the adjacent groundwater tables, the rivers become effluent again and water held in bank storage is gradually released (Meyboom 1961 and 1961b). River bank storage has an important effect in groundwater flooding by delaying the release of water to the river for several days. In some cases the groundwater levels are maintained when the river flood level is already decreasing (Becker et al 2015).

3.2 Physiographic Setting

The study area comprises the footprint of the river-connected alluvial aquifer underlying the Bow and Elbow Rivers in Calgary (see Figure 3). The study area extends from the northwest, at the Bearspaw Dam (1,074 meters above sea level [masl]) along the Bow River, to the south near the bridge at Highway 201 (1,003 masl). The study area includes the river-connected alluvial aquifer along the Elbow River to the west, from 1,103 masl, to its confluence with the Bow River at approximately 1,036 masl, to the north, including the Elbow River in Calgary (downstream of the Glenmore Reservoir). The topography map and topography data used to construct the cross sections were based on the Lidar topographic and river bathymetric data provided by The City.

3.3 Bedrock Elevation

The Paleocene Paskapoo Formation bedrock beneath the river-connected alluvial aquifer underlying the Bow and Elbow Rivers in Calgary consists of local and widespread weathered sandstones, siltstones, shales and mudstones as defined by Meyboom (1961). Meyboom defined the Paskapoo Formation as a “low production” and “low hydraulic conductivity” aquifer with a characteristic “decreasing in head with increasing in depth” in the vicinity of Calgary.

The Paskapoo Formation elevation below the alluvial aquifer (see Figure 4) attains 1,073 masl near the Bearspaw Dam. The Paskapoo Formation elevation decreases further east along the Bow River to approximately 1,041 masl at Montgomery, with the lowest point below downtown Calgary at 1,028 masl. At the confluence of the Bow and Elbow Rivers the interpreted Paskapoo Formation elevation was approximately 1,030 masl (see Figure 4). At Inglewood the Paskapoo Formation elevation is 1,018 masl. Towards the south, near the bridge at Highway 201 South, the Paskapoo Formation elevation is 996 masl.

Beneath the Calgary downtown area the Paskapoo Formation topography varies by up to 20 m or more in elevation, over very short horizontal distances. The high variability is possibly the result of “old” Bow River erosional processes combined with glacial erosion (Meyboom 1961). The presence of paleo-channels is insinuated in Figure 4 by the highs and lows in the Paskapoo Formation topography. These trends potentially form avenues of preferential groundwater flow depending on the infilling sediment.

3.4 Alluvial Aquifer

A glacial till layer has been identified above the Paskapoo Formation in multiple boreholes mainly beneath the downtown area. The glacial till comprises a discontinuous blanket of very stiff and dense, olive brown to gray, clays and silts, with localized percentages of gravel. According to Moran (1986) the oldest sediment of glacial origin recognized in the Calgary area is the Pre-Spy Hill till which ranges in thickness between 3.0 and 16.5 m. In addition the Spy Hill, Lochend and Balzac Formations comprise tills. It is difficult to assign these glacial deposits to a particular formation, based on the available borehole descriptions.

The glacial till thickness attains up to 2.5 m, but it may be thicker at some locations, as shown in multiple borehole logs along the cross sections constructed and illustrated in Figures 7 to 9. Cross-section 1 (Hillhurst, see Figure 7) to the east of the downtown area indicates that the glacial till is less than 1.5 m thick, whereas at cross-sections 2 and 3 (Eau Claire and Mission, see Figure 8), the glacial till ranges from 0.7 to 3.0 m. Although similar thickness is observed in cross-section 4 along the Bow River, the glacial till may be thicker locally.

The thickness of alluvial sediment was estimated using a constraint mapping procedure whereby the kriging-interpolated surface of the Paskapoo Formation and overlying localized accumulations of glacial till was subtracted from the ground surface topography. Figure 5 shows the approximate alluvial aquifer thickness contours. The thickness of alluvial deposits varies up to 20 m, from the edges to the center of the alluvial plain.

At Montgomery, to the west of downtown Calgary, the alluvial deposits are locally up to 20 m thick. Further downstream at Hillhurst and Sunalta the thickness decreases to between 5 and 10 m locally. Towards the Sunnyside area the thickness increases locally to 16 m as a result of a drop in the bedrock elevation (see Figure 4). Towards downtown following 9th Avenue, a drop in the bedrock elevation appears to cause an increase in thickness to approximately 20 m whereas at Mission the aquifer is locally up to 10 m thick.

At Inglewood, east of the Elbow River confluence, the thickness increases up to approximately 18 m, according to Meyboom (1961). South of that area the thickness appears to vary between 10 and 15 m. South of the Calf Robe Bridge the thickness varies more randomly. Beyond that location and to the south, the contour elevations decrease in accuracy.

The alluvial aquifer comprises coarse, medium and fine grained sands and coarse, well rounded, dry and loose, olive brown, gravels and cobbles of fluvial origin. Silt layers may also be present within the alluvial aquifer. The sand and gravel lenses were defined by Meyboom (1961) as being part of the Saskatchewan sand and gravels unit (Figure 2). They locally rest directly upon the Paskapoo Formation, but more frequently they are underlain by gravel and the glacial till veneer described above.

Silts and silty sand horizons and, more rarely, clays (possibly from the Calgary Formation – Figure 2, from Meyboom 1961 and Lake Calgary (Osborn and Rajawitz, 1998)) overlay the sands and gravels. The sands and gravels occupy the bed of the Bow River towards downtown Sunnyside enabling a good hydraulic connection between the river channel and aquifer. The silts are present sporadically within the alluvial aquifer but mainly towards the upper levels close to ground surface (see Figure 8). At the upstream Elbow River reach, the aquifer is occupied by sands and gravels or gravels between 3 m and 4 m below the surface.

3.5 Hydraulic Characteristics

Meyboom (1961) reported a transmissivity value of 450,000 gpd/ft, equivalent to 5,590 m^2/d, for the Calgary Brewery Well (NE, ¼ Sec 11, Tp, 24, R.1, W, 5th Mer.). That value is equivalent to a hydraulic conductivity of 3.6 x10^{-3} m/s (310 m/d) assuming an 18 m aquifer thickness estimated by Meyboom for the Inglewood area. Other hydraulic conductivity values for the alluvial aquifer reported by Candel (2014) are summarized in Table 1.

As illustrated in Table 1, the alluvial aquifer displays a wide range of hydraulic conductivity values that range within six orders of magnitude (i.e., from 0.05 to1,843 m/d). This wide range is expected for an alluvial deposit with presence of gravels, cobbles, sands and gravels, sands and silts. Sharp (1977) reported specific yield values for alluvial aquifers ranging from 0.001 to 0.2 with an average value of 0.14. According to Candel (2014) the lowest reported value is related to confined conditions whereas the higher values are related to unconfined alluvial conditions.

According to Meyboom (1961), wells in the bedrock display a decreasing head with an increasing depth relationship, particularly for those wells located at a higher elevation. The bedrock has a low transmissivity of 100 to 200 gpd/ft (1.2 to 4.2 m^2/d), and the wells yield up to 3.0 gpd (2.6 m^3/d). This compares with wells situated in the highly permeable alluvial aquifer that may yield up to 1.0 x 10^6 gpd (64.8 m^3/d).

Table 1: Hydraulic Conductivity Values for the Alluvial Aquifer Based on Candel (2014)

Study	Hydraulic Conductivity (m/d)			
	Range from Tests Other than Multi-Well Pumping Tests		Values from Multi-Well Pumping Tests	
	Min	Max	Min	Max
Savage (2006)[(a)]	5.5	137	626	
Woods (2010)[(b)]	3.8	158	-	
Bel (2000)[(c)]	-	-	181	
Waterline (2011)[(d)]	-	-	0.05	1,843
Van Everdingen et al (2011)[(e)]	-	-	0.05	618

(a) One pumping test was conducted. Minimum and maximum values based on two downhole tests;
(b) Values from slug tests;
(c) One pumping test with four observation wells;
(d) Transmissivity estimates from 40 wells which Candel (2014) used to recalculate hydraulic conductivity.
(e) Reported transmissivity values which were recalculated by Candel (2014) into hydraulic conductivity values based on an average alluvial aquifer thickness.

3.6 Groundwater Flow Directions and Gradients

Figure 6 shows a classed post map showing groundwater elevations measured between 1993 to 2013 using data extracted from borehole logs in the ESAR and the Alberta Water Well databases. The ground surface topography contour map is also shown on the figure. The majority of data represented in Figure 6 are situated between Hillhurst and the area north of the Calf Robe Bridge. Note that circles indicate hydraulic heads less than 1,100 masl whereas squares indicate the heads are greater than or equal to 1,100 masl. Inspection of Figure 6 reveals the following hydraulic head patterns:

- Hydraulic heads decrease from the topographic highs outside the alluvial aquifer toward the rivers, indicating flow toward the alluvial aquifer.
- On the west side of the study area and south of the Bow River heads range from 1180 to 1220 masl, and decrease to between 1055 masl and 1065 masl in the alluvial aquifer. Lateral distances separating these well groupings range between approximately 1,500 m to 2,700 m. Gradients calculated between pairs of head measurements in the uplands and the alluvial aquifer are in the range of 7% to 12%, consistent with the conceptual model of lower hydraulic conductivity outside the alluvial aquifer. These values should be considered rough estimates given the wide range of measurement dates between the data.
- On the west side of the study area and north of the Bow River (northwest of the Hillhurst cross-section), hydraulic heads range from 1085 to 1120 masl and drop to a range of 1058 to 1060 masl in the alluvial aquifer. Lateral distances separating these well groupings range from 1,400 m to 2,300 m. Gradients calculated between pairs of head measurements in the uplands and the alluvial aquifer are significantly lower than those to the south, in the range of 2% to 4%.
- Within the upland area enclosed by the Bow River to the north and the Elbow River to the south and east, gradients are estimated to be approximately 2%.

- Head within the alluvial aquifer follow the same decreasing trend as the river stage elevations. Heads decrease from west to east to south along the Bow River and from south to north along the Elbow River.
- Hydraulic heads in the alluvial aquifer along the Bow River going from west to east show the following ranges:
  - Montgomery: 1056 masl to 1061 masl;
  - Hillhurst-Sunalta-Kensington: 1045 masl to 1049 masl;
  - Downtown area east of the Eau Claire cross-section: 1040 masl to 1043 masl;
  - Fort Calgary: 1038 masl to 1039 masl;
  - Bow Habitat Station: 1032 masl to 1034 masl;
  - Between the Bow Habitat Station and the Calf Robe Bridge: 1029 masl to 1031 masl; and
  - Calf Robe Bridge: 2023 masl to 2024 masl.
- Corresponding gradients in the alluvial aquifer along the Bow River range from:
  - Montgomery to Hillhurst: 0.18%;
  - Hillhurst to Kensington: 0.22%;
  - Kensington to Fort Calgary: 0.21%;
  - Fort Calgary to Bow Habitat Station: 0.17%;
  - Bow Habitat Station to mid-way between the Calf Robe Bridge: 0.38%; and
  - Mid-way between the Calf Robe Bridge to the Calf Robe Bridge: 0.24%.
- Meyboom (1961) reports up to 18 m of gravel in the Inglewood area, which may explain the particularly low gradient estimated between the Fort Calgary and Bow Habitat Station areas.
- The lowest measured hydraulic head in the downtown area is 1,031 masl, northwest of Fort Calgary. It is possible this groundwater depression is caused by aquifer dewatering to maintain dry underground parking facilities. Give the short distance to the Bow River (approximately 100 m), it is likely the dewatering system is drawing in water from the Bow River and possibly the Elbow River which is approximately 625 m away.
- Heads decrease in the alluvial aquifer along the Elbow River going north from the Rideau Park area (1045 masl) to Fort Calgary (1038 masl). The corresponding hydraulic gradient estimate over this stretch of the Elbow River is 0.44%, possibly suggesting the presence of less conductive materials.

The groundwater flow directions described above follow similar regional trends described by Meyboom (1961) for the alluvial aquifer.

Four monitoring wells and data loggers were installed by The City in close proximity to the Bow and Elbow Rivers, as shown on Figure 6. The monitoring well situated at Fort Calgary (N:5656476, E:-3363.491, Elevation:1044.25 masl) shows a simultaneous response with respect to the Bow River streamflow fluctuation (see Figure 10) where the lowest groundwater level attained a base level of 1,028 masl in 2015. This response is indicative of a strong interaction between the Bow and Elbow Rivers and the alluvial aquifer.

As illustrated in Figure 10, there is no delay in the Fort Calgary monitoring well response located approximately 120 m south of the Bow River and 460 m northwest of the Elbow River. A similar response is observed downstream at the Bow Habitat Station monitoring well (N:5655972.6, E:-1317, Elevation:1036.2 masl) located in Inglewood, approximately 220 m south of the Bow River. The recession curves of these two wells closely follow the surface water streamflow declines.

A third monitoring well was installed at Sunnyside (N:5658075, E:-5171, Elevation:1045.5 masl) and a fourth at Kensington (N:5657165, E:-6272.749, Elevation:1048.49 masl). These two wells are located at 400 m and 250 m, respectively, north of the Bow River. The Sunnyside and Kensington monitoring wells display a muted and lagged response to the maximum peaks of river flows. This may be due to these wells not being as strongly connected to the river hydraulically as the other two wells because of a variable hydraulic diffusivity effect in that area of the alluvial aquifer.

The observed increase in hydraulic head during the period of river stage rise versus distance to the river relationship between the Kensington and Sunnyside wells is significantly different from that observed for the Fort Calgary and Bow Habitat Station wells. The Kensington well water level rises approximately 20 cm during early June 2015 whereas the Sunnyside well water level rises approximately 10 cm (Figure 10). This observation is expected since the Sunnyside well is farther from the Bow River (400 m) compared to the Kensington well (250 m). Further east along the Bow River, the groundwater rise during early June 2015 at the Fort Calgary well (120 m from the river) and the Bow Habitat Station well (220 m from the river) are approximately 50 cm and 56 cm, respectively. Although the Fort Calgary monitoring well is situated half the distance to the river compared to the Bow Habitat Station well, the water level rises in the two wells are similar. One possible explanation for this observation is the fact that the Fort Calgary well is proximal to both the Bow and Elbow Rivers. Water from the Bow River recharging the alluvial aquifer in the Fort Calgary area may be discharging near the mouth of the Elbow River.

River bank storage within the alluvial aquifer appears to provide a weak buffering effect to groundwater flooding in the Calgary downtown area. A rough approximation of the entire area of alluvial aquifer in the study area (refer to Figure 5) is 99.3 km^2. Assuming a range of unsaturated aquifer thickness from 3 to 5 m and porosity from 20% to 30%,provides a range of unsaturated pore space volume in the alluvial aquifer between approximately 59.6 Mm^3 and 148.9 Mm^3. Integrating the area under the Calgary downtown 20 and 100 year streamflow hydrographs developed during the hydrological modelling (see below) results in estimates of flood water volumes of approximately 379.6 Mm^3 and 623.4 Mm^3, respectively. Assuming this range of unsaturated thickness and porosity, for the 20 year flood the unsaturated portion of the entire alluvial aquifer could store approximately 16% to 40% of the Bow River flood water (this does not account for flood water from the Elbow River). For a 100 year flood, between 10% and 24% of the Bow River flood water could be stored in the aquifer.

In summary, the sand and gravel aquifer has the most favourable hydraulic properties in terms of facilitating groundwater flow. The lateral continuity of sand and gravel accumulation provides for lateral hydraulic continuity between the locally thicker sand and gravel pockets. Layers of silt and till are inter-bedded within the sand and gravel aquifer. The heterogeneity is reflected by the large range of hydraulic parameter values. Groundwater hydrograph responses closely mimic changes in the Bow River streamflow (see Figure 10 and Candel 2014) provide evidence of strong groundwater-surface water interactions.

Most of the monitoring wells included in previous studies are located in natural areas (e.g. wells at Shouldice Park, Sue Higgins Park, alluvial aquifer wells below Lynnview Ridge and Camp Gardner (Candel 2014) and The City wells at Fort Calgary and the Bow Habitat Station). The City wells at Sunnyside and Kensington are the only urban wells. It is possible (Dr. Cathy Ryan, personal communication) that wastewater and stormwater infrastructure may act as preferential flow conduits, and if so urban settings is under represented in the groundwater monitoring dataset.

4.0 GROUNDWATER FLOW MODELLING

4.1 Alternative Approaches

The following three alternative groundwater flow modelling approaches were identified in this study:

- Option 1 – Small Scope

  This option involved selection of two cross sections along the Bow River, and one cross section along the Elbow River. A two-dimensional (2D) groundwater flow program (i.e., MODFLOW) was used to develop the groundwater models at these cross sections. The river water level hydrographs estimated at these cross sections were used as hydraulic head boundary condition for the groundwater flow modelling. Three selected flood return periods (e.g., 20-, 100- and 500-year floods) were modelled.

- Option 2 – Medium Scope

  The approach for this option is the same as Option 1 except for selection of additional cross sections. This option would involve selection of seven cross sections along the Bow River, and three cross sections along the Elbow River.

- Option 3 – Large Scope

  This option would involve the construction of a three-dimensional (3D) groundwater model (i.e., Hydrogeoshere) to simulate the groundwater flow for the entire study area. The surface water flood model (i.e., HEC-RAS) would be run in a dynamic mode to generate the water level hydrographs at all the river cross sections currently in the HEC-RAS model. Both the surface water and groundwater models would be run for the 13 flood events with return periods ranging from 2 to 1,000 years.

The advantages and disadvantages of the above-mentioned options were identified and listed in Table 2. These options were discussed with The City. The City selected the small scope approach mainly in consideration of the required effort and study schedule.

Table 2: Comparison of Alternative Groundwater Flow Modelling Approaches

Option	Advantages	Disadvantages
Small Scope	■ Minimum effort requirement	■ Very rough estimates of maximum groundwater levels and areas of groundwater flooding
Medium Scope	■ Medium level of effort required ■ Improved representation of the entire study area using more cross sections relative to the small scope option	■ Rough estimates of maximum groundwater levels and areas of groundwater flooding
Large Scope	■ Accurate estimates of the maximum groundwater levels and areas of groundwater flooding in the entire study area ■ A valuable tool for evaluating potential flood mitigation options in terms of their effects on groundwater flooding (i.e., increased or reduced groundwater flooding damage) ■ The tool can be used for other groundwater management studies in the future	■ A large level of effort required

4.2 Methodology Applied in this Study

The modelling methodology applied in this study involved the following steps:

1) Three geologic cross sections which locations are shown in Figure 6 (sections 1 through 3) were selected for the groundwater modelling based on discussions with The City. These cross sections were selected to represent typical alluvial aquifer conditions beneath the Calgary downtown area.

2) The detailed borehole geologic data along the three cross sections were extracted from the ESAR database and used to develop the two-dimensional (2D) vertical representation of hydrostratigraphy. Hydrogeologic maps available in the public domain were used as a guide during interpretation of the borehole data control points.

3) The geologic cross sections were used in the following two 2D vertical groundwater flow models:

    a. Hillhurst cross-section model; and

    b. Eau Claire and Mission combined cross-section model.

4) The United States Geological Survey groundwater flow program - MODFLOW (McDonald and Harbaugh, 1988) was used to develop the groundwater flow models. VISUAL MODFLOW (Version 4.6, 2013; Schlumberger 2013) was used as the pre- and post-processor for the groundwater simulations.

5) The groundwater model was run in steady-state mode using the pre-flood river elevations to simulate the pre-flood water tables.

6) Transient groundwater flow models were then run using the river flood level hydrographs in the MODFLOW RIVER boundary cells to simulate the maximum groundwater levels for three selected flood events (i.e., 20-, 100- and 500-year floods). The river flood level hydrographs at the three geological cross sections were estimated based on the simulated river water levels for the various flood events (Golder July 2015) and the estimated design flood flow hydrographs for the Bow and Elbow Rivers (Golder January 2015).

7) A sensitivity analysis was conducted to evaluate the degree of uncertainty related to various model parameters.

4.3 Cross Sections and Flow Model Setup

The three selected cross sections are shown in the following figures:

- Figure 7: Cross-section 1 – Hillhurst, and
- Figure 8: Cross-section 2 – Eau Claire and Cross-section 3 – Mission.

The selected cross sections were oriented approximately perpendicular to the longitudinal axis of the alluvial aquifer and the Bow and Elbow River valleys. These cross sections, located at Hillhurst (Section 1), Eau Claire (Section 2) and Mission (Section 3) were used to construct the 2D vertical groundwater flow models.

The Hillhurst model domain length is 4,000 m, and the combined Eau Claire and Mission model domain length is 5,250 m (see Figure 11). For the Hillhurst cross section model an extended area of 1 km south and north was defined in MODFLOW to avoid artificial boundary effects on the model results. As indicated above, the Eau Claire and Mission sections were modelled as one continuous 2D vertical section. However, the results were reported separately for the Eau Claire section, that is adjacent to the Bow River, and the Mission section, that is adjacent to the Elbow River.

Professional judgement was applied in selecting the borehole logs to represent the lithological predominance along each cross section. The lithological conditions pertaining to each site are illustrated in Figures 7 and 8. Numerical model construction consisted of the following elements:

- The 2D vertical cross-section models were discretized as follows:
  - Hillhurst cross-section model - 42 rows and 465 columns resulting in 19,530 cells; and
  - Combined Eau Claire and Mission cross-section model - 62 rows and 752 columns resulting in 44,950 cells.
- Both models were discretized using columns of 5 m in the horizontal direction and rows of 0.5 m in the vertical direction. The selected spatial distribution and model cell size were considered adequate and practical to represent the lithological variability in the cross sections, the depths of the rivers, and the deflections of the groundwater table.
- Hydraulic conductivities and storage coefficients of various hydrostratigraphic units were compiled from the published literature (Table 1).
- The hydrostratigraphy developed during the conceptual model step was mapped in the numerical model by assigning the appropriate hydraulic conductivity and storage coefficient values to the model cells.

- The Bow and Elbow Rivers were modelled using the MODFLOW RIVER boundary condition. River water surface elevations were based on either the pre-flood level (for the steady-state model to simulate the initial hydraulic head condition for the transient simulations), or the river flood water level hydrographs (for the transient model to simulate the groundwater level rise and fall during each flood event).
- MODFLOW CONSTANT HEAD boundary conditions were applied to the two side boundaries of each cross-section model. The constant head boundary value in the bedrock for each cross section was assigned such that 0.2% to 0.6% of the mean river discharge was sourced from the bedrock (Cantafio and Ryan 2014).
- A high hydraulic conductivity value equal to 1 m/s (86,400 m/d) was assigned to the model domain above the ground surface to allow simulation of overland flooding conditions (see Table 3).
- The hydraulic parameter values specified for each lithological unit in MODFLOW are summarized in Table 3. The values in Table 3 fall within the ranges of hydraulic parameter values (see Table 1) reported by Candel (2014).

Table 3: Hydraulic Parameters Applied to the Groundwater Flow Model

Material	Hydraulic Parameters				
	K (x,y,z) (m/d)	Ss(1/m)	Sy	Eff. Por.	Tot. Por.
Sand	8.6	1.0 x E-4	0.22	0.17	0.35
Silt	0.86	1.0 x E-4	0.15	0.22	0.45
Till	8.6×10^{-4}	1.0 x E-4	0.05	0.27	0.55
Gravel	864	1.0 x E-4	0.1	0.1	0.4
Sand and Gravel	86.4	1.0 x E-4	0.2	0.19	0.38
Bedrock (Paskapoo Formation)	4.3×10^{-4}	1.0 x E-4	0.1	0.1	0.15
Zone of High Conductivity Above Ground Surface to Allow Ponding During Flood Conditions	86,400	1.0	1.0	1.0	1.0

4.4 Modelling Results

4.4.1 Analysis of the Modelling Results

The modelling results were analyzed in terms of the delta H versus distance for the simulated flood events. Delta H represents the difference between the simulated peak of the groundwater level hydrographs at various locations and the peak levels of the Bow/Elbow River flood hydrographs. The distance for all delta H plots was calculated from the edge of surface flooding. The distances (X-axes) shown on Figures 14 and 16 (Delta H plots) are therefore different than the distances shown on Figures 13 and 15, which are the distances from the edge of the pre-flood river channels.

The estimated delta H values are influenced by the hydraulic conductivities of the various hydrostratigraphic units. The pressure transient effect in relatively low conductive materials (e.g., silt or clay) is delayed and muted resulting in a larger delta H value. Conversely, the pressure transient effect in relatively high conductive materials (e.g., sand or gravel) is more immediate and unimpeded resulting in a smaller delta H value.

The modelling results are discussed in the following sections.

4.4.2 Cross-Section 1 – Hillhurst

The groundwater conditions during floods for the Hillhurst area (i.e., Cross-section 1) were evaluated using the Hillhurst cross-section model. A model sensitivity analysis was conducted for this cross-section model (see Figure 12). The modelling results for the 20-, 100- and 500-year flood events are shown in Figure 13 and are discussed below:

- For the 20-, 100- and 500-year floods, at a distance of 50 m from the Bow River, the maximum groundwater levels would occur approximately 0.25, 0.05 and less than 0.01 day, respectively after the Bow River flood levels peak.
- Further away from the river the groundwater response is more lagged and muted.
- For the 20-year flood, at a distance of 300 m, the maximum groundwater level is simulated to be 1048.7 masl which is attained in approximately 2.6 days after the Bow River flood level peaks. The pre-flood groundwater level at this location was simulated to be 1048 masl.
- For the 100-year flood, at a distance of 300 m, the maximum groundwater level is simulated to be 1049.6 masl which is attained in approximately 1.7 days after the Bow River flood level peaks.
- For the 500-year flood, at a distance of 300 m, the maximum groundwater level is simulated to be 1050.5 masl which is attained in approximately 1.7 days after the Bow River flood level peaks.
- The modelling results for the southern and northern floodplain areas are similar at this cross section. The relationships of delta H versus distance for both floodplain areas are very similar. Therefore, an averaged relationship is provided in Figure 14.
- The average delta H values versus distance for the three flood events are presented in Table 4.

Table 4: Delta H versus Distance Hillhurst Model

Ave. Distance (m)	Ave. Delta H (m) (20 year)	Ave. Distance (m)	Ave. Delta H (m) (100 year)	Ave. Distance (m)	Ave. Delta H (m) (500 year)
0	0	0	0	0	0
18.46	0.32	11.46	0.76	8.96	0.67
68.55	0.74	61.48	1.39	58.98	1.56
118.36	1.08	111.35	1.84	108.85	2.19
165.48	1.26	162.54	2.20	157.54	2.53
243.68	1.55	211.71	2.31	209.21	2.87
343.48	1.74	286.48	2.51	283.98	3.14
443.29	1.90	361.29	2.71	358.79	3.41
715.50	2.28	562.50	3.36	557.50	4.26

4.4.1 Cross-Section 2 – Eau Claire

The groundwater conditions during floods for the Eau Claire area (i.e., Cross-section 2) were evaluated using the combined Eau Claire and Mission model. The modelling results are shown in Figure 13 and are discussed below:

- For the 20-year flood event, at a distance of 50 m south of the Bow River, the maximum groundwater level would occur at approximately 0.6 day after the Bow River flood level peaks. No groundwater level change was simulated beyond 300 m south of the Bow River.
- The delta H versus distance plot for the southern floodplain of the Bow River for the 20-year flood event is shown in Figure 14. This relationship is similar to that for the Hillhurst cross-section for the same flood event.
- For the 20-year flood event, the modelling results indicate that the aquifer north of the Bow River would be fully flooded. Therefore, no hydrograph and delta H versus distance results are presented.
- Similarly, the modelling results pertaining to the 100- and 500-year floods indicate a fully flooded aquifer in both the northern and southern floodplains. Therefore, no hydrograph and delta H versus distance plot were generated for these two flood events.

4.4.1 Cross-Section 3 – Mission

The groundwater conditions during floods for the Mission area (i.e., Cross-section 3) were evaluated using the combined Eau Claire and Mission model. The modelling results for Mission are shown in Figure 15 and discussed below:

- For the 20-year flood event, at a distance of 50 m south and north of the Elbow River, the maximum groundwater levels would occur at approximately 0.23 day after the Elbow River flood level peaks.
- For the 20-year flood event, the delta H values versus distance for the southern and northern floodplains are shown in Figure 16 and Table 5. The results show an increasing trend in the delta H value which tends to stabilize beyond 150 m from the south edge of the Elbow River overland flooding, whereas the modelling results for the northern floodplain indicate a continuous increasing of delta H values with distance. A relatively low conductive silt unit located north of the Elbow River acts as a barrier for the propagation of the flood water (see Figure 11), so the delta H continues to increase. The south floodplain of the Elbow River consists of relatively high conductive gravels that result in easier propagation of hydraulic pressure.
- The modelling results pertaining to the 100- and 500-year floods indicate a fully flooded aquifer. Therefore, no hydrographs and delta H versus distance plots were presented for those two flood events.

Table 5: Delta H vs. Distance - Mission Model

Distance (m)	South Delta H (m) (20 year)	North Delta H (m) (20 year)
0	0	0
50	0.66	0.50
100	1.06	1.05
150	1.35	1.60
200	1.46	2.23
250	1.49	2.27
300	Not Determined	3.11

Model Sensitivity Analysis

To evaluate the model uncertainty, a suite of sensitivity analysis was conducted on the hydraulic parameters (i.e., hydraulic conductivity and storage coefficients) of each hydrostratigraphic unit by adjusting their values within a reasonable range. The sensitivity analysis was performed only for the Hillhurst cross-section model for the 100-year flood event. The changes applied to the model are summarized below:

- The hydraulic conductivity values for each hydrostratigraphic unit were increased, and decreased, by a factor of 10. Note that the hydraulic conductivity values for the high conductive zone above the topographic surface were unchanged.
- The specific yield value for each hydrostratigraphic unit was increased or decreased by approximately 50%. Note that the specific yield value for the high conductive zone above the topographic surface was unchanged.

The results of the sensitivity analysis (Figure 12) show that the models are more sensitive to changes in the hydraulic conductivity values than changes in specific yield.

4.5 Input to Groundwater Flood Damage Modelling

The modelling results illustrated in Figure 14 and in Table 4 were used as groundwater level inputs for the groundwater flood damage modelling. Model results indicate a different Delta H versus Distance relationship north of the Elbow River at the Mission cross-section compared to the Mission cross-section south of the river (Figure-16) and the Hillhurst and Eau Claire South cross-sections (Figure 14). The different Delta H versus Distance relationship has been inferred to be caused by the presence of lower hydraulic conductivity silt north of the Elbow River in the Mission cross-section (Figure 8). Due to the absence of a three dimensional geologic model of the alluvial aquifer that could more appropriately consider near-river lithology changes, it was decided to use the more typical Delta H versus Distance relationship throughout the study domain based on the 20, 100 and 500 year average curves shown on Figure 14. This relationship was used to determine the maximum groundwater table rise within the alluvial aquifer. Maximum groundwater elevations are calculated by subtracting the Delta H value (based on distance from the surface inundation) from the maximum surface inundation water level. The surface inundation water level was calculated from the HEC-RAS model developed by the water resources team.

If the extent of inundation for a particular flood return period completely covered an area of the alluvial aquifer this scenario was not simulated with the groundwater flow model and the maximum groundwater elevation will be assigned the elevation of the surface water. In order to more reliably assess how quickly the alluvial aquifer becomes flooded in inundated areas a refined modelling approach should be used, as discussed in Section 5.

Figures 17 to 19 show the alluvial aquifer extent and inundation areas for 20, 100 and 500 year floods. There are portions of the alluvial aquifer that are not connected to regions where inundation occurs, the MacLeod channel being a prominent example. In order to not over-estimate the potential for groundwater flooding damage, the maximum groundwater table rise surface for each return period was constrained to be only over portions of the aquifer that are hydraulically connected to areas where surface inundation was simulated to occur. The distance from inundated areas selected to crop areas of the aquifer not included in the maximum groundwater rise calculation was 750 m. This distance was selected because modelling results indicated minimal groundwater level rise at this distance from the river (Figure 13). Areas of the alluvial aquifer that are included in the water table rise calculation are shown on Figures 17 to 19. Note that for the 500 year flood (Figure 19), surface inundation was modelled to occur over the Highfield Channel portion of the alluvial aquifer (refer to Figure 5). This area was modelled separately, meaning the groundwater surface was calculated using only the surface water inundation elevations that occur within the footprint of the Highfield channel. This was necessary because there are areas where the 500 year surface inundation extent along the Elbow River is within the 750 m buffer distance of the Highfield Channel portion of the alluvial aquifer.

There are two major limiting assumptions implicit in how the groundwater flow modelling results were used to develop the groundwater surfaces over the entire alluvial aquifer extent for each return period required for the IBI Flood Damage Model, namely:

- The Delta H versus Distance relationship that determines the groundwater elevation and was developed using a minimal number of two-dimensional groundwater flow models was extrapolated over the entire extent of the alluvial aquifer.
- The Delta H versus Distance relationships developed for three flood return periods (20, 100 and 500 years) were used for all the return periods used in the IBI Flood Damage Model (ranging from 5 to 1000 years).

These limiting assumptions necessitated that the approach used to extrapolate the groundwater modelling results over the entire alluvial aquifer be iteratively refined in order to remove spurious effects such as discontinuities in the calculated groundwater surface. The final approach to developing the groundwater surfaces for each return period consisted of the follow steps:

1) For each return period, the maximum surface-water inundated elevations were extrapolated from the HEC-RAS-estimated inundation footprint over the extent of the alluvial aquifer. The extrapolation was completed by extending the cross-sections across the river (that were used by the water resources engineering team to calculate the HEC-RAS inundation surfaces) over the extent of the alluvial aquifer. Elevation data along these cross-sections were then interpolated over the extent of the alluvial aquifer. Over small areas there were instances of over-estimation of the surface water inundation elevation grid (i.e. a surface inundation for a higher flood return period being slightly lower than that for a lower return period). This was interpreted as being caused by the interpolation process. The surface water elevation grids were thus constrained such that elevations for any particular return period were always greater than or equal to the elevation of the next lower return period grid at the same location.

2) The surface water elevation required in the groundwater surface calculation (GW Elevation = SW Elevation – Delta_H(Distance)) was based on the surface water elevation maps produced in Step 1 above. The extrapolated surface water elevation maps were required because using the nearest surface water elevation in the inundation zone produced significant discontinuities in the resulting groundwater elevation surface. To understand how this occurs, consider two points in the alluvial aquifer that are close together, outside the inundation zone, and near a bend in the river. The nearest surface inundation elevation for one of the points may be significantly upstream of the nearest surface inundation elevation of the second point. Consequently, the surface water elevations used in the groundwater equation can be significantly different for two locations within the alluvial aquifer that are close to each other, which propagates through to the groundwater surface elevation calculation.

3) Delta H versus Distance relationships were developed using the groundwater modelling results for the 20, 100 and 500 flood return period cross-section models. For other return periods, the Delta H versus Distance relationships were calculated using the 20, 100 and 500 year results, as shown below:

   - Return Period 5 years to 50 years: use the 20 year model result;
   - Return Period 75 years to 200 years: use the 100 year model result; and
   - Return Period 350 years to 1000 years: use the 500 year model result.

4) The groundwater table elevation grids for each return period were calculated using the extrapolated surface inundation elevation grids described in Step 1, the distance to the nearest flooded area (i.e. surface water inundation) and the Delta H versus Distance relationships described in Step 3. This approach is conservative since it assumes there is direct hydraulic connection between the ponded surface water and the underlying alluvial aquifer. The presence of asphalt or a laterally extensive zone of low permeability silts or clays close to surface would act to hydraulically isolate the water ponded at surface with the alluvial aquifer. The preliminary assessment discussed herein indicates low permeability sediments are frequently found close to surface, however, it was beyond the scope of the project to map out the areal extent of these low permeability sediments. Consequently, it was conservatively assumed that there are sufficient areas of high permeability sediments at surface (that may possibly be disconnected) such that the alluvial aquifer was essentially hydraulically connected to the ponded surface water.

5) The average, long term river elevations from the HEC-RAS modelling (representative of pre-flooding conditions) were extrapolated over the extent of the alluvial aquifer in the same manner as the extrapolated flood return period inundation surfaces described in Step 1. In some locations, it was observed that the calculated groundwater surfaces dropped below the interpreted long term average surface water elevation grid. This was interpreted as the Delta H versus Distance relationship over-estimating the difference between the surface water and groundwater surfaces. The final groundwater surfaces were constrained to always being greater than or equal to the long term average surface water elevation grid.

6) A final consistency check was made to constrain the groundwater surface for any particular return period being greater than or equal to the groundwater surface for the next lower return period.

Groundwater elevation contours for the 20, 100 and 500 year return periods are shown on Figures 17 to 19.

The groundwater levels estimated for the entire study area using the above-mentioned approach are approximate because of the following:

- A minimum number (i.e., three) of geological cross sections were used for setting up the groundwater flow models.
- Model results from the Hillhurst cross-section, north and south of the Bow River, were used to develop the Delta H versus Distance relationship that was used to calculate the water table rise over the river connected alluvial aquifer. Results for the Mission South cross-section were very similar to the Hillhurst results.
- The selected cross sections are indicative of the typical alluvial aquifer configurations, but they are not expected to capture the spatial variability of the alluvial aquifer throughout the study area.
- The selected cross sections are indicative of the typical types of the alluvial sediments, but they are not expected to capture the lithological variability in the alluvial aquifer throughout the study area.
- The hydraulic parameter values and water levels simulated in the models have not been calibrated using field measurements.
- The 2D approach is inherently approximate as the actual groundwater flow conditions are three dimensional.

- The Delta H versus Distance relationships for return periods other than 20, 100 and 500 years were not based on groundwater modelling results but rather estimated from the model results developed for the 20, 100 and 500 year return periods.

4.6 Assessment of Survey Data from the 2013 Calgary Flood Event

After the 2013 Calgary flood, Professor C. Ryan's University of Calgary research team conducted a survey to assess flood damage in different areas of Calgary's downtown. Part of the survey involved determining the type of flood impact and estimating the maximum groundwater elevation in flooded basements. Since the 2013 flood is estimated to represent a flood return period of between 50 and 100 years (probably closer to 100 years), this data represented an opportunity to compare predicted groundwater elevations against elevations estimated during the 2013 survey.

4.6.1 Comparison of Model Predictions to the 2013 Calgary Flood Event

In order to ensure confidentiality, the university research team provided Golder with a data set of downtown Calgary locations that included both actually surveyed locations in addition to fictitious locations were no survey data were collected. Golder provided the predicted (or simulated) groundwater elevations at these locations for the 50 and 100 year return periods and returned the dataset to the university research team who prepared calibration plots that included the survey locations. The simulated 50 and 100 year return period groundwater elevations were calculated by subtracting the Delta H versus Distance results for these return periods from the corresponding surface water inundation surfaces. Calibration plots showing estimated groundwater elevations based on survey responses (X-axis) and the predicted groundwater elevations from the Golder geospatial modelling (Y-axis) were produced for both return periods, and are shown on Figure 20.

The data on the plots shown on Figure 20 have been classed based on the distance from the surface inundation zone. Unfilled circles represent locations that were overland flooded (as determined by their location inside the interpreted 2013 inundation extent polygon provided by the City of Calgary). Colour-filled circles indicate locations outside the 2013 inundation polygon, grouped into classes as shown in the figure legend. Data points falling closer to the 45 degree solid line indicate a better match between predicted and survey-estimated groundwater elevations compared to points that fall further away from the line. Data points above the 45 degree line indicate predicted groundwater elevations are higher than survey-estimated elevations whereas point below the line indicate predicted elevations are lower than those estimated during the 2013 flood survey. Data corresponding to higher elevations on the plots occur further upstream along the river. Data locations are not shown on a map to maintain the confidentiality of survey respondents, but the majority of the data was collected in the communities of Sunnyside, Hillhurst and West Hillhurst (for Bow River data locations; data not published) and Roxboro, Rideau Park and Elbow Park (for Elbow River data locations; Abboud, 2014).

The following observations are made from comparing the 50 and 100 year flood return period groundwater elevation calibration plots shown on Figure 20:

- The 100 year flood return period results provide a better match between predicted and estimate groundwater elevations than the 50 year flood return period results.

- In particular, the match for points within the inundation extent polygon (open circles) fall much closer to the line for the 100 year modelled results. This is interpreted to simply indicate that the 2013 Calgary flood is better represented by the 100 year flood return period hydrology model than by the 50 year flood return period model.
- The 100 year predicted groundwater elevations are consistently lower than the survey-estimated elevations for elevations above approximately 1047 masl. At lower elevations, the predicted elevations are consistently above the estimated elevations.
- At the lower elevation range (less than 1047 masl), the predicted elevations within the inundation zone (i.e. the surface water inundation level) are consistently greater than the estimated elevations. Golder infers from this observation that the trend reversal (i.e. predicted greater than survey-estimated) at lower elevations is either a result of the approximations made during the hydrology modelling or how the water elevations were estimated during the survey.
- At higher elevations, locations further from the inundation zone (purple, blue and green dots) show a larger discrepancy between predicted and estimated groundwater elevations than locations closer to the inundation zone (red, orange and yellow dots).
- Over most of the range of elevations, the predicted elevations are consistently lower than the estimated groundwater elevations from the 2013 survey. This indicates the model results may under-predict the actual groundwater flooding elevations, i.e., the results are not conservative from a flood damage modelling perspective.
- Although the mean residual for the 100 year flood return period is -0.5 m, this statistic is influenced by the trend reversal noted above. Over most of the elevation range, the predicted groundwater elevations visually appear to be on average approximately 1 m below the estimated groundwater elevations.

Aside from the limitations of the modelling approach listed in Section 4.5 above, the calibration to the 2013 Calgary flood data was limited by the fact that the groundwater elevation calculation was based on the hydrological modelling for a 100 year flood return period and not on the actual 2013 maximum flood inundation surface.

Although there are discrepancies between predicted and estimated groundwater elevations from the 2013 Calgary flood, the match is considered sufficiently adequate to suggest the preliminary numerical groundwater flow modelling and geospatial modelling approach developed for this study can be used to refine the Flood Damage Model. Filling in data gaps and a more refined modelling approach (discussed below) would improve the match between predicted and estimated groundwater elevations.

4.6.2 Survey Data Related to Flood Resistant Basements

Table 6 summarises the results of the University of Calgary 2013 Calgary flood survey data (personal communication, Jason Abboud and Cathy Ryan). The results from this particular survey indicate approximately 7% of the homes were resistant to groundwater flooding, i.e., had “impermeable” basements. A range of between 4% and 10% to estimate the number of homes resistant to groundwater flooding is suggested for use in the IBI Flood Damage Model.

Table 6: Summary of University of Calgary 2013 Flood Survey Data

Description	Number of Homes	Percent of Flooded Homes
Only groundwater flooding (no surface flooding)	22	13%
Groundwater flooding first, followed by overland flooding	74	43%
Only overland flooding (no groundwater flooding prior to overland flooding)	12	7%
Unknown route of water entry	63	37%
Total flooded homes surveyed	**171**	**100%**
Total non-flooded (either surface or groundwater) homes surveyed within the flood risk area)	12	
Total number of homes surveyed	183	
Percentage of homes that experience neither surface nor groundwater flooding that were within the flood risk area	6.6%	

5.0 DATA GAPS AND OPPORTUNITIES FOR IMPROVEMENT

5.1 Geological Data

The main sources of geological information available for the study area are listed below in the order of importance:

- the ESAR database;
- the Alberta Well Database;
- the City of Calgary Database and reports; and
- the digitized maps from the Alberta Geological Survey (Meyboom 1961 and Moran 1986).

The geologic data correlated for the study is limited to the hydrogeologic characterization along the selected cross sections. Based on the information extracted and correlated, there is uncertainty in characterizing the lithological variability. The degree of uncertainty is influenced by the number of borehole logs available (and the level of detail in each log), the distance between borehole logs, and the distance from the cross section. To reduce the uncertainty, a three-dimensional geological model supported with a geostatistically-based method of analysis can be constructed, and the resulting geological model can then be used to extract the cross-sectional information.

The ESAR Database has the information for a good characterization of the variable geological conditions in the study area, including variability of the alluvial aquifer thickness and lithological variability. Other potential sources of information might be geotechnical drilling reports completed for building or bridge foundation assessments.

There is an opportunity for The City to use the ESAR database to conduct a detailed geologic interpretation for refined definition of the distribution of permeable alluvial sediment within the study area. The outcome would be a set of maps including a net sand and gravel thickness map, a sand and gravel top structure map, and silt thickness distribution map.

Review of the available information shows that there is limited geological data for the study area along the Bow River downstream of the Calf Robe Bridge.

5.2 Constraint Mapping

Once the detailed geological mapping information would be available, there would be an opportunity to develop constraint maps for estimating the groundwater flood risk areas. Constraint mapping would involve comparing the trends of sand and gravel and the top elevation of the sand and gravel with the elevations of priority sub-surface infrastructure. This is a screening level activity for identifying the following:

- the areas that are well defined and are of relatively high risk to groundwater flooding;
- the areas that are poorly defined but potentially at risk of groundwater flooding; and
- the areas that are likely to be at relatively low risk of groundwater flooding.

5.3 Groundwater Monitoring

There are a large number of shallow wells installed in the alluvial aquifer in the study area. There is an opportunity to compile and collate these monitoring data to generate a detailed groundwater hydraulic head contour map in the study area. These data would be valuable for characterizing the groundwater conditions in the study area and for calibrating groundwater flow models. In particular, expanding the monitoring network near the confluence of the Bow and Elbow Rivers would be beneficial when studying how the groundwater system interacts with hydrological conditions of both rivers.

5.4 Hydraulic Conductivity Measurement

The results of the groundwater models show that the simulated groundwater levels are highly sensitive to the hydraulic conductivity of the alluvial aquifer (see Figure 12). Measurements of hydraulic conductivity at strategic locations by pumping tests or slug tests will be highly beneficial for refined estimation of the hydraulic conductivity values and their variability throughout the study area.

5.5 Additional Groundwater Flow Modelling

The 2D groundwater flow modelling completed in this study was based on a minimum number of geological cross sections. While 2D modelling would improve the City's understanding of the spatially variable hydrostratigraphic conditions within the alluvial aquifer, the approach implicitly assumes flow into and out of the cross-section is negligible. Even if the alluvial aquifer is completely homogenous (which it is not) the variable river stage elevations along different reaches of the river will cause some component of flow into or out of any vertical cross-section perpendicular to the river. The relative importance of the three-dimensional nature of the groundwater flow dynamics can only be assessed with a three-dimensional groundwater flow model.

For this reason, Golder suggests that ultimately, a 3D groundwater flow model based on detailed geologic mapping should be developed for the study area. A 3D modelling approach would remove the dimensionality restriction that constrains groundwater flow along the section profile and would account for the geologic variability throughout the alluvial aquifer. Using an integrated surface water-groundwater model would allow a rigorous treatment of unsaturated groundwater flow conditions coupled to the transient hydrological conditions. Advances in coupled modelling approaches now make such models feasible. An integrated 3D modelling approach would be particularly useful in understanding the interaction of both the Bow and Elbow Rivers on groundwater conditions near the confluence of the rivers and assessing groundwater flooding mitigation options.

The modelling could be completed in a phased approach, if desired. For example, the initial phase might implement a three-dimensional framework that assumes a simplified alluvial aquifer geology and subsequent phases could incorporate refined interpretations of the geologic spatial variability developed from detailed mapping programs.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions are drawn based on the analysis and results of the groundwater flow modelling conducted in this study:

- The estimated maximum extents of the alluvial aquifer and maximum groundwater flood levels provided an improved basis for updating the groundwater flood damage model.
- The simulated groundwater levels are most sensitive to the hydraulic conductivity values. The level of certainty associated with the groundwater modelling results will be increased if the appropriate groundwater monitoring data are used for calibrating the models.
- A limited number of geological cross sections were used for the groundwater flow modelling. They represent typical geological conditions of the alluvial aquifer only. They are not expected to capture the spatial variability of the alluvial aquifer hydraulic conditions and lithologic variability throughout the entire study area.
- The groundwater flow analysis was completed using a two-dimensional vertical cross-section approach. While simpler to implement, and therefore less costly, the approach implicitly assumes flow into and out of the cross-section is negligible. Even if the alluvial aquifer is completely homogenous (which it is not) the variable river stage elevations along different reaches of the river will cause some component of flow into or out of any vertical cross-section perpendicular to the river. The relative importance of the three-dimensional nature of the groundwater flow dynamics can only be assessed with a three-dimensional groundwater flow model.

6.2 Recommendations

The following recommendations are made:

- The estimated extents of the alluvial aquifer (see Figure 3) should be used in the groundwater flood damage model to define where potential groundwater flooding might occur as a result of rising river flood levels.
- The modelled maximum groundwater levels in the alluvial aquifer (see Figures 14 and 16, and Tables 4 and 5) should be used in the groundwater flood damage model to estimate maximum groundwater levels throughout the study area.
- A number of data gaps and opportunities to address these gaps were identified in this study (see Section 5.0). In its future efforts, The City should consider the following opportunities to improve the understanding, characterization and modelling of the groundwater conditions in the study area:
  - detailed geologic mapping using ESAR database;
  - constraint mapping for estimating groundwater flood risk areas;
  - additional groundwater monitoring; and
  - additional groundwater flow modelling including application of a 3D groundwater flow model based on detailed geologic mapping.

Report Signature Page

GOLDER ASSOCIATES LTD.

Donald Haley, M.Sc.
Associate, Senior Groundwater Scientist

Dejiang Long, Ph.D, P.Eng
Principal, Senior Water Resources Engineer

DH/DL/CR/sb

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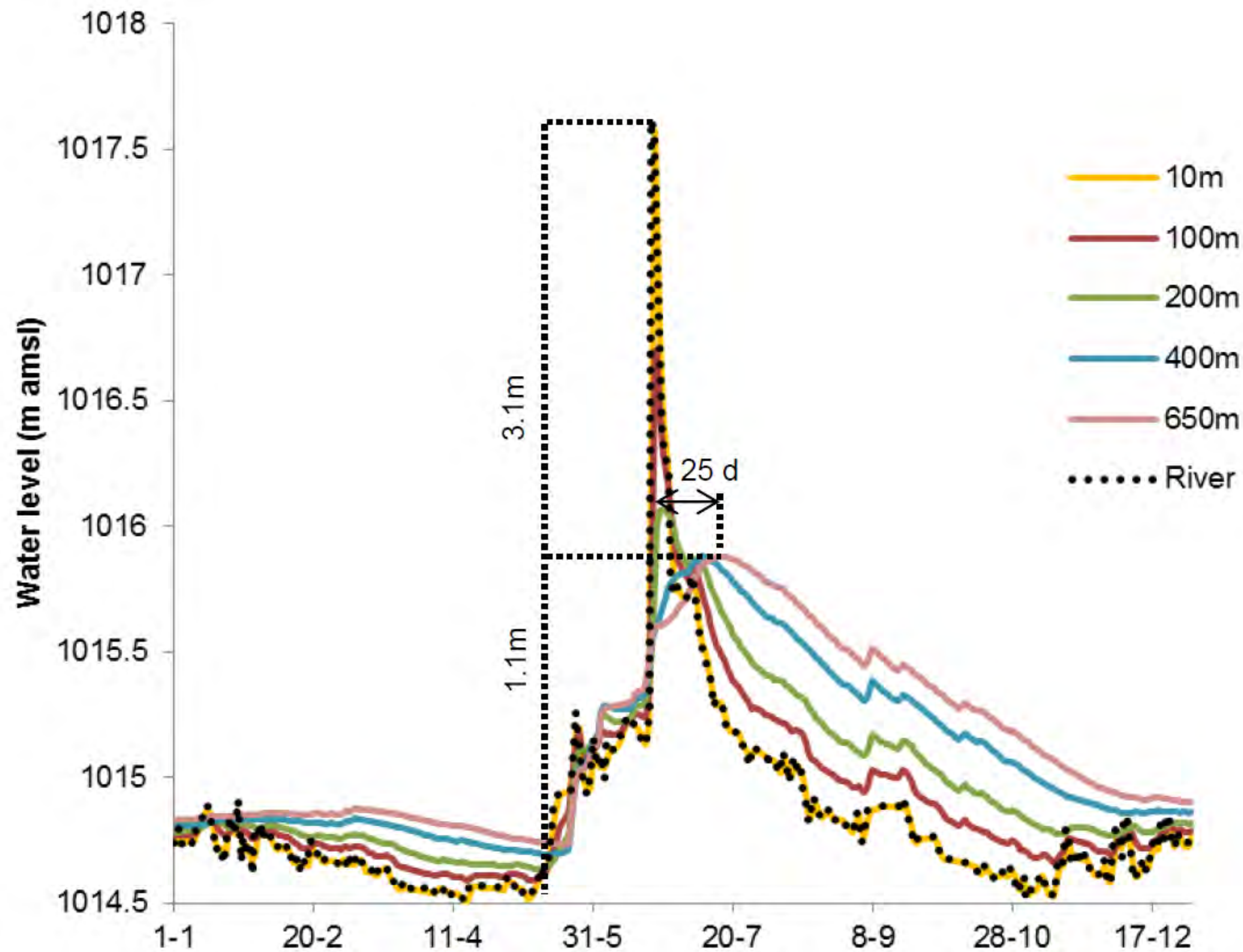
FIGURES



CLIENT City of Calgary			PROJECT **GROUNDWATER FLOODING**	
CONSULTANT	YYYY-MM-DD	2015/09/30	TITLE Simulated Groundwater Levels (after Candel 2014)	
Golder Associates	PREPARED	BL		
	DESIGN	FJCM		
	REVIEW	KB	PROJECT No. 1531394	Rev 1
	APPROVED	DL	Rev. 1	FIGURE 1

Period \ Area	Mountains	Intermediate	Plains
Period	Stratigraphic units		
Recent	river gravels and sand dunes		
PLEISTOCENE	Morley gravels	Balzac stratified drift	Crossfield stratified drift
	Morley till	Calgary silt; Balzac till	Crossfield till
	Spy Hill till	Lochend stratified drift	Lochend stratified drift
	Spy Hill till	Lochend till	Lochend till
	Orange drift		
	Orange till		
	unconformity		
	Saskatchewan sands and gravels		
	unconformity		
PALEOCENE	Paskapoo		

CLIENT
City of Calgary

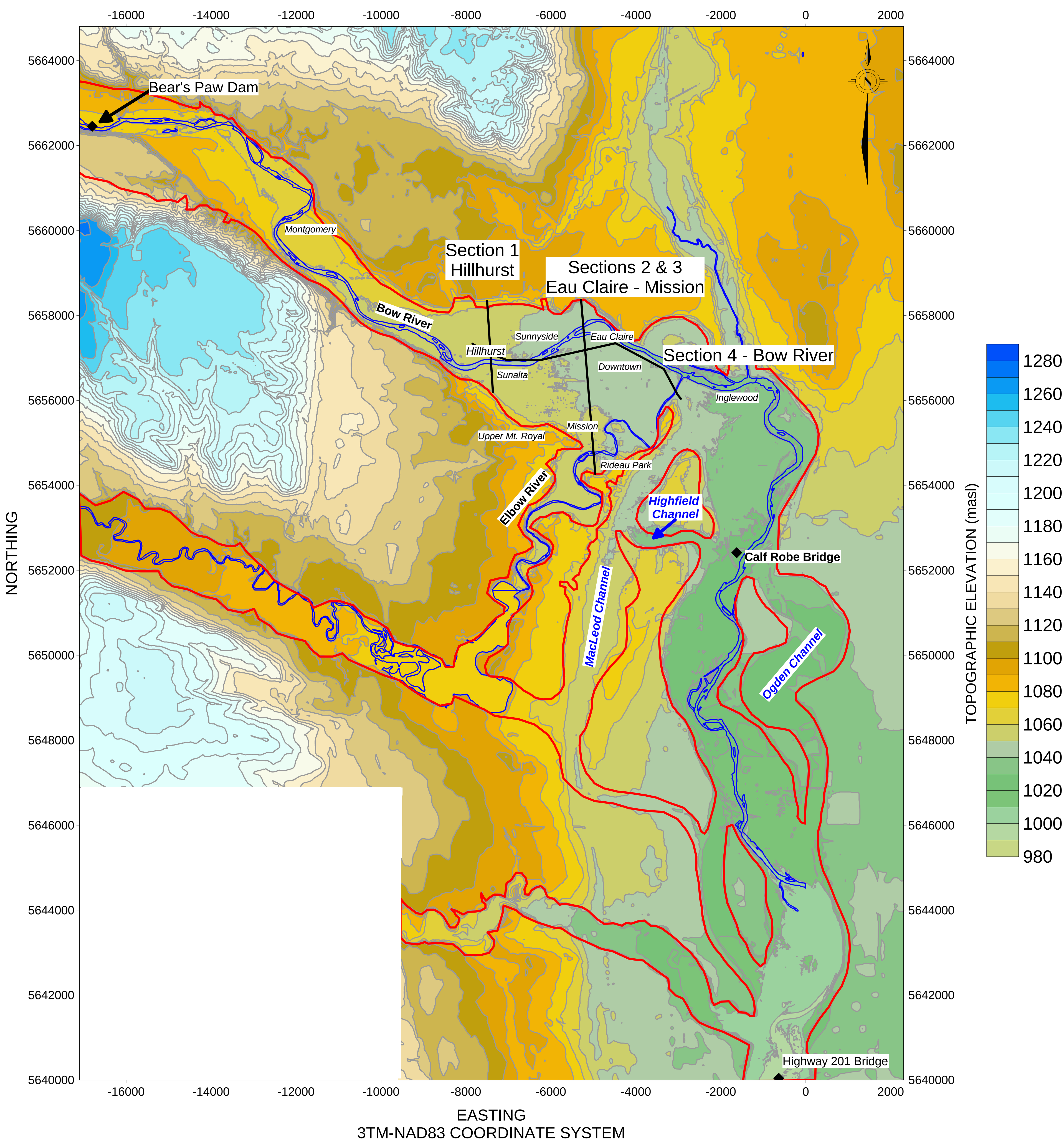
PROJECT
GROUNDWATER FLOODING

CONSULTANT
Golder Associates

YYYY-MM-DD	2015/09/30
PREPARED	BL
DESIGN	FJCM
REVIEW	KB
APPROVED	DL

TITLE
Stratigraphic Column for Calgary Area (after Tharin 1960)

PROJECT No.	Rev	Rev.	FIGURE
1531394	1	1	2



LEGEND

- Alluvial Aquifer Boundary
- River or Stream
- Cross-Section

REFERENCES

1. LIDAR DEM AND TRANSPORTATION DATA OBTAINED FROM THE CITY OF CALGARY. REMAINING DEM FROM ALTALIS 1:20.000.
2. DEM © GOVERNMENT OF ALBERTA 2014. ALL RIGHTS RESERVED.
3. ALLUVIAL AQUIFER BOUNDARY BASED ON MEYBOOM (1961).

CLIENT
CITY OF CALGARY

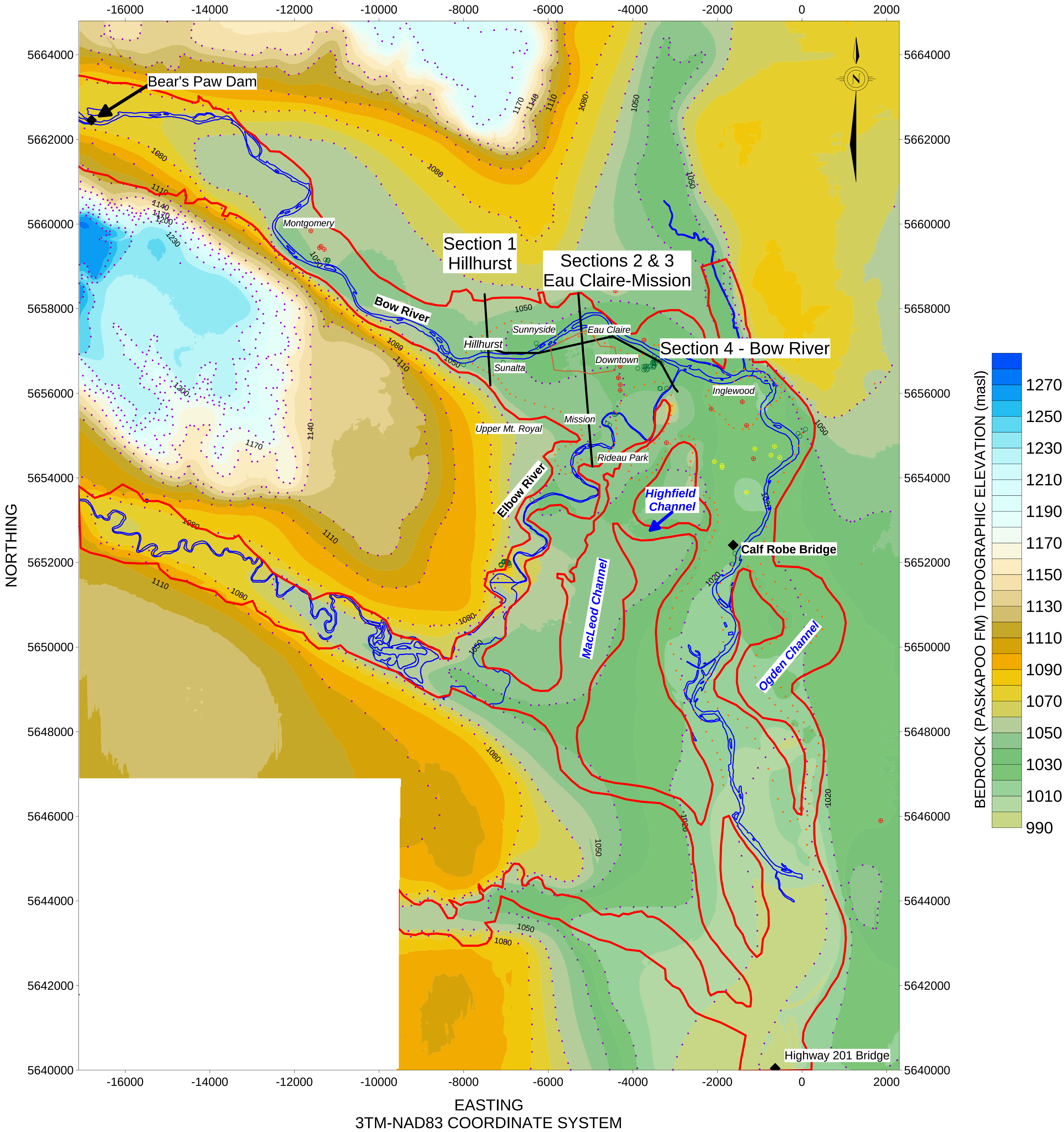
PROJECT
GROUNDWATER FLOODING

CONSULTANT
Golder Associates

YYYY-MM-DD	2015-10-05
PREPARED	BL
DESIGN	FCM
REVIEW	KB
APPROVED	DL

TITLE
Topographic Elevation Map
Showing the Alluvial Aquifer Boundary

PROJECT No.	Phase	Rev.	Figure
1531394	1	1	3



LEGEND

- Alluvial Aquifer Boundary
- Digitized Points (Moran, 1986)
- Digitized Points (Meyboom, 1961)
- Boreholes provided by the City of Calgary
- Boreholes Data (ESAR Database)
- Boreholes Data (Alberta Environmnetal Database)
- Location of Digitized Points (Eau Claire, Topography of Bedrock; HARDY Associates, 1978)
- Cross-Section

REFERENCES

1. BEDROCK ELEVATION BASED ON MORAN (1986) AND MAYBOOM (1961) WITH ADDITIONAL DATA FROM ALBERTA ENVIRONMENT AND PARKS, THE CITY OF CALGARY, AND THE ESAR DATABASE.
2. ALLUVIAL AQUIFER BOUNDARY BASED ON MEYBOOM (1961).

CLIENT
CITY OF CALGARY

PROJECT
GROUNDWATER FLOODING

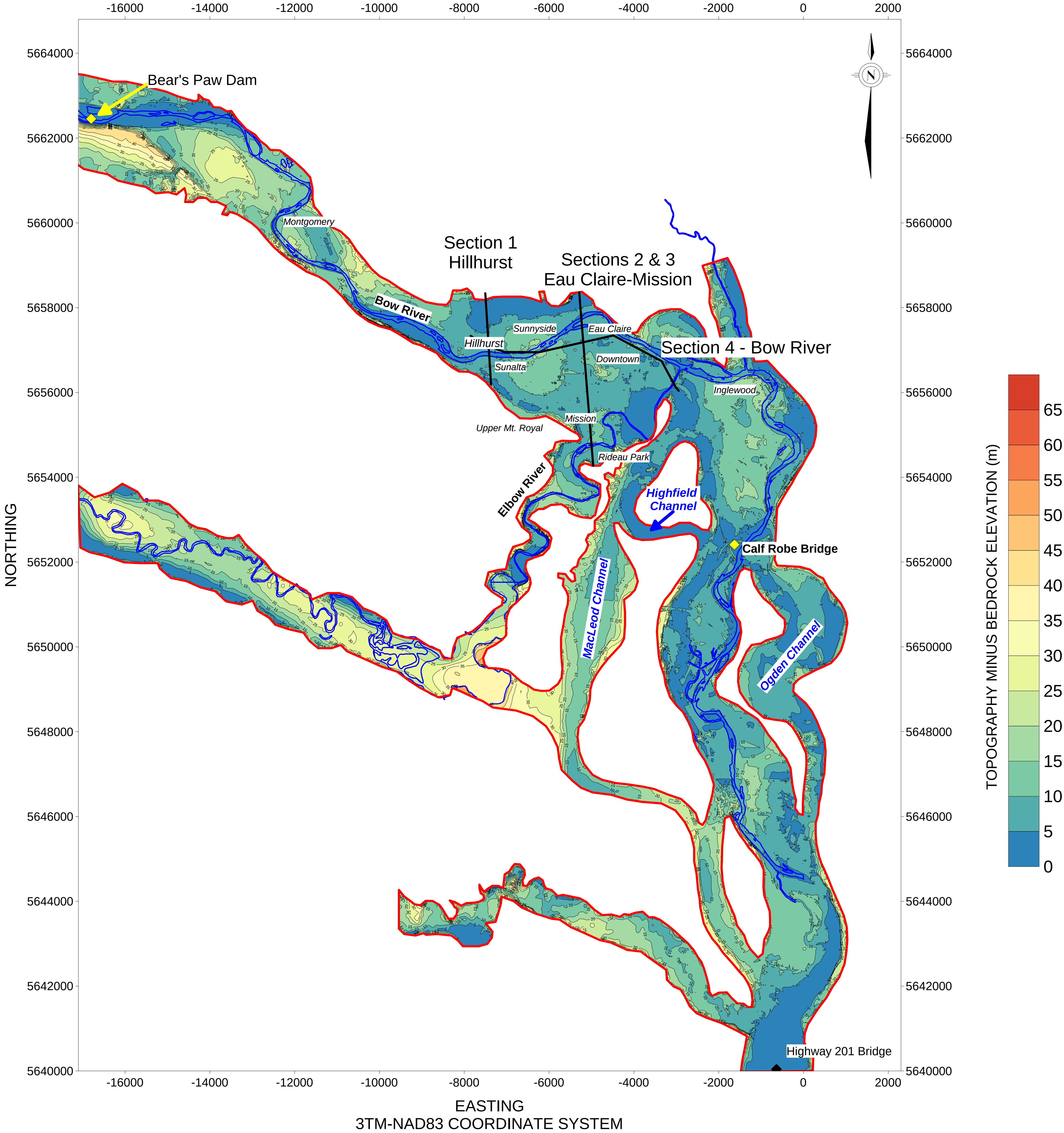
CONSULTANT

Golder Associates

YYYY-MM-DD	2015-08-20
PREPARED	BL
DESIGN	FCM
REVIEW	KB
APPROVED	DL

TITLE
Bedrock Elevation Map

PROJECT No.	Phase	Rev.	Figure
1531349	1	1	4



LEGEND

- Alluvial Aquifer Boundary
- River or Stream
- Cross-Section

REFERENCES

1. BEDROCK ELEVATION BASED ON MORAN (1986) AND MAYBOOM (1961) WITH ADDITIONAL DATA FROM ALBERTA ENVIRONMENT AND PARKS, THE CITY OF CALGARY, AND THE ESAR DATABASE.
2. ALLUVIAL AQUIFER BOUNDARY BASED ON MEYBOOM (1961).
3. LIDAR DEM OBTAINED FROM THE CITY OF CALGARY. ADDITIONAL DEM FROM ALTALIS 1:20.000 DEM © GOVERNMENT OF ALBERTA 2014. ALL RIGHTS RESERVED.

CLIENT
CITY OF CALGARY

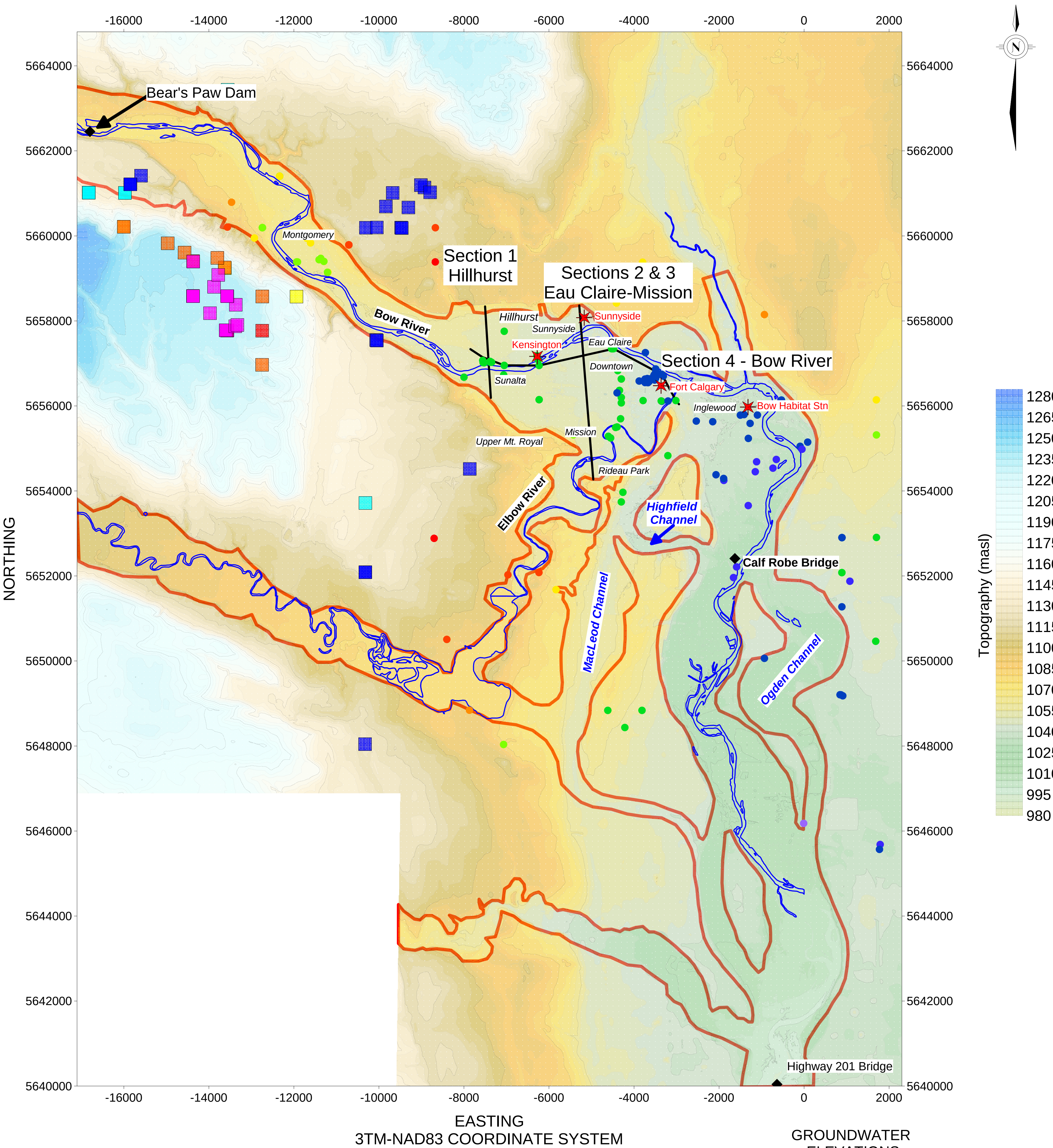
PROJECT
GROUNDWATER FLOODING

CONSULTANT

YYYY-MM-DD	2015-10-06
PREPARED	BL
DESIGN	FCM
REVIEW	KB
APPROVED	DL

TITLE
Thickness Distribution of the Alluvial Sediments

PROJECT No.	Phase	Rev.	Figure
1531394	1	1	5



GROUNDWATER ELEVATIONS MEASURED BETWEEN 1993 AND 2012 (masl)

- 1010 to 1020
- 1020 to 1030
- 1030 to 1040
- 1040 to 1050
- 1050 to 1060
- 1060 to 1070
- 1070 to 1080
- 1080 to 1090
- 1090 to 1100
- 1100 to 1120
- 1120 to 1140
- 1140 to 1160
- 1160 to 1180
- 1180 to 1200
- 1200 to 1220
- 1220 to 1235

LEGEND

- Alluvial Aquifer Boundary
- River or Stream
- Cross-Section
- 2015 Bow River Seepage Study Well

REFERENCES

1. ALLUVIAL AQUIFER BOUNDARY BASED ON MEYBOOM (1961).
2. GROUNDWATER ELEVATION DATA FROM ALBERTA ENVIRONMENT AND PARKS AND ESAR DATABASES AND DATA PROVIDED BY THE CITY OF CALGARY. MEASUREMENT DATES VARY OVER A PERIOD OF 20 YEARS (1993 TO 2012).

CLIENT
CITY OF CALGARY

PROJECT
GROUNDWATER FLOODING

CONSULTANT
Golder Associates

YYYY-MM-DD	2015-10-06
PREPARED	BL
DESIGN	FCM
REVIEW	KB
APPROVED	DL

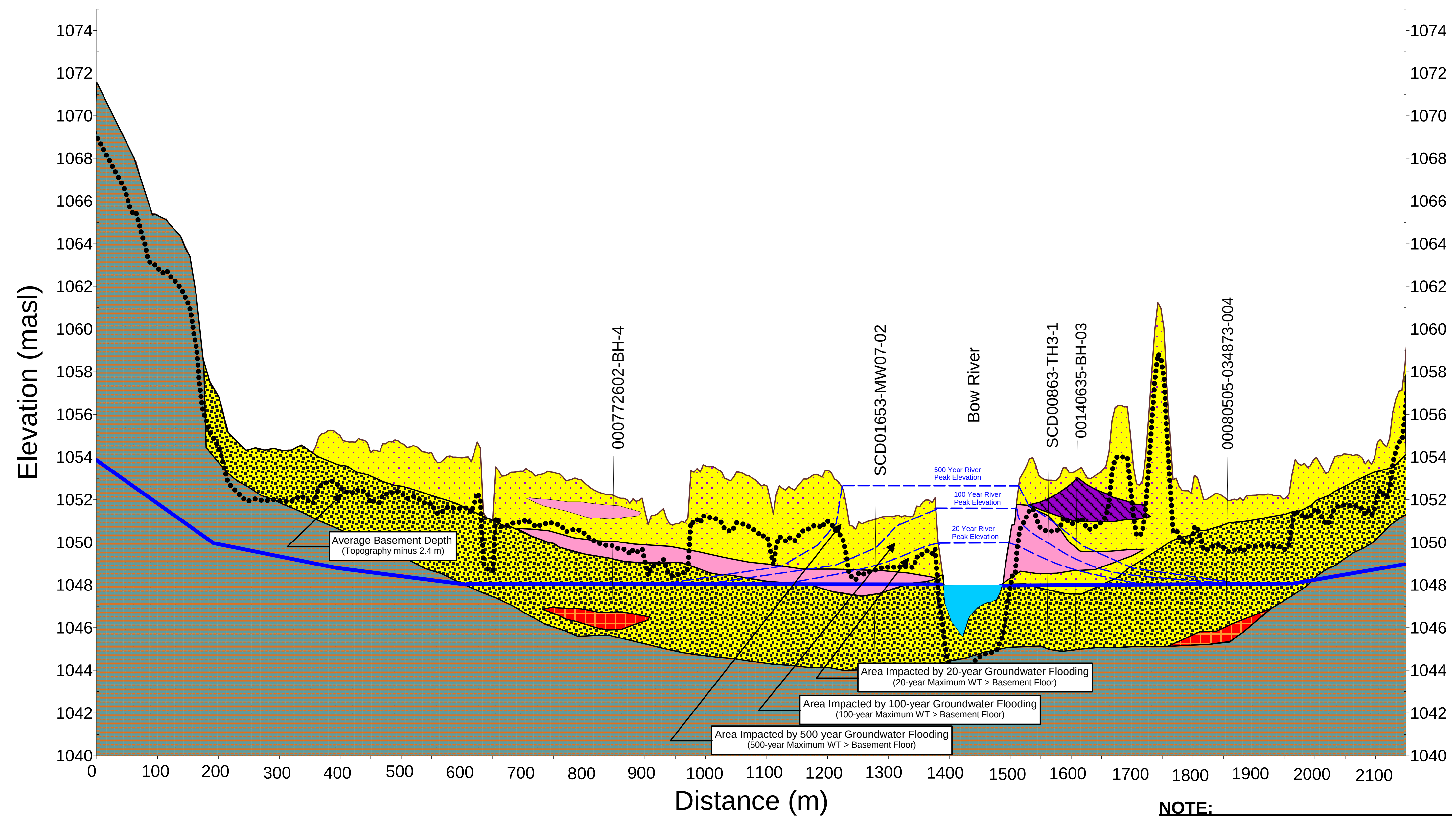
TITLE
Measured Groundwater Elevations 1993 to 2012 and Locations of 2015 Seepage Study Monitoring Wells

PROJECT No.	Phase	Rev.	Figure
1531394	1	1	6

Section 1- Hillhurst

North

South



NOTE:

Vertical Exageration is 35:1

LEGEND

- River
- Silt and silty clay
- Sand
- Sand and Gravel
- Gravel
- Glacial Till (clay and silt)
- Paskapoo Formation
- 20, 100, and 500 Year Maximum Groundwater Surface Profiles
- Pre-Flood Groundwater Surface
- Topography - 2.4 m (average depth of basements)

REFERENCES

1. LIDAR DATA OBTAINED FROM THE CITY OF CALGARY. REMAINING DEM FROM ALTALIS 1:20.000 DEM © GOVERNMENT OF ALBERTA 2014. ALL RIGHTS RESERVED.
2. BOREHOLE LOG SOURCES: ESAR DATABASE

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City of Calgary

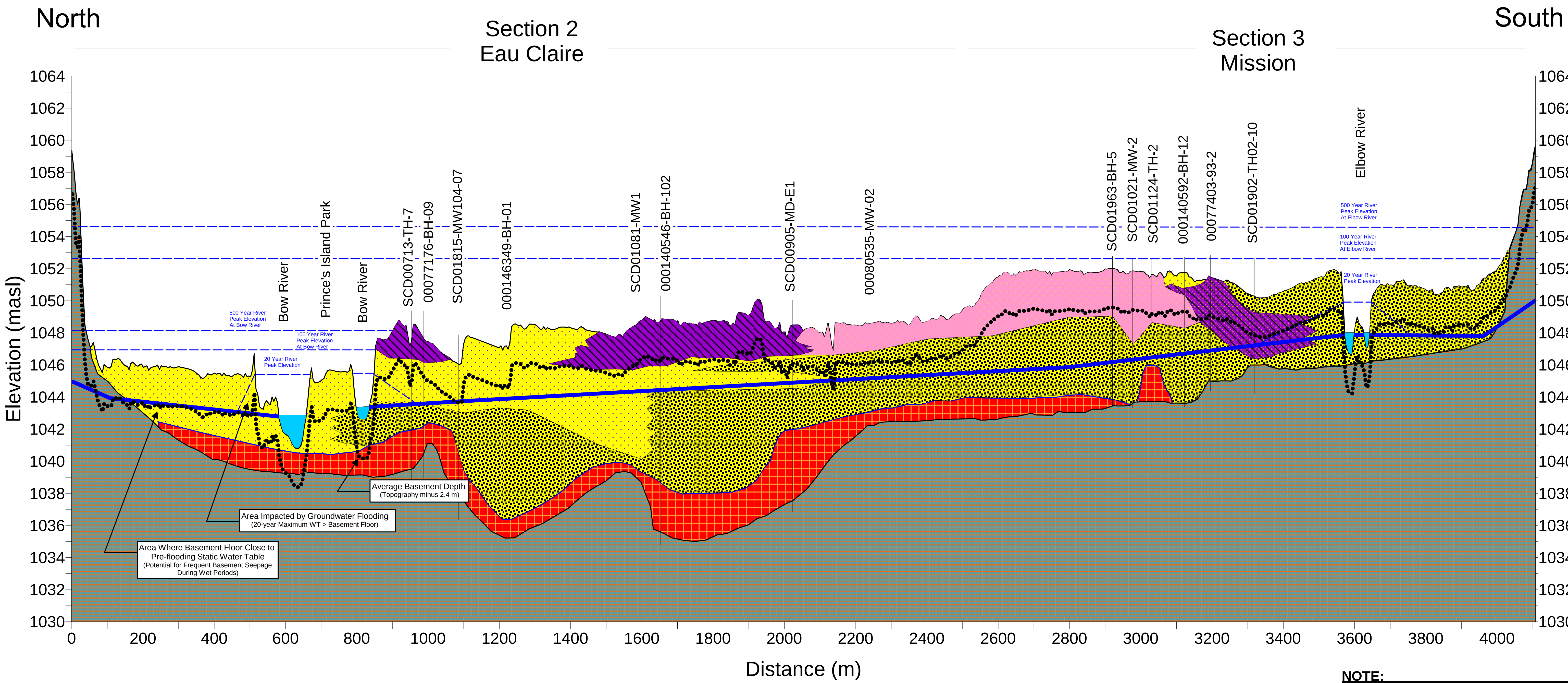
PROJECT
GROUNDWATER FLOODING

CONSULTANT
Golder Associates

YYYY-MM-DD	2015/09/30
PREPARED	BL
DESIGN	FJCM
REVIEW	KB
APPROVED	DL

TITLE
Hydrogeologic Cross-section - Section 1- Hillhurst

PROJECT No.	Rev	Rev.	FIGURE
1531349	1	1	7



NOTE:

Vertical Exageration is 45:1

LEGEND

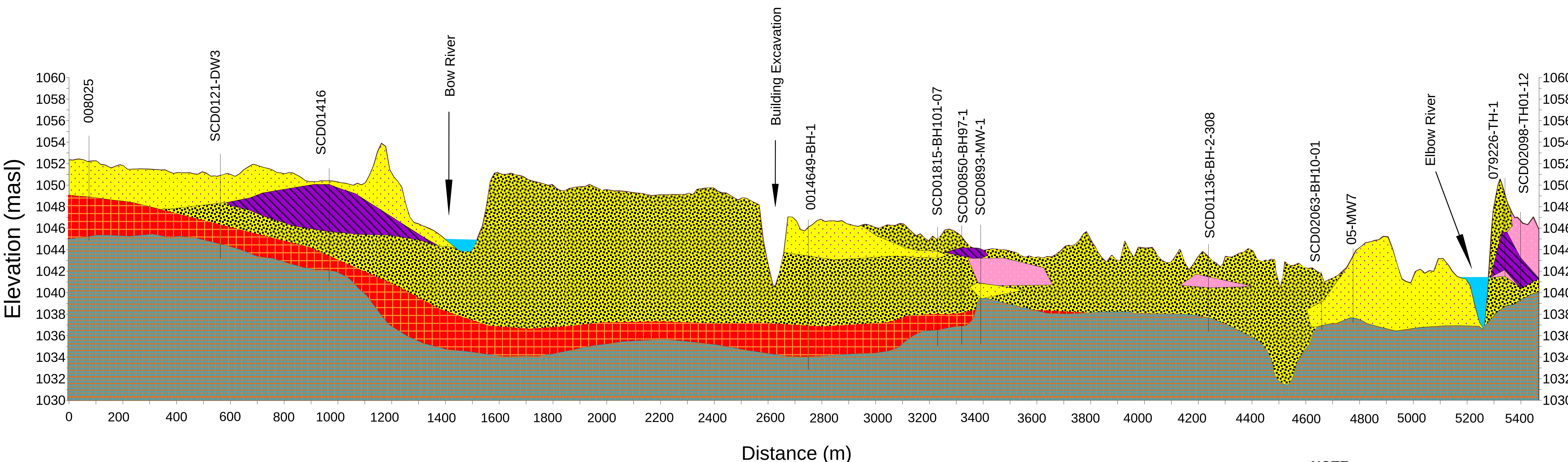
- River
- Silt and silty clay
- Sand
- Sand and Gravel
- Gravel
- Glacial Till (clay and silt)
- Paskapoo Formation
- 20, 100, and 500 Year Maximum Groundwater Surface Profiles
- Pre-Flood Groundwater Surface
- Topography - 2.4 m (average depth of basements)

REFERENCES

1. LIDAR DATA OBTAINED FROM THE CITY OF CALGARY. REMAINING DEM FROM ALTALIS 1:20.000 DEM © GOVERNMENT OF ALBERTA 2014. ALL RIGHTS RESERVED.
2. BOREHOLE LOG SOURCES: ESAR DATABASE

CLIENT City of Calgary	PROJECT **GROUNDWATER FLOODING**
CONSULTANT Golder Associates YYYY-MM-DD 2015/09/30 PREPARED BL DESIGN FJCM REVIEW KB APPROVED DL	TITLE Hydrogeologic Cross-sections - Section 2 - Eau Claire and Section 3 - Mission PROJECT No. 1531349 Rev 1 Rev. 1 FIGURE 8

Section 4 - Bow River



NOTE:

Vertical Exageration is 50:1

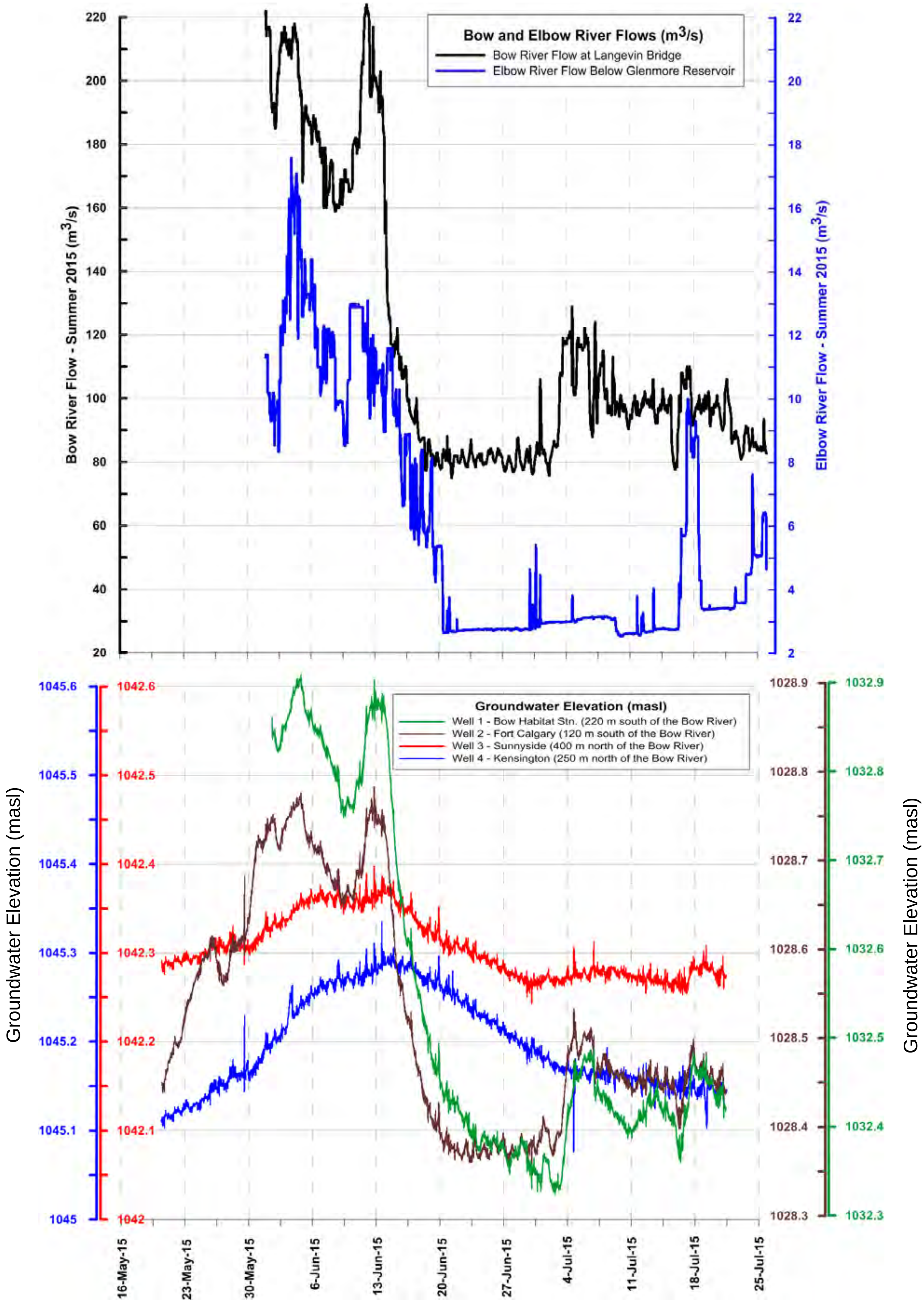
LEGEND

- River
- Silt and silty clay
- Sand
- Sand and Gravel
- Gravel
- Glacial Till (clay and silt)
- Paskapoo Formation

REFERENCES

1. LIDAR DATA OBTAINED FROM THE CITY OF CALGARY. REMAINING DEM FROM ALTALIS 1:20.000 DEM © GOVERNMENT OF ALBERTA 2014. ALL RIGHTS RESERVED.
2. BOREHOLE LOG SOURCES: ESAR DATABASE

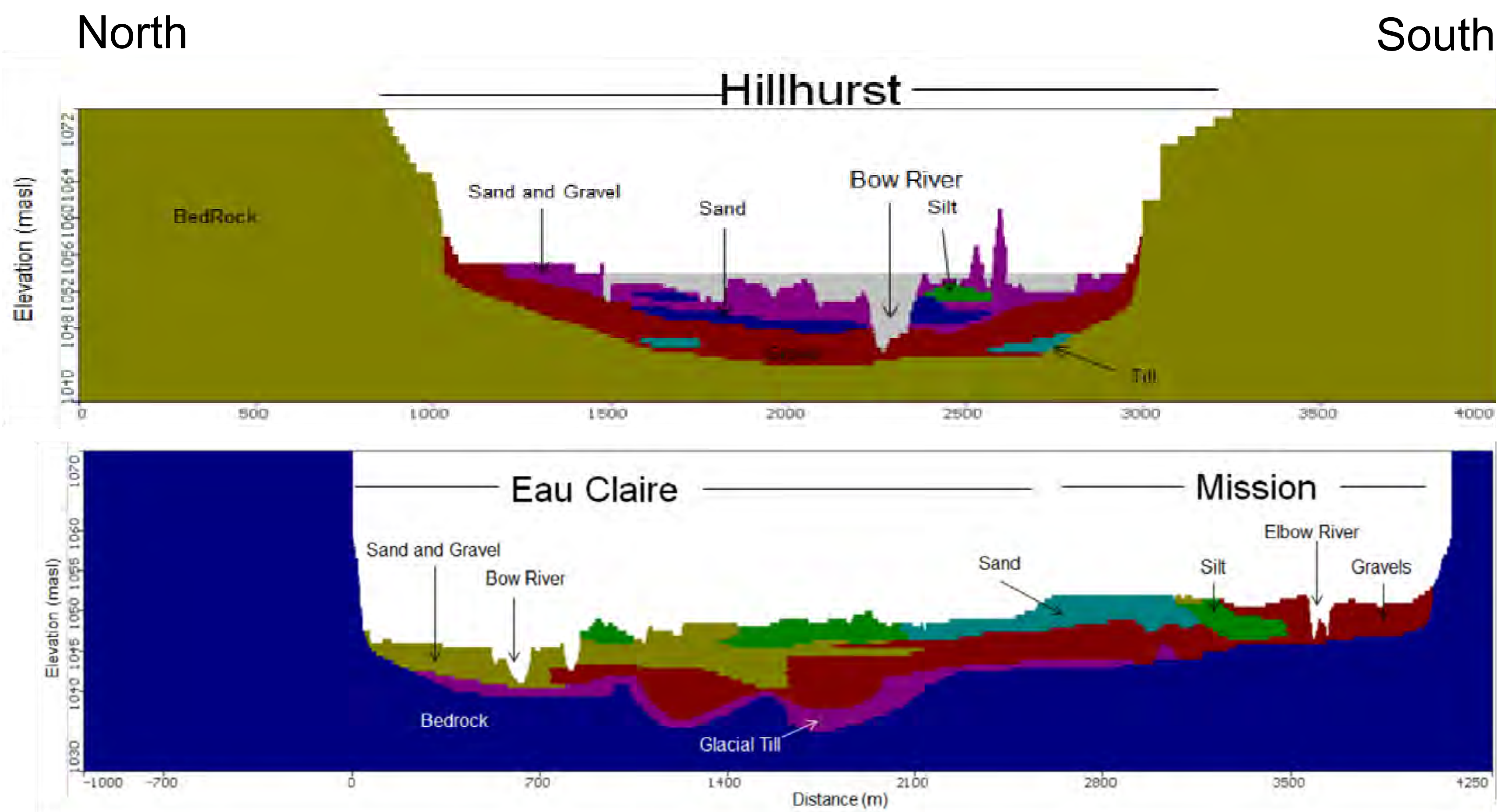
CLIENT	City of Calgary
PROJECT	GROUNDWATER FLOODING
CONSULTANT	Golder Associates
YYYY-MM-DD	2015/09/30
PREPARED	BL
DESIGN	FJCM
REVIEW	KB
APPROVED	DL
TITLE	Hydrogeological Cross-section - Section 4- Bow River
PROJECT No.	1531349
Rev	1
Rev.	1
FIGURE	9



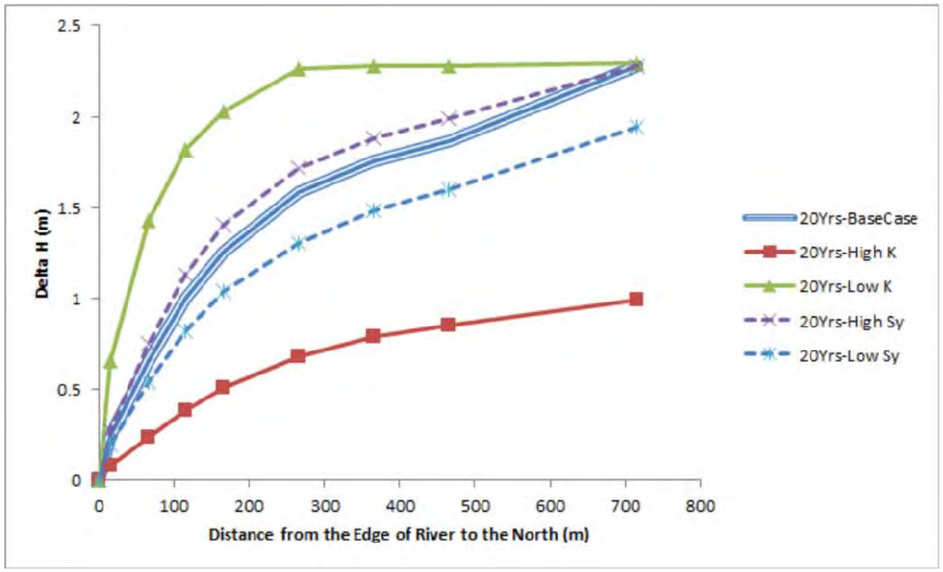
NOTES:

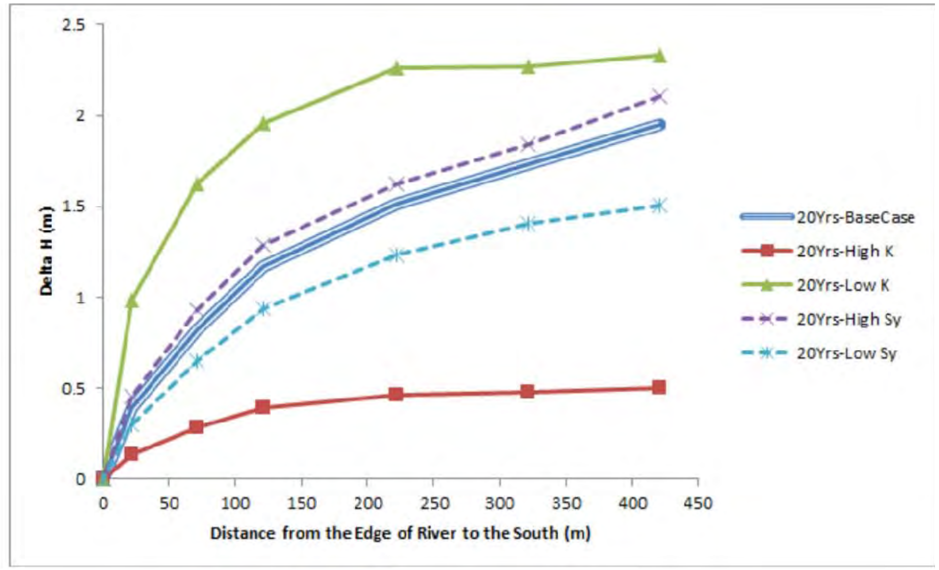
1. Data provided by The City of Calgary.
2. The Bow River flow data is a factor of 10 times larger than the Elbow River flow data.
3. The *range* of all groundwater well hydrographs is the same (60 cm)

CLIENT City of Calgary			PROJECT **GROUNDWATER FLOODING**
CONSULTANT	YYYY-MM-DD	2015/09/30	TITLE Groundwater Elevations and River Flows
Golder Associates	PREPARED	BL	
	DESIGN	FJCM	
	REVIEW	KB	
	APPROVED	DL	PROJECT No. 1531394 · Rev 1 · Rev. 1 · FIGURE 10



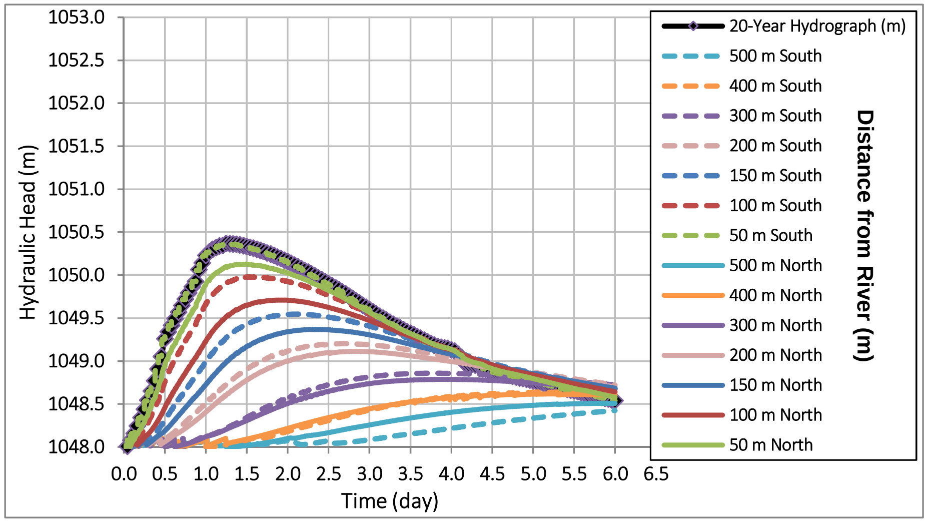
CLIENT City of Calgary		PROJECT **GROUNDWATER FLOODING**	
CONSULTANT Golder Associates	YYYY-MM-DD: 2015/09/30 PREPARED: BL DESIGN: FJCM REVIEW: KB APPROVED: DL	TITLE Structure of Numerical Model Sections 1, 2 and 3	
		PROJECT No. 1531394	Rev 1 / Rev. 1 / FIGURE 11



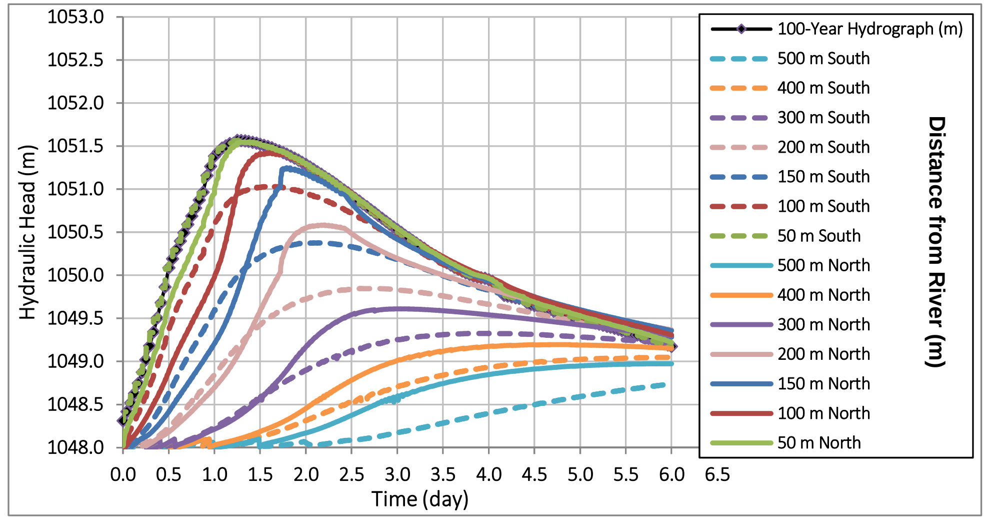


CLIENT City of Calgary		PROJECT **GROUNDWATER FLOODING**	
CONSULTANT Golder Associates	YYYY-MM-DD: 2015/09/30 PREPARED: BL DESIGN: FJCM REVIEW: KB APPROVED: DL	TITLE Model Sensitivity Analysis – Section 1 - Hillhurst	PROJECT No. 1531394 Rev 1 Rev. 1 FIGURE 12

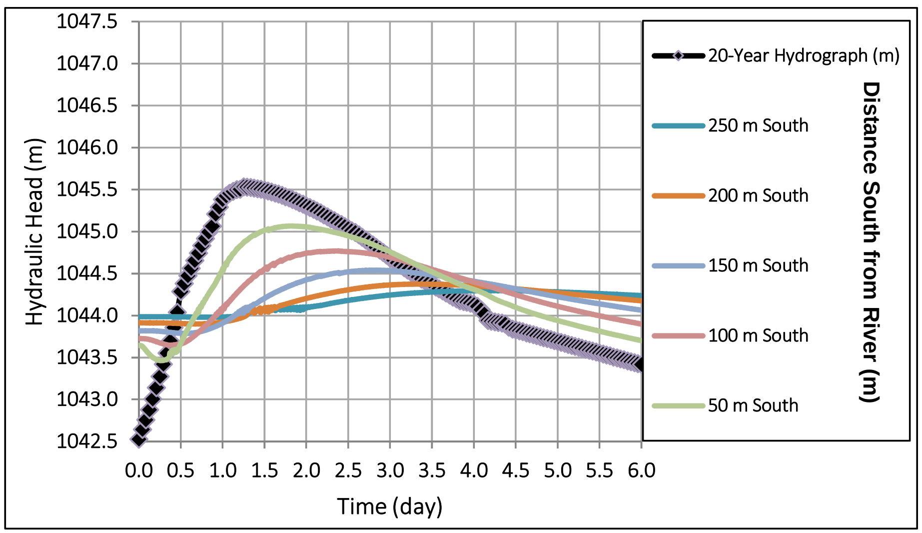
Hillhurst - 20 Year Return Period



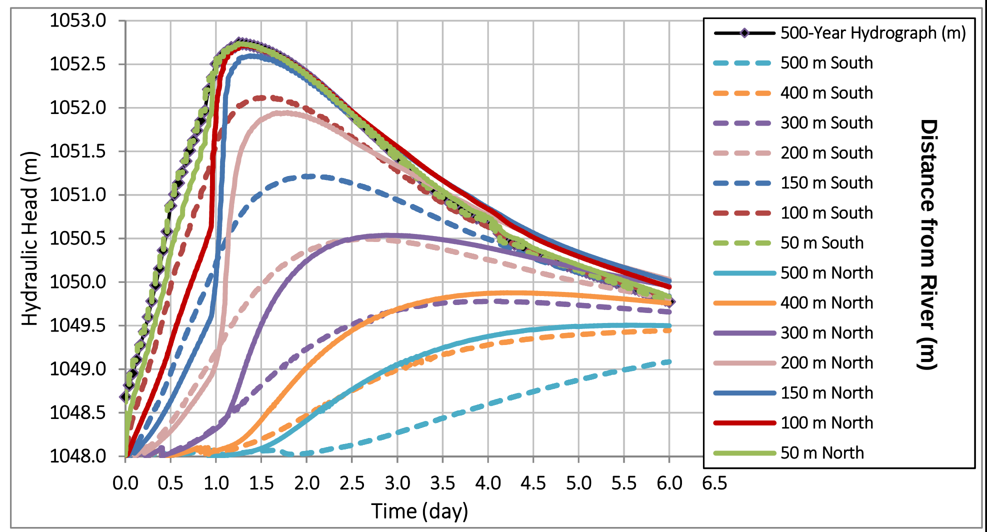
Hillhurst - 100 Year Return Period



Eau Claire South - 20 Year Return Period



Hillhurst - 500 Year Return Period



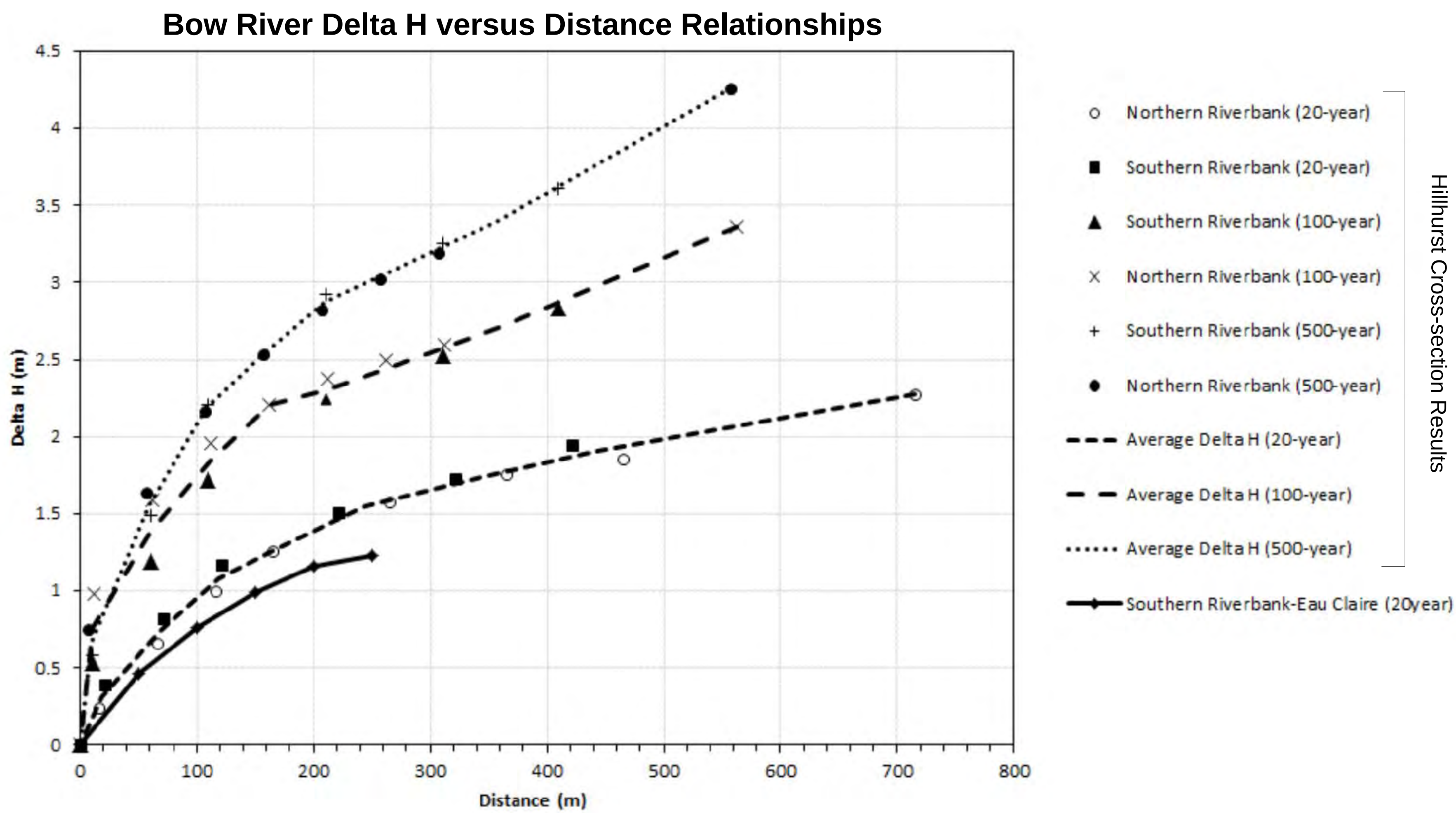
CONSULTANT

Golder Associates

YYYY-MM-DD	2015/09/30
PREPARED	BL
DESIGN	FJCM
REVIEW	KB
APPROVED	DL

TITLE
Hydraulic Head versus Time –
Section 1 Hillhurst and Section 2 Eau Claire

PROJECT No.	Rev	Rev.	FIGURE
1531394	1	1	13



Notes:

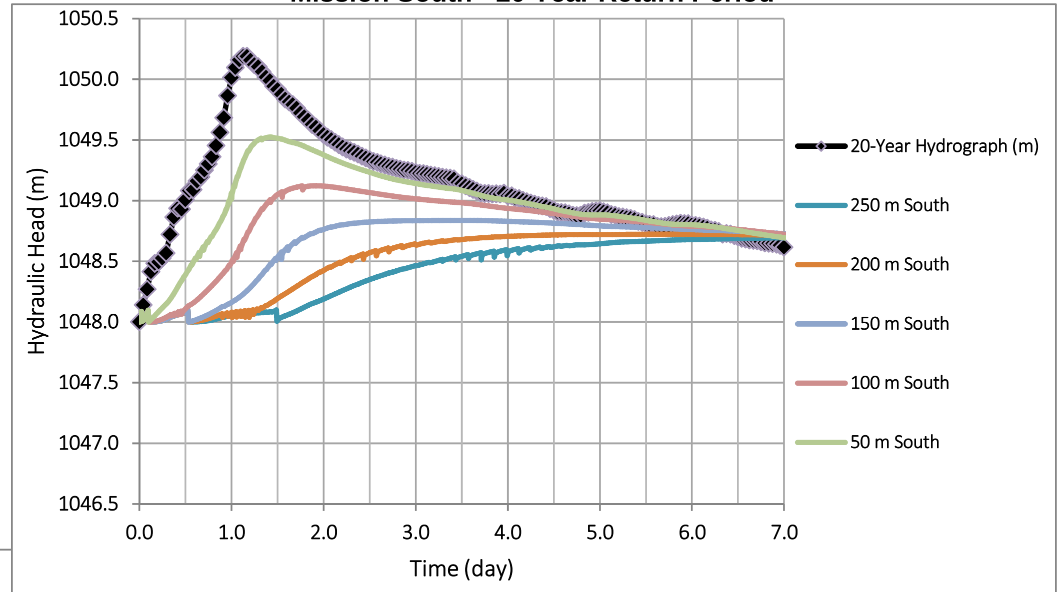
1. Delta H represents the difference between the simulated peak of the groundwater hydrograph and the peak of the simulated (HEC-RAS) Bow River hydrograph.

2. Greater delta H values represent a greater capacity of the alluvial aquifer to attenuate the groundwater flooding and vice versa.

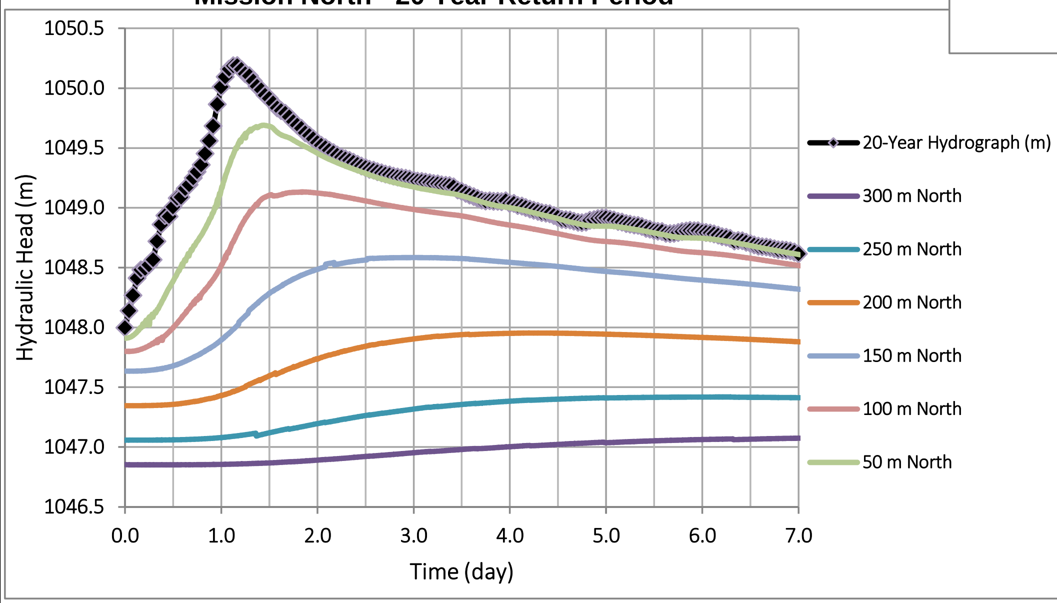
3. The X-axis is the distance from the edge of surface water inundation and not the distance from the edge of the pre-flood river channel. Distances on this plot, therefore, are not the same as those shown on Figure 13 since the edge of surface inundation varies between the cross-sections north and south of the river and for different return periods.

CLIENT City of Calgary			PROJECT GROUNDWATER FLOODING	
CONSULTANT Golder Associates	YYYY-MM-DD	2015/09/30	TITLE Delta H versus Distance - Section 1 Hillhurst and Section 2 Eau Claire	
	PREPARED	BL		
	DESIGN	FJCM		
	REVIEW	KB	PROJECT No. 1531394	Rev 1
	APPROVED	DL	Rev. 1	FIGURE 14

Mission South - 20 Year Return Period



Mission North - 20 Year Return Period



CLIENT
City of Calgary

PROJECT
GROUNDWATER FLOODING

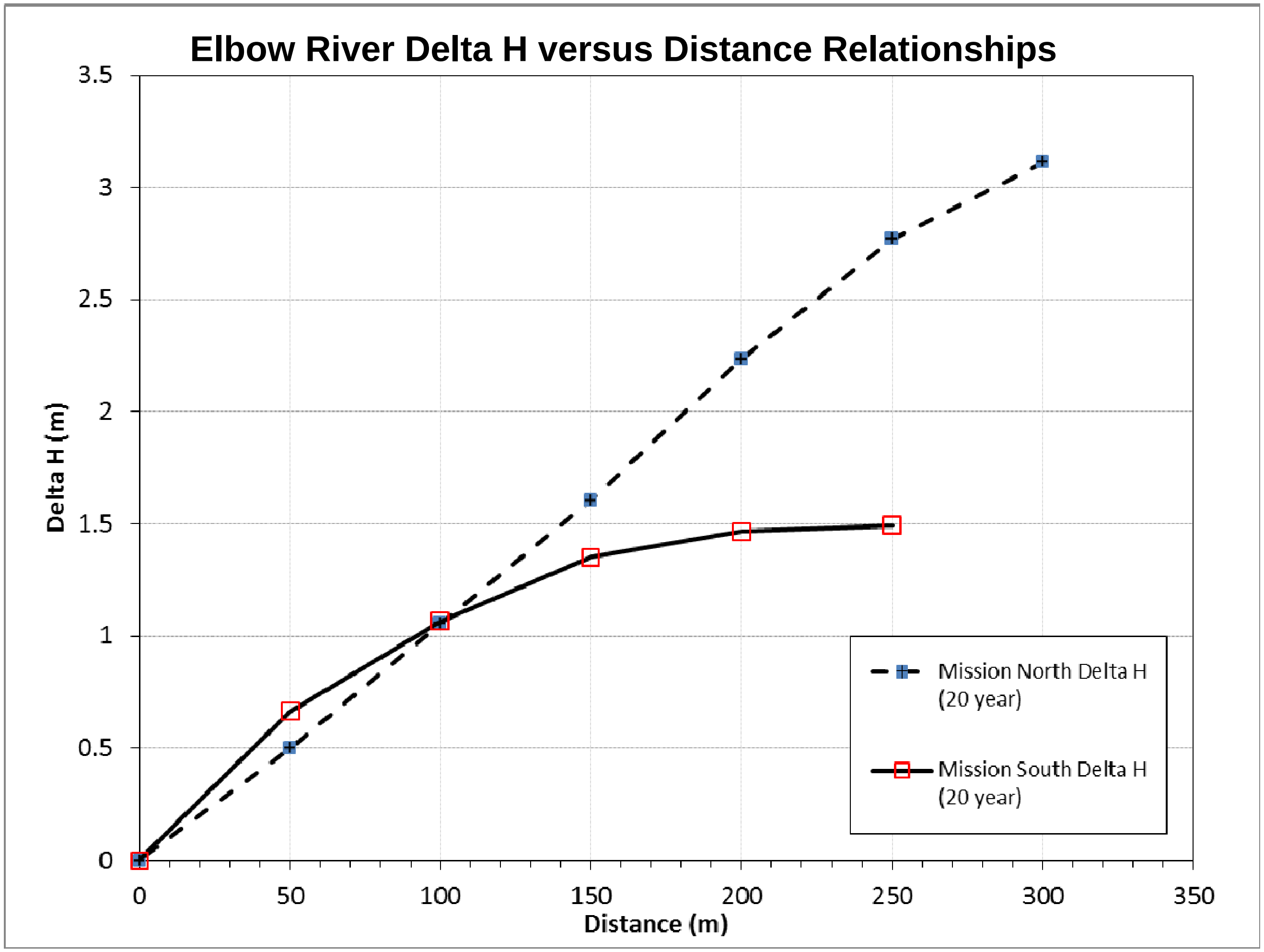
CONSULTANT

Golder Associates

YYYY-MM-DD	2015/09/30
PREPARED	BL
DESIGN	FJCM
REVIEW	KB
APPROVED	DL

TITLE
Hydraulic Head versus Time -
Cross-section 3 - Mission

PROJECT No.	Rev	Rev.	FIGURE
1531394	1	1	15



Notes:

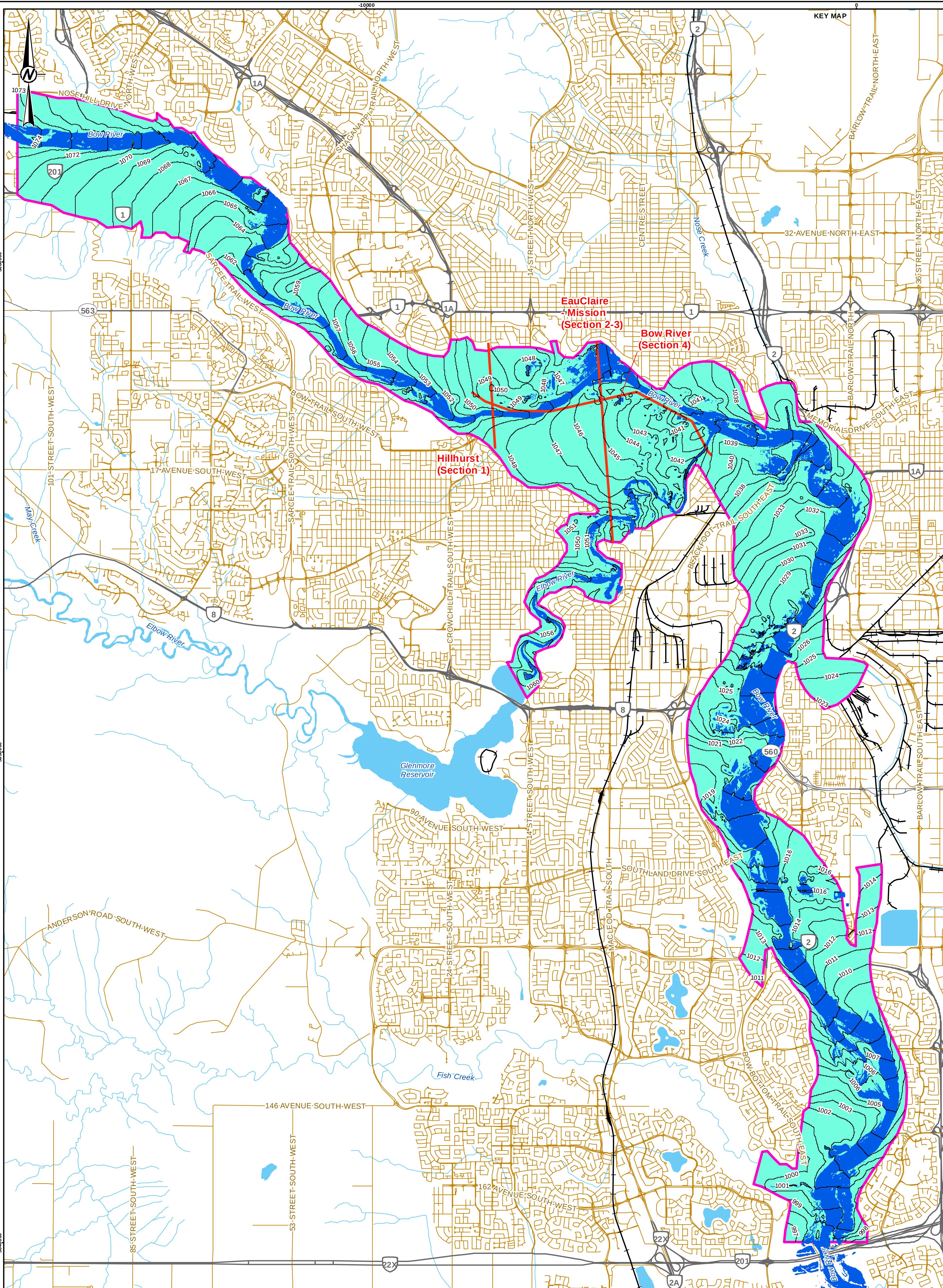
1. Delta H represents the difference between the simulated peak of the groundwater hydrograph and the peak of the simulated (HEC-RAS) Elbow River hydrograph.

2. Greater delta H values represent a greater capacity of the alluvial aquifer to attenuate the groundwater flooding and vice versa.

3. The X-axis is the distance from the edge of surface water inundation and not the distance from the edge of the pre-flood river channel. Distances on this plot, therefore, are not the same as those shown on Figure 15 since the edge of surface inundation varies between the cross-sections north and south of the river and for different return periods.

CLIENT City of Calgary			PROJECT **GROUNDWATER FLOODING**
CONSULTANT Golder Associates	YYYY-MM-DD	2015/09/30	TITLE Delta H versus Distance - Cross-section 3 - Mission
	PREPARED	BL	
	DESIGN	FJCM	
	REVIEW	KB	
	APPROVED	DL	PROJECT No. 1531394 / Rev 1 / Rev. 1 / FIGURE 16

PATH: I:\2015\1531394\Mapping\MXD\Hydrogeology\1531394_Fig17_20y_Inundation-AlluvialAquifer-Modeling_RevB.mxd PRINTED ON: 2016-01-29 AT: 9:56:44 AM



LEGEND

RAILROAD
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD
1m GROUNDWATER CONTOUR
GROUND WATER CROSS SECTION
20-YEAR INUNDATION EXTENT
MODELLING DOMAIN

0 2,000 4,000

1:75,000 METRES

REFERENCE(S)

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2. HYDROGRAPHY © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED.

CLIENT
CITY OF CALGARY

PROJECT
FLOOD MITIGATION OPTIONS ASSESSMENT

CONSULTANT
Golder Associates

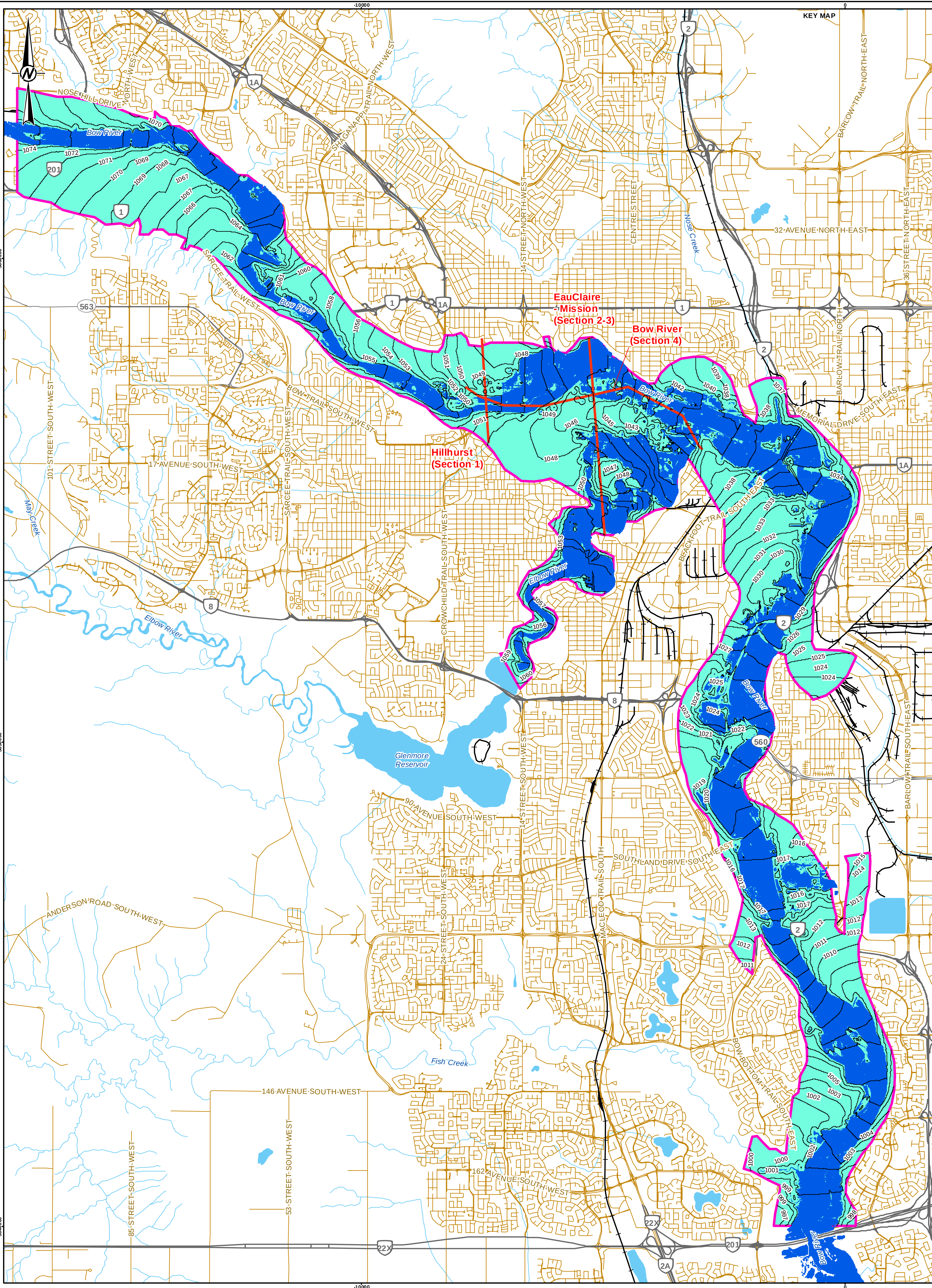
YYYY-MM-DD	2016-01-11
DESIGNED	D.HALEY
PREPARED	P.THIEDE
REVIEWED	####
APPROVED	####

TITLE
ALLUVIAL AQUIFER, FLOOD INUNDATION EXTENT AND MODELLED GROUND WATER ELEVATIONS FOR 20-YEAR FLOOD

PROJECT NO.	CONTROL	REV.	FIGURE
1531394		B	17

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25mm
0

PATH: I:\2015\1531394\Mapping\MXD\Hydrogeology\1531394_Fig18_100y_Inundation-AlluvialAquifer-Modeling_RevB.mxd PRINTED ON: 2016-01-29 AT: 9:57:35 AM



LEGEND

- RAILROAD
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- 1m GROUNDWATER CONTOUR
- GROUND WATER CROSS SECTION
- 100-YEAR INUNDATION EXTENT
- MODELLING DOMAIN

0 2,000 4,000

1:75,000 METRES

REFERENCE(S)

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CLIENT
CITY OF CALGARY

PROJECT
FLOOD MITIGATION OPTIONS ASSESSMENT

CONSULTANT

Golder Associates

YYYY-MM-DD	2016-01-11
DESIGNED	D.HALEY
PREPARED	P.THIEDE
REVIEWED	####
APPROVED	####

TITLE
ALLUVIAL AQUIFER, FLOOD INUNDATION EXTENT AND MODELLED GROUND WATER ELEVATIONS FOR 100-YEAR FLOOD

PROJECT NO.	CONTROL	REV.	FIGURE
1531394		B	18

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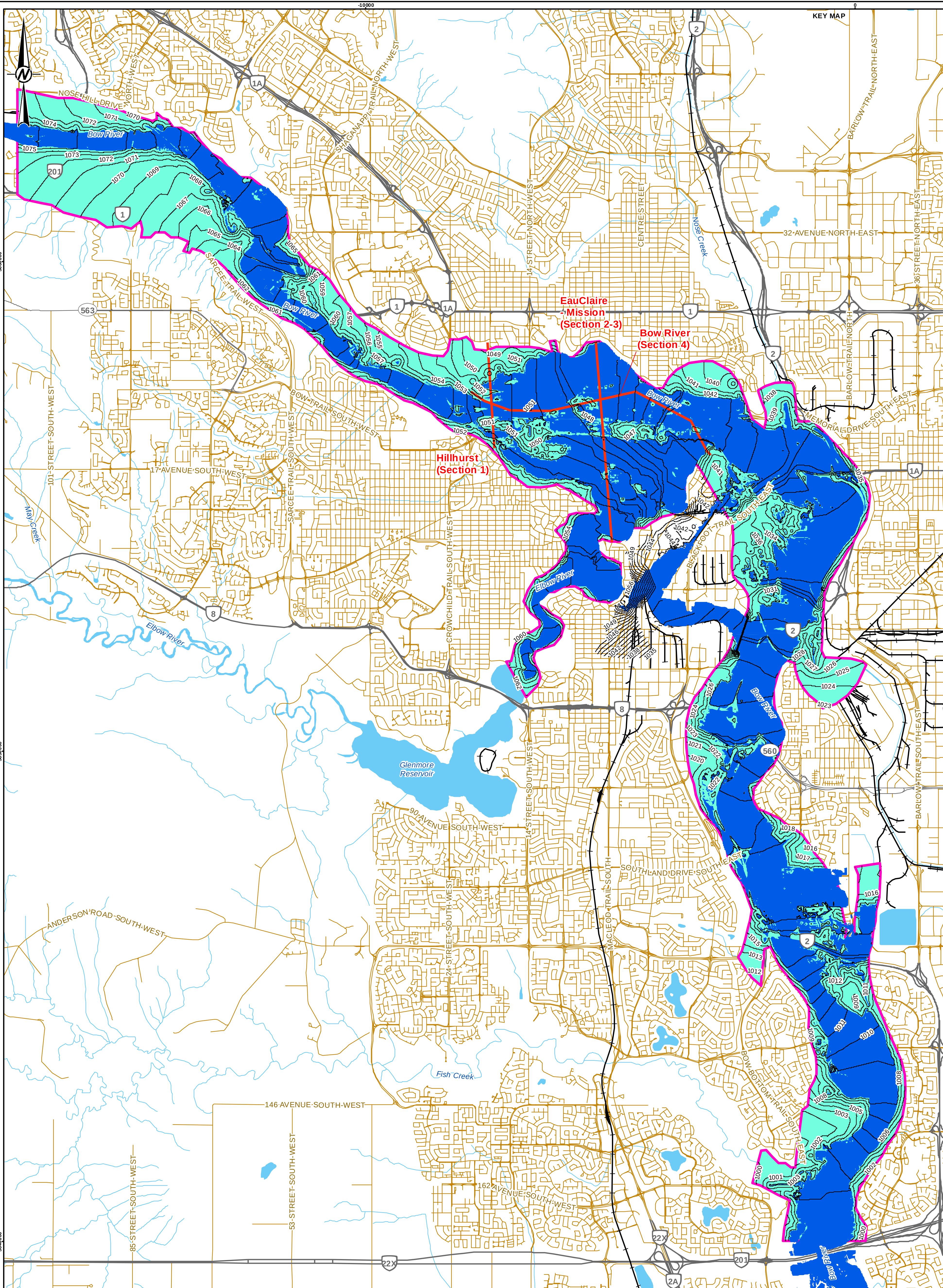
PATH: I:\2015\1531394\Mapping\MXD\Hydrogeology\1531394_Fig19_500y_Inundation-AlluvialAquifer-Modeling_RevB.mxd PRINTED ON: 2016-01-29 AT: 9:57:44 AM



LEGEND

- RAILROAD
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- 1m GROUNDWATER CONTOUR
- GROUND WATER CROSS SECTION
- 500-YEAR INUNDATION EXTENT
- MODELLING DOMAIN

0 2,000 4,000
1:75,000 METRES

REFERENCE(S)

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CLIENT
CITY OF CALGARY

PROJECT
FLOOD MITIGATION OPTIONS ASSESSMENT

CONSULTANT

Golder Associates

YYYY-MM-DD	2016-01-11
DESIGNED	D.HALEY
PREPARED	P.THIEDE
REVIEWED	####
APPROVED	####

TITLE
ALLUVIAL AQUIFER, FLOOD INUNDATION EXTENT AND MODELLED GROUND WATER ELEVATIONS FOR 500-YEAR FLOOD

PROJECT NO.	CONTROL	REV.	FIGURE
1531394		B	19

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25mm
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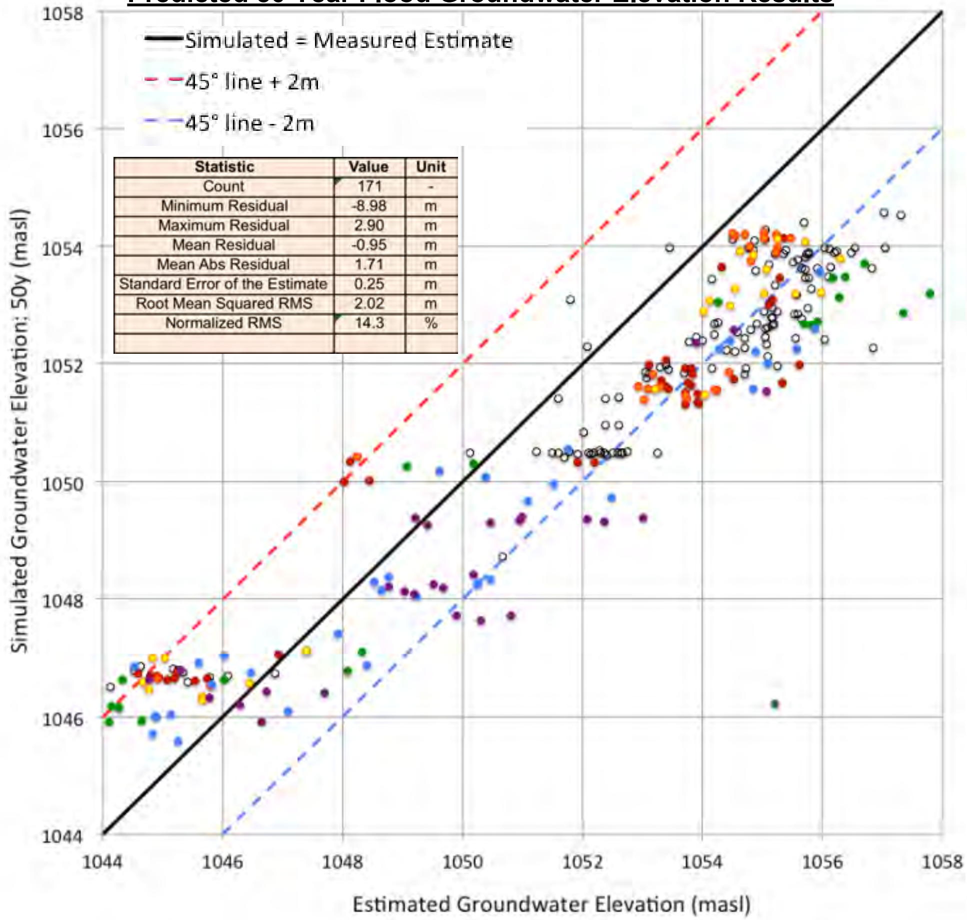
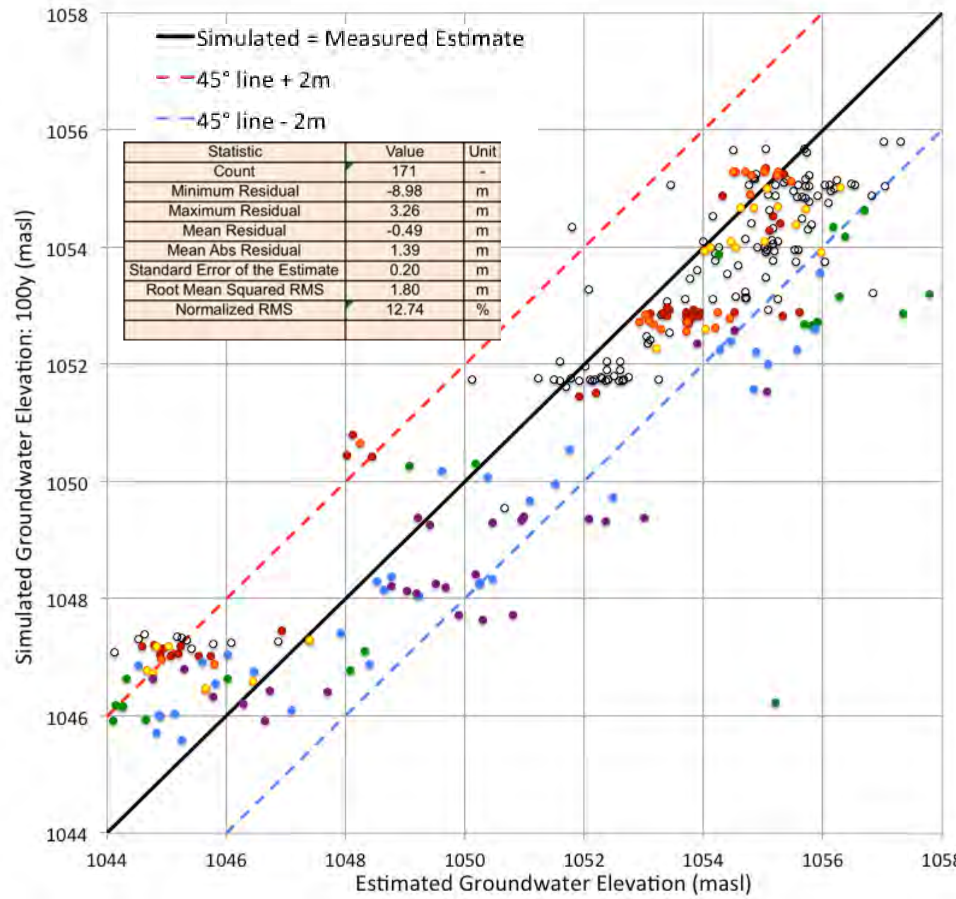
Predicted 50 Year Flood Groundwater Elevation Results



Predicted 100 Year Flood Groundwater Elevation Results



Distance to Surface Inundation (m)

- Within inundation zone
- 1 - 20
- 21 - 30
- 31 - 70
- 71 - 140
- 141 - 300
- 300+

CLIENT City of Calgary		PROJECT **GROUNDWATER FLOODING**	
CONSULTANT	YYYY-MM-DD: 2015/09/30	TITLE Comparison of Predicted Groundwater Elevations and Estimated Groundwater Elevations from the 2013 Calgary Flood Survey	
Golder Associates	PREPARED: DH		
	DESIGN: DH		
	REVIEW: DL	PROJECT No. 1531394	Rev 1
	APPROVED: DL	Rev. 1	FIGURE 20

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Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 44 1628 851851
North America	+ 1 800 275 3281
South America	+ 56 2 2616 2000

solutions@golder.com
www.golder.com

Golder Associates Ltd.
102, 2535 - 3rd Avenue S.E.
Calgary, Alberta, T2A 7W5
Canada
T: +1 (403) 299 5600

Golder Associates

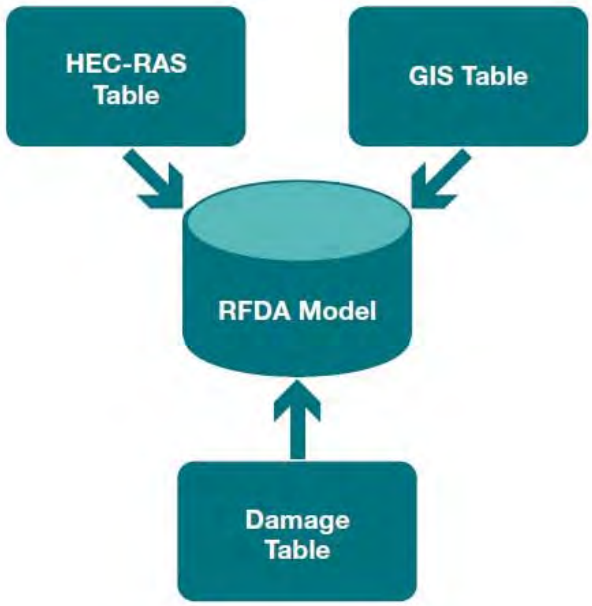
D

APPENDIX D:
RFDA MODEL USER MANUAL

RAPID FLOOD DAMAGE ASSESSMENT MODEL (RFDAM)

The RFDA model works with three input tables: (1) the GIS inventory table of residential, and commercial/retail buildings in the study area; (2) the specific depth-damage curves for contents and structures indexed to that community; and (3) the hydraulic flood-frequency-elevation table derived from the HEC-RAS model (see **Exhibit A-1**).

Exhibit A-1: RFDAM Input Tables

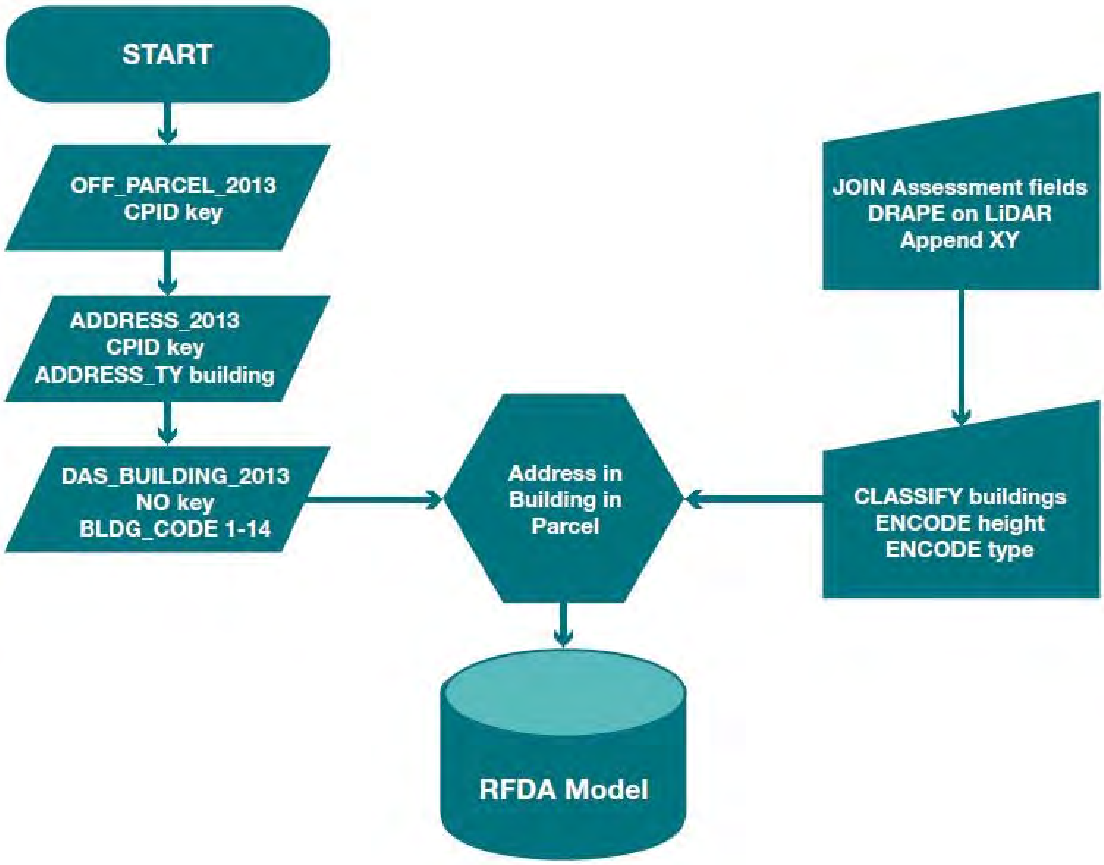


Municipalities in flood risk areas have access to high resolution satellite imagery, or orthophotos, which can clearly show the location of all buildings in their community. In addition they can overlay the images with property parcel boundaries. Many local governments have replaced contour mapping with LiDAR DEMs, which provide dense 3D points scanned by airborne radar with higher accuracies than traditional photogrammetry. This means that buildings in the floodplain and adjacent-to areas can be geocoded to a coordinate system.

The GIS building inventory table was designed to provide maximum flexibility in data collection input to the model. In the case where assessment data is available, main floor and basement areas can be extracted for use in the model. In cases where that is not available, the areas can be estimated via remote sensing.

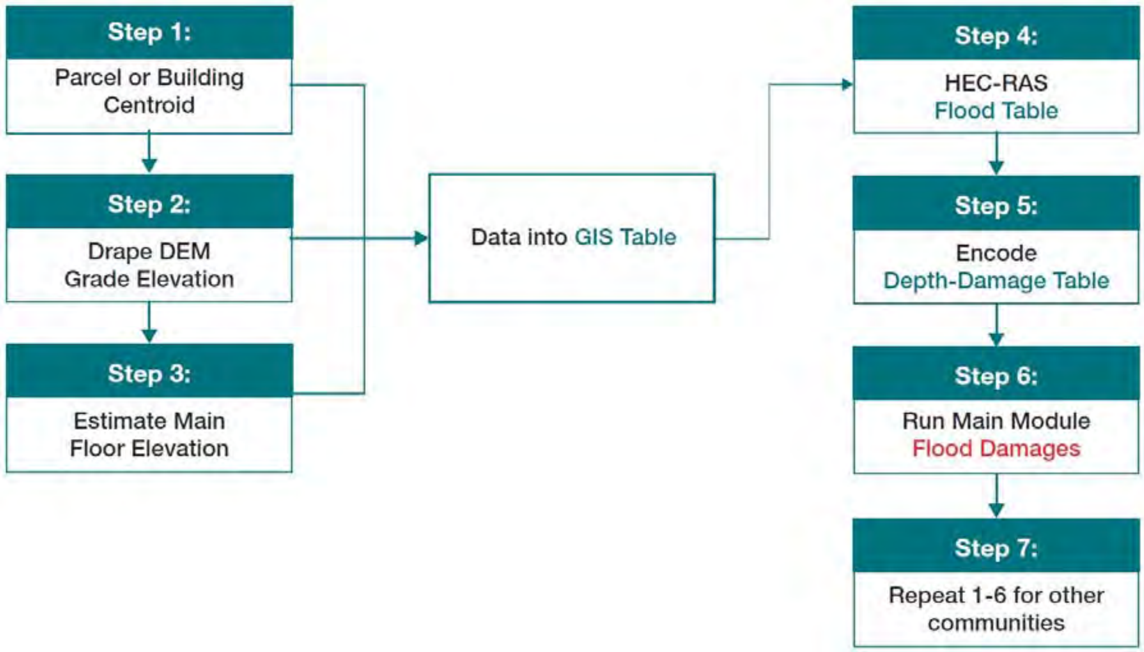
Similarly, the elevation grade for the property can be extracted by draping on the 3D surface from LiDAR or other DEMs. Naturally the denser the ground points are, the more accurate the elevation will be. In the worst case elevations can be extracted from contour maps. The process is illustrated in **Exhibit A-2**.

Exhibit A-2: Calgary GIS and Assessment Data Preparation Process



The process for estimating flood damages using the model is shown in **Exhibit A-3** and is described on a step-by-step basis as follows:

Exhibit A-3: RFDAM Damage Estimate Steps



1. Load parcel base map coverage in GIS to generate centroid for draping. If the main floor area is available from assessment then this value should be used. This is available in larger communities but may not be readily available in smaller ones. In addition the building outline may be available. If not the building area could be digitized and automatically computed using GIS if necessary.

Note: FDDBMS used damage curves that were averaged to residential building types and class because it was not possible to easily obtain individual building areas at that time. Now assessment or GIS areas for buildings can be employed.

1. Drape centroids on LiDAR DEM bare earth (BE) coverage to obtain grade elevation. BE coverage is created by applying sophisticated algorithms to compute the ground elevations without structures or vegetation.

2. Grade to main floor height may be estimated from a windshield level loop survey or Google Earth type street level photography. If that is not possible then an average grade height from past observations can be used in the model. The information from steps 1 to 3 are added to the 'GIS Inventory Table'.

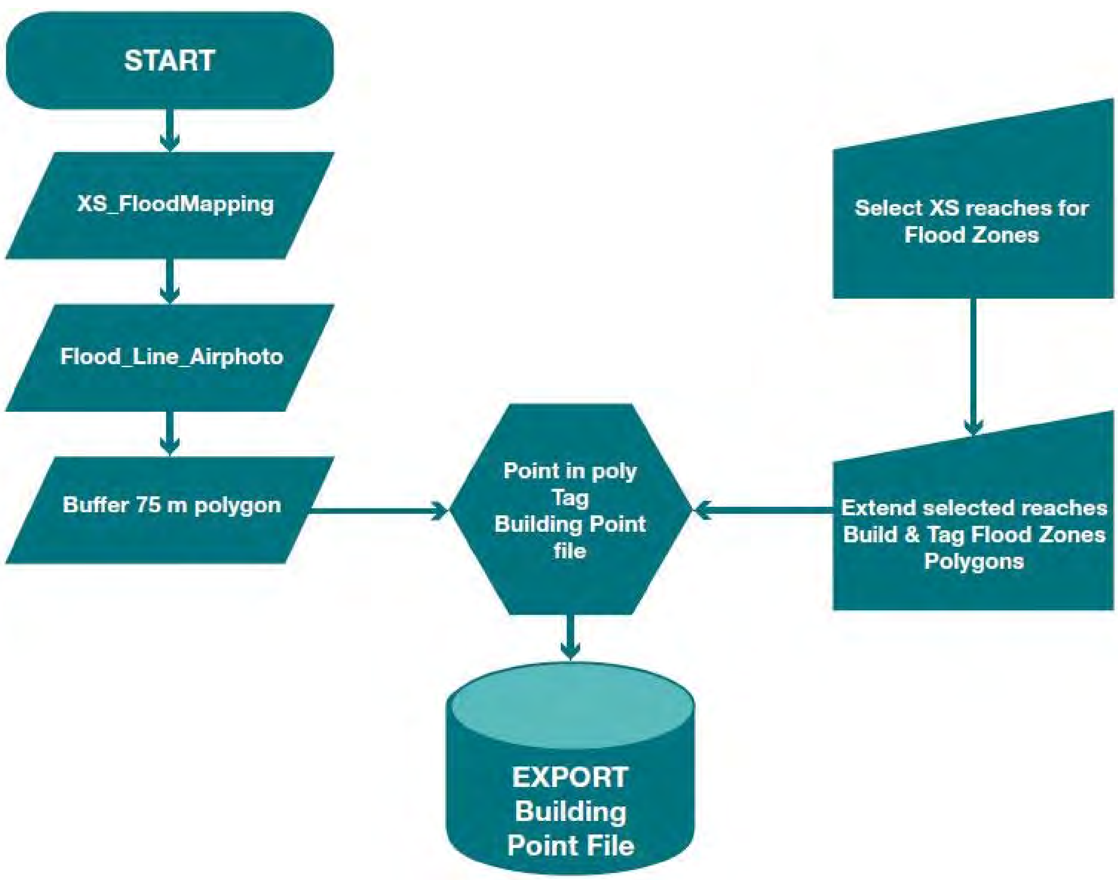
3. Use the HEC-RAS model sections to define floodplain zones in the community, include the adjacent-to areas using a buffer zone on the left and right of the cross-sections. Input table of flood elevations for the different return flood levels that will be used for flood damage calculations. This can be referred to as the 'Flood Table' (see **Exhibit A-4**).

4. Code updated depth-damage curves for structure and contents for residential and commercial buildings into a 'Depth-Damage Table'. Damage curves developed specifically for Alberta were employed in the 1980s. These have been updated to 2014 values for use within the entire Province through place-to-place indexing. These are the most current and accurate synthetic flood damage curves for depicting damages in Alberta.

5. Once the three key tables are generated the RFDAM model can be run to calculate the flood damages to residential and commercial structures within the floodplain and adjacent-to areas for various return floods. From these, the average annual damages (AAD) can be estimated.

6. Steps 1 to 6 are repeated for each flood risk community. The RFDAM system has been developed using Free and Open-Source Software (FOSS). Quantum GIS (QGIS) has been selected as the GIS application of choice. RFDAM has improved significantly on the previous FDDBMS and provides a user-friendly, made in Alberta approach to flood damage assessment.

Exhibit A-4: Flood Cross-Sections and Hydraulic Data Preparation Process



APPENDIX E:
FLOOD DAMAGE REDUCTION ALTERNATIVES

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Structural, Corrective

Alternative

Dams and Reservoirs

Description

Involve the creation of a man-made impoundment within the valley of the basin. In terms of flood control, the primary purpose is to attenuate peak flows through storage by manipulation of the inflow/outflow hydrographs.

Discussion

These measures have been widely used in the past. The scarcity of available sites with acceptable construction and environmental costs has resulted in a marked reduction in the building of dams and reservoirs. As dams can rarely provide protection from the maximum probable flood, especially in large rivers, development downstream after the construction of the dam could still encroach on the ultimate floodplain. Traditionally, reservoir projects have been developed on the basis of multi-purpose use of water. However, use including flood control, urban water supply, irrigation, pollution abatement, maintenance of low flow and recreation are often incompatible. These conflicting demands, coupled with environmental considerations, have slowed the construction of reservoirs in recent years.

Advantages

- Potential for improved aesthetics and expanded recreational opportunities.
- Decreases existing floodplain.
- Minimizes need for localized structural measures.
- Concentrates structural measures in single area; therefore impacts are confined to one location.
- Reduces floodlines for same runoff condition.
- Provides protection for existing development within the floodplain.

Disadvantages

- Requires suitable topographic conditions.
- High capital costs.
- Requires large areas of land.
- Protects only up to the design storm.
- Encourages encroachment in floodplain by creating false sense of security.
- Environmental constraints: loss of habitat, habitat destruction, erosion, intrusion of exotic flora/fauna, obstruction of fish spawning and migration routes, changes in water temperature, oxygen depletion, thermal stratification, impedes mobility of wildlife.

Feasibility

The SRI - Springbank Flood Storage Reservoir is being designed for implementation on the Elbow River. Appropriate sites will also be evaluated for the Bow River.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

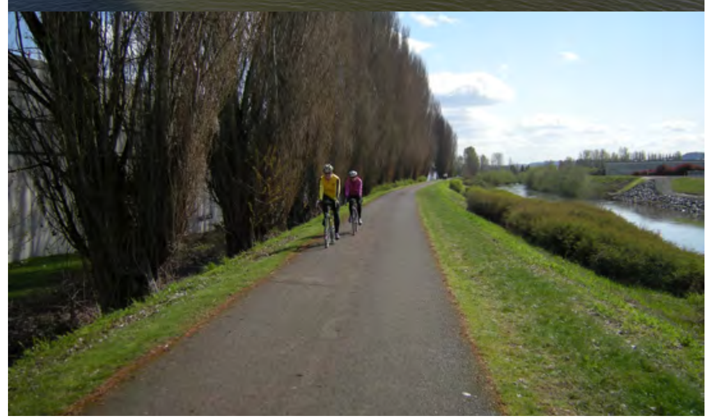
Structural, Corrective

Alternative

Dykes, Levees, Floodwalls

Description

Earthen or structural embankments constructed along the edge of a river to control the flow within the floodway.



Discussion

These measures are considered in instances where it may be more feasible to confine flood waters by raising the banks of the stream channel than to control the streamflow rate with reservoirs. Dykes are usually constructed where suitable earth materials are available and where the rights-of-way are inexpensive. In urban areas concrete floodwalls may be utilized to reduce the right-of-way requirement. Interior drainage, patrol during floods, emergency operations for seepage, and other features must be considered in dyke and floodwall design. Dykes usually give an erroneous impression that all future floods will be “Controlled”. This can lead to land use changes with a higher intensity of development and occupancy and if the dykes are ever breached or over-topped, the results may be sudden and catastrophic. Resulting property damages and loss of life may be many times greater than before the dykes were built.

Advantages

- Relatively cheap structural alternative requiring a right-of-way along the bank.
- Represents a local remedial alternative.
- Minimal environmental impact.
- No relocation is required.
- Protects existing development.
- Reduces annual damages for a specific area.

Disadvantages

- Larger dykes tend to be aesthetically displeasing.
- Depending upon the height of the dyke, when the structure is over-topped, damage and loss of life can be considerable.
- Local drainage requires special treatment (i.e., conventional storm sewer system with flap-gated outfalls).
- Added costs for associated storm drainage system and maintenance (pumps, control gates, etc.).
- Creates false sense of security resulting in flood-plain encroachment and decreases the incentive for flood-proofing.

Feasibility

These types of barriers have been implemented in Calgary in the past and will be considered as a principal means of protecting existing communities.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Structural, Corrective

Alternative

Channel Improvements

Description

Involve the application of structural modifications in order to increase the conveyance of flood flows within the channel. This can be achieved through the straightening and/or realignment, steepening of the gradient, deepening, widening, and changing the channel geometry.

Discussion

Channel improvements are fairly common and numerous schemes have been implemented throughout the province to lower flood levels in hazard areas by increasing waterway capacities. While channelization does provide relief from periodic inundation, officials have become increasingly aware that adverse environmental changes may be introduced due to increased discharge velocities and flood peaks. In general, improvements only marginally increase flood carrying capacity of the river.

Advantages

- Most construction work can be undertaken within the floodway and consequently, this measure tends to be less disruptive socially.
- Facilitates evacuation proceedings if floods exceed the capacity of the channel.
- Fairly low capital and maintenance costs compared to larger dam and reservoir structures.

Disadvantages

- Increases velocities resulting in erosion and subsequent sedimentation and deterioration of water quality.
- Construction impacts most disruptive to natural stream channel.
- Increased maintenance.
- Existing development may inhibit construction accessibility precluding extensive modification and thereby limiting the effectiveness of the remedial measures.

Feasibility

Can improve conditions related to higher frequency events in key locations. Limited utility in reducing overall damages.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Structural, Corrective/Preventive

Alternative

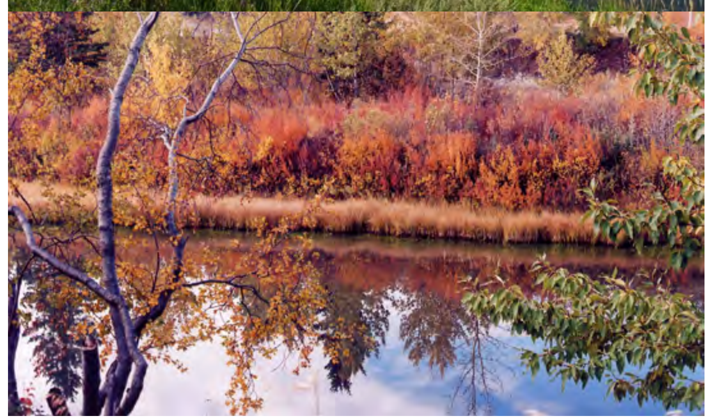
Watershed Treatment

Description

Watershed treatment entails a modification of the snowmelt/rainfall runoff through land use changes intended to make the soil more capable of absorbing and storing runoff including: crop rotation, contour farming, terracing, reforestation, construction of water retention structures, preservation of wetlands, etc.

Discussion

This remedial alternative has limited potential for flood reduction, particularly on small watersheds. Studies have shown that, unless very extensive, these measures have a minor effect on major floods from large drainage areas and are generally not considered comparable with other measures for urban flood protection. Problems also exist with respect to land use zoning and regulation, which tend to be complex due to the number of agencies involved and the fact that political boundaries do not reflect watershed boundaries.



Advantages

- Relatively low costs associated with implementation.
- Can be tied in with general conservation practices.
- Least environmental impact.

Disadvantages

- Long term measure.
- Complex from a planning standpoint.
- In Alberta, no one agency has a mandate to undertake this type of regulatory control.
- Has only minor effect for major floods and limited potential on small watersheds.

Feasibility

Very limited effect on damages within Calgary. Not considered a viable option, although long term could reduce flood peaks somewhat.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

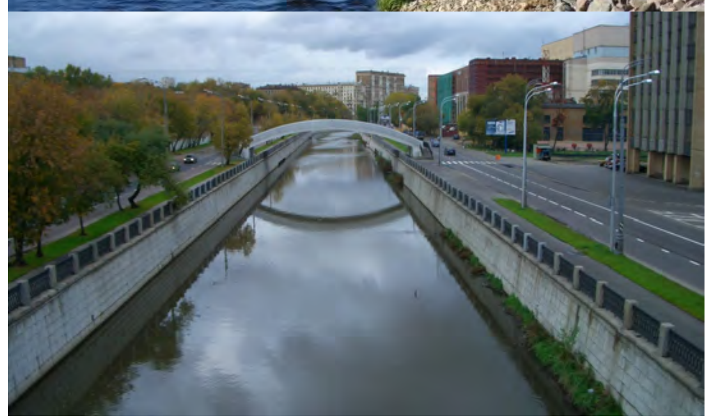
Structural, Corrective

Alternative

Bypass and Diversion Channels

Description

Entails construction of a new channel to divert all, or a portion, of the floodflows around the problem areas.



Discussion

As in the case of flood channels, these bypasses may prove inadequate for flows which exceed the capacity of the works and flooding may occur in a similar manner. A diversion scheme was part of the SRI Flood Mitigation project for the Elbow River.

Advantages

- Provides a high level of protection.
- Eliminates need to modify existing natural channel.
- It may be located on less desirable land.
- Can be designed to receive only floodflows and thereby maintain the natural ecological processes within the stream.

Disadvantages

- Represents a very costly alternative.
- High land requirements.
- Limited applicability dependent upon topography of surrounding land.

Feasibility

SRI for the Elbow River includes a diversion channel to the flood storage reservoir. A similar approach may be possible for the Bow River.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

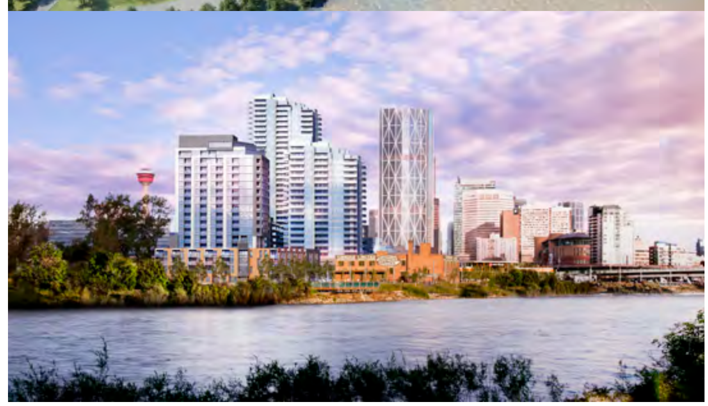
Non-Structural, Corrective

Alternative

Urban Redevelopment

Description

This entails a comprehensive program to upgrade by reconstructing and floodproofing those structures in the flood plain and in particular the flood fringe area.



Discussion

Given that redevelopment would take place over a period of time and would in all likelihood be subsidized, capital expenditures can be dispersed, making this measure a more attractive alternative.

Advantages

- Costs are spread over a long period of time.
- As the program proceeds, annual damages decrease.
- There is encouragement through subsidies for individual contribution.
- Facilitates well-planned floodproofing program.

Disadvantages

- Constitutes a long term program.
- Problems are related to complex planning and implementation as a result of the long term nature of this alternative.
- Until redevelopment is complete, the potential for flood damage still exists.

Feasibility

Could be considered for specially designated areas subject to frequent flooding, ie. Sunnyside.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Non-Structural, Corrective

Alternative

Relocation/Acquisition

Description

Entails relocation of residential population to areas outside the floodplain through the acquisition of floodplain improvements and properties.

Discussion

Frequently, structures are bought out and demolished. Alternatively, the structures can be physically removed intact and relocated. In the cases where the Municipality has property, i.e. existing UR or parkland outside the floodplain, new residential areas could be created vis a vis, a land exchange.

Advantages

- Eliminates annual and potential floodplain damages.
- Eliminates social disruption incurred as a result of flooding.
- Represents a very viable alternative if only a few structures are involved.

Disadvantages

- The expropriation/demolition alternative is very expensive.
- Although the land exchange alternative is less expensive, considerable costs can still be incurred.
- In some cases, older structures cannot be moved.

Feasibility

Limited potential for Calgary except for specific floodway locations.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Structural, Corrective

Alternative

Storm Water Management

Description

Entails the implementation of storm water controls intended to increase infiltration, increase lag time, and establish storage systems to attenuate peak post urbanization discharge.

Discussion

Storm water management is effective where flooding is caused by rain events resulting in runoff from urban areas (i.e., small watershed with large urban centres or urban drainage systems). This method has a potential to be very effective if correctly applied and the approach is being given wide consideration as part of L.I.D. initiatives across the city.

Advantages

- Decreases local damages.
- The pond systems created may provide recreational/ aesthetic benefit.
- Potential environmental problems associated with increased storm water runoff are modified.

Disadvantages

- Hard to implement when existing system has not been designed with storm water management in mind.
- Does not have significant impact for large drainage systems.

Feasibility

Limited ability to effect flood damage in this instance.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Non-Structural, Preventive

Alternative

Floodplain Regulations

Description

Essentially, floodplain regulations set guidelines which determine permissible land use within the floodplain. Floodplain regulations are usually implemented by means of enabling legislation, which takes the form of a statute or legislative act, that declares, commands or prohibits something.

Discussion

Statutes dealing with flood waters are aimed at preventing conditions that increase flows and flood heights caused by the acts or omissions of others. A regulation cannot reduce the risk to existing flood prone development, however, existing non-conforming uses can usually be brought into conformity by floodproofing.

The feasibility of regulations is contingent upon strong enabling legislation at the provincial level. U.S. experience has shown that courts have thrown out local bylaws relating to floodplain regulations. However, they have upheld statewide legislation. Additional requisites to ensure a viable regulatory program include:

- a review/referral procedure
- an appeal process (L.A.B., O.M.B.)
- definition of an applicable design flood
- a program to undertake accurate floodplain mapping which is the basis of floodplain regulation.

In Ontario, the Conservation Authorities Act provides a mandate to the conservation authorities to regulate activity within floodplains delineated by the regional storm. An appeal procedure assigned to the Ministry of Natural Resources provides some flexibility in the application of the regulations.

If regulations are to be successful, they should serve as a guide, be reasonable and non-discriminatory rather than totally prohibitive. Techniques for applying floodplain regulation include subdivision controls, building codes, and zoning.

Advantages

- Prohibits future development, thereby minimizing increased damages associated with floodplain development.
- Creates standard criteria throughout the province.
- Studies have shown that it is cost-effective to implement floodplain regulations.

Disadvantages

- Does not reduce risk to existing floodplain development.
- Involves down-zoning of existing floodplain development.
- Restricts development of existing serviced land in floodplain.

Feasibility

Design flood needs to be evaluated and regulations strengthened throughout the province.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

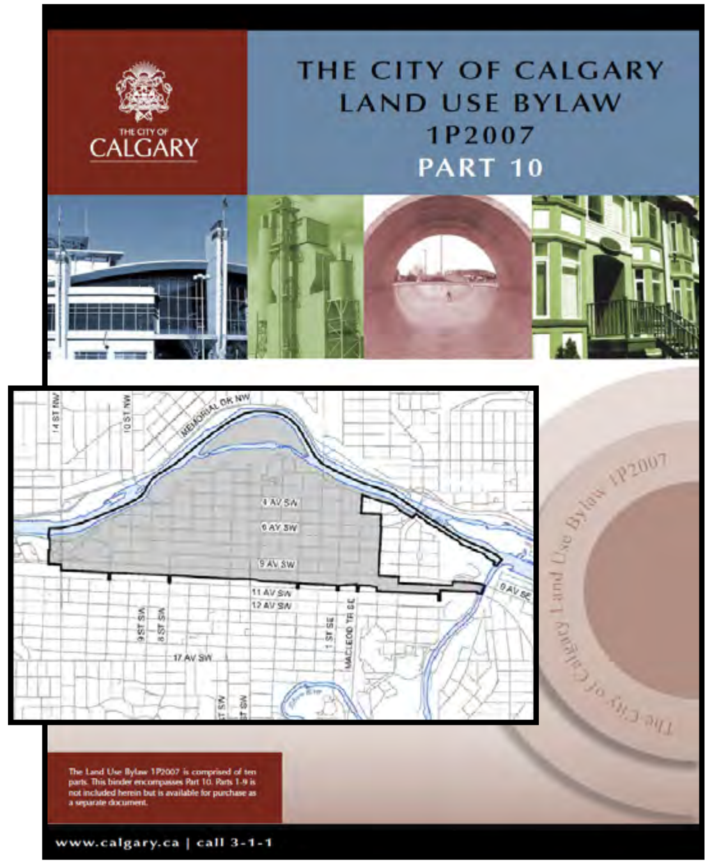
Non-Structural, Preventive

Alternative

Zoning and Land Use Bylaws

Description

These are public laws which regulate and restrict the use of land, water, and structures in the public interest under the powers of local government.



Discussion

The boundaries of various zones must be delineated and the appropriate regulations defined for each zone. The most common zones which permit uses compatible with flood hazards are agricultural, conservation and wildlife, open space for recreational use and secondary forms of transportation.

Advantages

- Similar to those of statutes.
- Prevents future development in flood prone areas within the municipality.

Disadvantages

- Can be amended.
- At the local level, conflicting interests of assessment through development and flood protection can cause problems.
- Tends to lose effectiveness without enabling or appropriate legislation at a higher level.
- Does not provide flood protection for existing development.

Feasibility

Consideration to upgrade existing bylaws to recognize new design flood and appropriate uses within flood hazard area along with conditions for re-development.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Non-Structural, Preventive

Alternative

Subdivision Regulations

Description

These are regulations which specify the manner in which the land may be divided and usually set out the various standards and design criteria a developer must meet in order to gain the approval of the governing authority.

Province of Alberta

MUNICIPAL GOVERNMENT ACT

SUBDIVISION AND DEVELOPMENT REGULATION

Alberta Regulation 43/2002

With amendments up to and including Alberta Regulation 119/2014

Office Consolidation

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Alberta Queen's Printer
7th Floor, Park Plaza
10611 - 98 Avenue
Edmonton, AB T5K 2P7
Phone: 780-427-4952
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Discussion

Regulations may be designed to prohibit the subdivision of flood hazard areas or the alteration of the natural floodway or to require the inclusion of flood protection measures for the structures that are going to be built. In addition, such regulations may prohibit the subdivision of lands which are unsuitable for the intended use of the development. Depending upon the provisions of a regulation, a developer may be prevented from subdividing flood prone lands, or as an alternative, he might be required to incorporate certain protective measures, i.e., minimum site elevation, into his plan. Experience in the United States has indicated that, by comparison with zoning regulations, subdivision regulations are not as simple and uniform and have not been too successful in flood damage protection.

One way to overcome the problems of conflicting agencies where valley lands/rivers occur would be deferment to the water resources area management body.

Advantages

- Development can be modified to mitigate flood hazard.
- Offers flexible form of control.

Disadvantages

- Objectives of reviewing agency may not be compatible with objectives of flood damage reduction.
- Mandates of agencies may be conflicting.
- Cooperation is difficult.
- In terms of enforcement, local/regional disparity may result.

Feasibility

Should be brought into alignment with revised provincial policies.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Non-Structural, Preventive

Alternative

Building Codes

Description

Building codes consist of minimum standards for construction which will ensure the safety of structures within the floodplain and thereby reduce potential damage.

Discussion

Building codes are implemented at the local level and can be readily applied in marginal flood areas. These codes can be developed in relation to the potential for flooding in a particular zone and require careful design and construction of structures to offset the threat of damage. With changing technology and construction techniques, building codes require periodic updating.

Advantages

- Ensures that new structures in the flood fringe will be floodproofed.
- Ensures floodproofing for redevelopment areas.
- Minimizes the increase in potential flood damage.

Disadvantages

- Uniform application is difficult.
- In a regional context, potential for large variance between municipalities as it relates to administration.
- No protection for existing development.

Feasibility

Needs to review building practices within the flood hazard area and enforcement of conditions/provisions, especially residential use of flood prone areas within buildings.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Non-Structural, Preventive

Alternative

Emergency Measures

Description

Emergency measures include emergency evacuation, flood fighting such as sandbagging and emergency relief services and facility repair.

Discussion

At times, these measures have been grouped and referred to as comprising elements of preparedness plans. The measures are compatible with other measures and are, in effect, a last resort serving primarily to save lives and prevent flooding from occurring when facilities are near their design limits of performance. The effectiveness of these measures relies heavily upon flood forecasting, upon prior organization and training at the community level, and upon property owner initiative. The information needs for formulation and evaluation of these measures include: (1) flood hazard and stream response characteristics; (2) infrastructure data on public utilities, services, transportation, etc.; (3) institutional structures and capabilities for managing information dissemination and organizing and supervising work crews; (4) social information related to property owner perceptions of flood hazard and propensity to undertake individual action; and (5) the effectiveness of each of the individual measures in terms of their performance during specific flood situations.

Significant direct damage reductions to both commercial and residential uses can be achieved through the implementation of an emergency measures program. In some of the more recent studies reviewed, these reductions range upwards to 40% but are generally in the 20% to 30% range. Additional benefits including reductions to indirect damages, social impact, and risk to loss of life can also accrue to emergency measures.

Advantages

- If effectively applied, this can significantly reduce potential damage and risk of loss of life.
- Can also result in reductions to indirect damages.
- Incur relatively low financial cost.
- Little or no environmental impact.
- Offer high degree of flexibility in meeting changing future conditions.
- Aid in promoting awareness in resident responsibility at local level.

Disadvantages

- Not effective as a “stand alone” alternative.
- Requires comprehensive plan and public education.
- Requires high level of response to be effective.

Feasibility

Educational and learning component of existing flood emergency measures plan needs to be improved. Contingency measures for homeowners should be added to protocols.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Non-Structural, Preventive/Corrective

Alternative

Floodproofing

Description

Floodproofing consists of various measures to render buildings, contents, and grounds less vulnerable to flood damage, i.e., raising structures by means of fill.

Discussion

Depending upon the source, floodproofing can be considered as a structural or non-structural alternative, as it can entail any number of structural aims to render a property less prone to flood damages. These include preventing water from entering the structure by means of waterproofing, waterproofing utilities and physically raising the floor level.

Building codes and regulations require special detailed design and construction methods to assure acceptable uniform application by floodplain users. Only moderate flooding characterized by shallow depth and low velocity can be economically floodproofed, and floodproofing techniques are most effectively utilized by commercial and industrial buildings. When the design flood capacity is exceeded, catastrophic losses can result. Floodproofing may give a false sense of security that could lead to increased occupancy of floodplains which in turn, could conflict with good land use planning.

Advantages

- Can be implemented on a unit per unit basis.
- Eliminates need for relocation.
- Minimizes basement damage.
- Minimizes environmental disruption.

Disadvantages

- Effectiveness is questionable for existing structures.
- Expensive and requires special building techniques.
- Only sufficient to offset shallow floods and low velocity.

Feasibility

Limited ability to effect damages. Suitable in select circumstances.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Non-Structural, Preventive

Alternative

Flood Forecasting and Warning

Description

This entails a program whereby local residents and responsible government authorities are alerted of an oncoming flood.

Discussion

Relatively short term action taken as a result of a reliable and timely forecast and warning of an impending flood, can significantly reduce the economic losses and human suffering that would otherwise be caused by the flood. However, the economic benefit of flood warning systems can be limited when there is a quick response by the river to rainfall or snowmelt events and a corresponding lack of appropriate warning time to effect evacuation measures. The provision of information relating to an imminent flooding situation requires that a relatively comprehensive hyrdometeorological data network be established, together with an experienced staff of forecasters to interpret information provided by this network. To be effective, a flood forecasting program must be closely integrated with the emergency measures program.

Another type of warning system is long term in nature and involves the education of the public. The developers of floodplains must be adequately warned of the possibilities of flooding if they are to be permitted to locate within the floodplain. Public information and education programs are usually the responsibility of regulation and enforcement agencies. Other methods of warning include signage, etc.

Advantages

- Provides the lead time required to implement emergency measures and thereby reduce damage and risk.

Disadvantages

- Not effective as a “stand alone” alternative.

Feasibility

May require consideration of current warning protocols.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Non-Structural, Preventive

Alternative

Development Policies

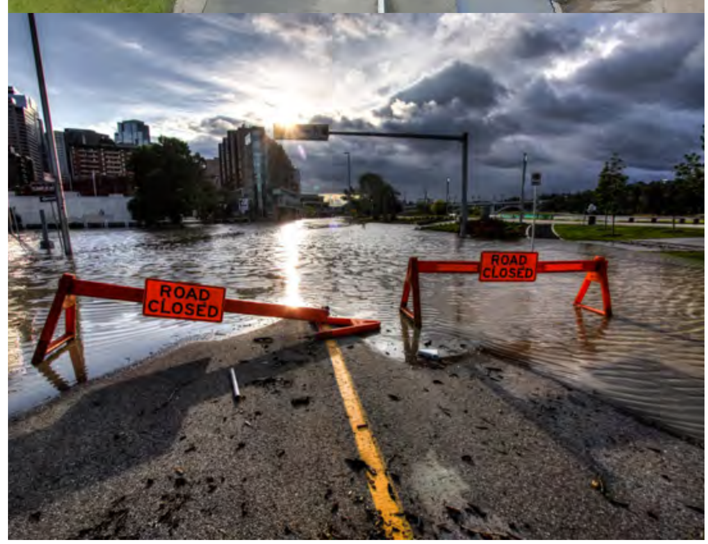
Description

Essentially, the Municipality adopts a policy whereby it refuses to extend utilities and construct streets in flood hazard areas.

Discussion

Street improvements elsewhere, schools and other public facilities wield a soft sell negative influence on floodplain exploitation and a positive incentive toward the safer but higher ground. These policies have no influence on an existing floodplain use; however, they deter new developments from flood prone areas, and thereby serve to minimize potential flood damages.

Under the present flood reduction program, once the design flood and floodplain has been defined and adopted by the Municipality, federal and provincial agencies will not support development within the floodlines. If development proceeds, no relief assistance will be provided should damage occur.



Advantages

- Effective in deterring future flood plain development.

Disadvantages

- No effect on existing damages.

Feasibility

Limited effect on the Calgary situation.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Non-Structural, Preventive

Alternative

Tax Adjustments

Description

Tax adjustments involve agreements by the owners of floodplain land to forfeit certain rights in return for a reduced tax assessment over a stated period of time.

Discussion

Tax adjustments can encourage property owners to forfeit rights to use their lands as they wish or to continue use of the lands in a manner consistent with a proposed plan. It may include assessment on the basis of current use rather than potential use and defer payment of taxes on lands sold for development prior to public purchase.

Tax adjustments related directly to the flood hazards and for lands dedicated to recreation, agricultural, reservoir sites, conservation or other open space uses can be effective in preserving floodways along streams. The tax adjustment alternative has seldom been used for the abatement of flood damages. Lack of understanding and support, intricacies of applications, and public attitude have been discouraging factors. As well, it is difficult to achieve a workable differential taxation scheme.

Advantages

- Encourage compatible land uses within flood plain.
- Can reduce flood damage potential.

Disadvantages

- Complexities render this alternative difficult to implement.
- Does not reduce risk to existing floodplain development.
- Does not constitute “stand alone” alternative.

Feasibility

Limited utility in the Calgary context.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Non-Structural, Preventive

Alternative

Flood Insurance

Description

Involves insuring structures and improvements within floodplain areas.

Discussion

Conceptually, insurance provides a system of protection against loss in which a number of individuals agree to pay certain sums (premiums) periodically in return for a guarantee that they will, under certain stipulated conditions, be compensated for any specified loss.

Insurance usually provides coverage against losses which occur under fortuitous circumstances (i.e. when an element of chance is involved). Higher premiums are paid for greater risks. In some instances, risks are judged to be too high to justify insurance. Under such conditions, the probability that loss will occur is usually high and is thus not considered to be fortuitous. Insurance against highly probable losses is rarely available and when it is made available the premium rate is extremely high.

Flood insurance is a major tool for floodplain management in the States, since it relates the cost of safe development to respective flood hazards. Generally it sets out standards for land use and building codes in flood prone areas. It also discourages unnecessary uses of floodplain by charging actuarial rates and also differentiates between existing and new uses by charging risk rates.

Government sponsored insurance schemes are a possibility with Provincial reserve funds to cover flood losses during the early stages of the program. Insurance rates would realistically equal the risk of loss plus the costs of administration. Flood insurance encourages efficient land use in the floodplain as the occupants are required to bear the costs through the annual premium. In order to be effective flood insurance should be compulsory for all occupants of the floodplain.

Advantages

- Seemingly elegant approach to risk management through a financial structure, establishing a hedged position that recognizes flooding potential as an opportunity cost.
- Could generate the development of flood management control expertise that can be exported to other municipalities.
- Environmentally acceptable.
- Flooding costs are borne directly to those who incur them.

Disadvantages

- Inflationary.
- Easily and historically counter-productive as it can encourage development on the Floodplain.
- High cost/benefit ratio.
- Requires competent supervision/management and leadership.
- Requires to be integrated into an overall urban design approach to the issues.
- Does not adequately reduce the risk to life.
- Probably requires outside subsidizing agency.
- There is no governmental structure in place at the moment to support a flood insurance program, as in the case of the U.S.
- Does not reduce flood damages.

Feasibility

Needs provincial policy directive to be effective. Limited effect on actual damages.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Structural and Non-structural

Alternative

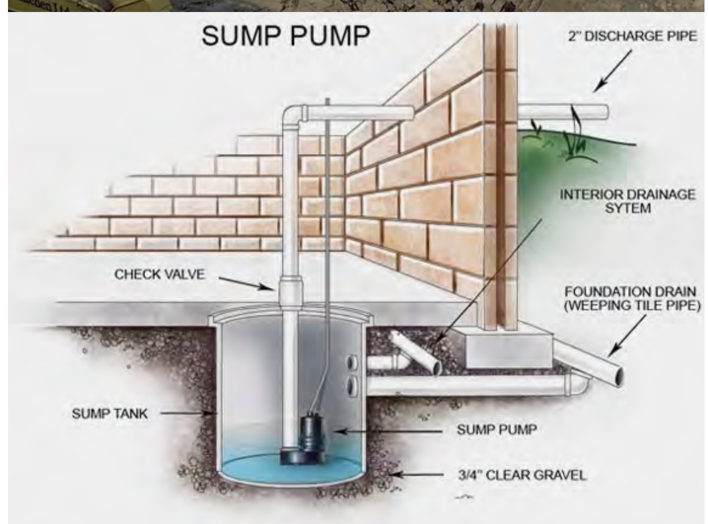
Groundwater Flood Control

Description

Groundwater flood mitigation, including basement flood mitigation, consists of various measures to control groundwater levels at underground structures including basements, and to control sewer backup due to high groundwater or surface water levels. The structural measures include low permeability barriers (e.g. slurry wall), wells/sumps and pumps, and sewer backup control valves. The non-structural measures include grants or policy to enable and support installation of backwater control valves, sumps, pumps, and generators at existing basements, or building codes to regulate basement construction or use in future development areas.

Discussion

Groundwater levels in the alluvial aquifers of Bow and Elbow Rivers may rise during flood events. High groundwater levels during floods may cause sewer backup and groundwater seepage inflow through cracks to underground structures including basements. Mitigation measures are provided to reduce groundwater levels at the underground structures or to reduce groundwater seepage inflow or sewer backup.



Advantages

- Reduce damage to underground structures including basements

Disadvantages

- Promote development of underground structures and basement, including storage of valuable contents, in the hazardous floodplain areas with risk of groundwater flooding.
- Large-scale groundwater control measures (e.g. slurry wall) are typically costly.
- Small-scale groundwater control measures (e.g. pumps and valves) may not be reliable.

Feasibility

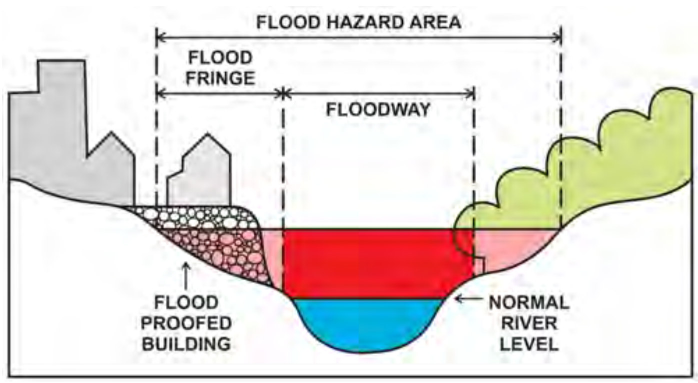
Should be considered for wholesale implementation / retrofit throughout flood hazard area, particularly the downtown.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type	Alternative
Non-structural	Identification and definition of flood hazard areas

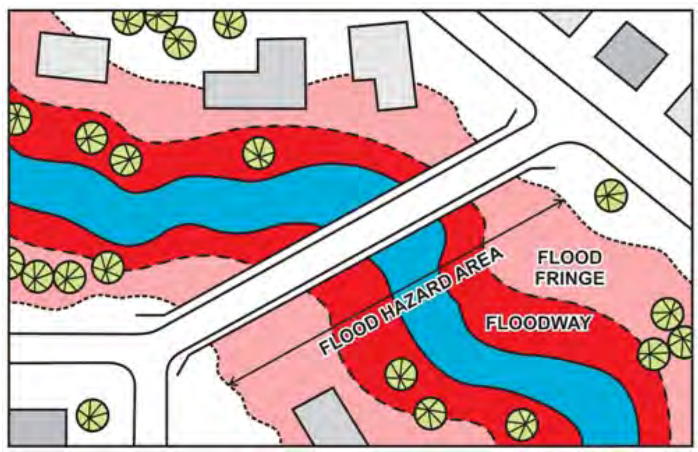
Description

Identification and definition of areas subject to river flood hazards due to flood water inundation or erosion for various flood return periods, including floodways and flood fringe limits. The flood hazard maps are used to support implementation of floodplain regulations, zoning and land use bylaws, emergency response planning, etc.



Discussion

In Alberta, Alberta Environment and Parks (AEP) manages the production of flood hazard studies and mapping under the provincial flood hazard identification program. The studies typically consist of review of historical floods, estimates of flood peak discharges for various return periods, river surveys, hydraulic modelling of river flood levels, preparation of flood inundation maps, definition of floodway and flood fringe areas for the 100-year design flood event, and identification of channel migration and bank erosion hazards.



Advantages

- Provide important flood hazard information to support planning, design and implementation of various flood mitigation measures

Disadvantages

- The flood hazard information needs to be combined with other measures (e.g. floodplain regulations) to form integrated flood mitigation measures

Feasibility

Maps need to be updated based on latest hydrology and annotated to inform emergency management plans.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Structural

Alternative

Temporary flood barriers installed prior to or during flood events

Description

Temporary barriers (e.g. sandbags, earth fill berms, water tubes, etc.) are installed prior to or during flood events to control river flood water from overflowing into the floodplain areas behind the barriers.

Discussion

Temporary barriers are one of the flood response measures. Temporary barriers are particularly applicable in already developed or populated areas where installation of permanent barriers (e.g. dykes) is not feasible, practical or desirable. The flood response plan adopted by the City of Calgary includes identification and design of temporary barriers. For each temporary barrier, a reference or information sheet is prepared to include such information as a site map, barrier alignment, material quantity estimates, and pertinent notes.

Advantages

- No permanent structure affecting existing access to river and riverine aesthetics
- Mitigation expenditure only when floods occur
- Engagement of local residents for installing the temporary barriers if needed

Disadvantages

- Less reliable for preventing or controlling river overflow than permanent barriers
- There may be limitation on the level of protection that the temporary barriers can provide (e.g. there is a limit on the maximum height of sandbagging).
- Timely and effective installation of the temporary barriers may be constrained by flood warning time and time available to mobilize the resources (i.e. labor and material)

Feasibility

Should be part of emergency response plans until permanent solutions implemented.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Structural

Alternative

River channel migration and bank erosion control works

Description

Bank stabilization and erosion works are typically designed and implemented to protect against channel erosion during select design flood events. There are various types of protection works, including riprap lining, groins, concrete lining, gabions, mattresses, articulated concrete mattresses, sacks and blocks, soil cement, retaining walls, gravity walls, sheet-piling walls, vegetated banks (e.g. with shrubs, trees and grasses), windrows and trenches, etc.

Discussion

Rivers carry large amounts of water and sediments during large flood events. In addition to conveying sediments generated from overland runoff, large flow velocities, turbulence and shear forces of flood water can cause channel bed and bank erosion. Channel bank erosion in particular can result in damages to city infrastructure, and commercial or residential buildings adjacent to river channels. Bank stabilization and erosion control works are effective mitigation measures to control, reduce or eliminate the risk of flood damage due to erosion.

Advantages

- Provide protection against channel erosion at select locations up to the design flood event.

Disadvantages

- Erosion protection work at one location may increase the risk of channel erosion at other locations downstream of the work
- There is still residual risk of channel erosion where there is protection work for flood events higher than the design flood.
- Bank erosion protection work may impact fish habitat and fish offsetting may be required
- Bank erosion protection work may impact navigation
- Bank erosion protection work may have negative impact on natural appearance of the riverine environment

Feasibility

Ongoing program will ameliorate worse impacts due to erosion.

FLOOD DAMAGE REDUCTION ALTERNATIVES

Type

Non-structural

Alternative

Integrated Basin Flood Management Planning and Operation

Description

Establishment of a single river basin authority responsible for planning and implementing flood management and mitigation plan, including preparation of flood hazard studies and maps, flood warning, and design/construction/operation of flood mitigation facilities.

Discussion

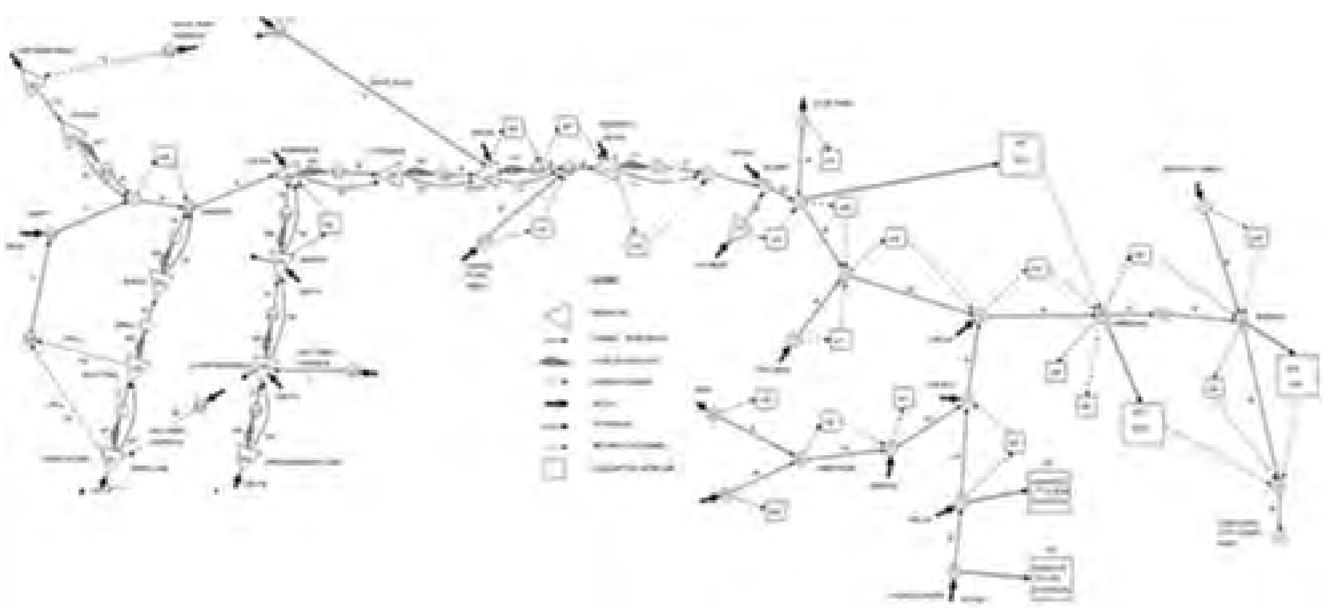
Integrated basin flood management planning and operation have many benefits. Large floods typically impact a large number of communities in a river basin. Management of such flood events require basin-wide information sharing and coordinated efforts. High levels of effectiveness and efficiency are achieved by an integrated approach.

Advantages

- Develop integrated flood mitigation measures to ensure that reduction of flood risk in one area would not increase the risk in other areas
- Optimize use of resources for planning, construction and operation of flood mitigation facilities to increase the total benefits
- Develop and execute flood management plan in an integrated manner to avoid duplication of efforts

Disadvantages

- A new single responsible authority for integrated basin flood management needs to be established



Feasibility

Provincial responsibility.

APPENDIX F:
CITY OF WINNIPEG FLOOD MITIGATION EXPERIENCE

Category	Type	Used in Red River Basin? (Y/N)	Qualitative Rating of Effectiveness*	Comments
Structural Measures	Dams and Reservoirs	Not on the Red River but a dam has been constructed on the Assiniboine River which is a major tributary to the Red River and a water control structure constructed on the Fairford River.	**2**	The Shellmouth Dam, located about 375 km from Winnipeg, is a component in the overall flood control infrastructure for the Province of Manitoba (Fig. 1) . A portion of flood water can be stored in the 56 km long upstream reservoir in the Assiniboine River valley. Improvements to the dam are planned that include the installation of spillway gates that would allow higher reservoir levels which could provide additional flood protection benefits. Although an important component of overall flood management, a score of 2 has been assigned to the due to the relatively small incremental effect on flood protection levels in the Red River basin.
			1	The Fairford Water Control Structure regulates water levels on Lake Manitoba and spills water into Lake St. Martin and the Dauphin River and finally Lake Winnipeg (Fig. 2). In this regard, Lake Manitoba provides storage of flood water diverted from the Assiniboine River west of Winnipeg (before the confluence of the Red River). In 2011, an emergency outlet channel was constructed to drain flood water from lake St. Martin and Lake Manitoba into Lake Winnipeg. A score of 1 has been assigned to the due to the relatively small incremental effect on flood protection levels in the Red River Basin.
	Permanent Dykes, Levees, Floodwalls	Permanent dykes within the City of Winnipeg.	**10**	These are primary dykes along the Red, Assiniboine, and Seine River, providing what is termed as the Primary Line of Defence (PLD) to the City of Winnipeg. Several of these dykes were raised following the 1997 flood. They are typically broad boulevard type earth fill dykes constructed to the Flood Protection Level (FPL) or higher. The FPL is the flood stage river elevation plus 0.6 m of freeboard. There are also secondary dykes along these rivers to protect low-lying properties on the river side of the primary dykes. Following the 1997 flood, many of these dykes were made permanent.
		Permanent dykes at Floodway Inlet Structure	**10**	Earth dykes on either side of the inlet structure for the Red River Floodway retain flood waters. East of the Red River, the dyke ties into the embankment from the original Floodway excavation. West of the Red River, the dyke extends about 20 km to a naturally high point (this is called the West Dyke) to prevent flood waters from passing into the LaSalle River and directly entering Winnipeg (i.e. it would bypass the Floodway Inlet). The West Dyke was raised and extended following the 1997 flood.
		Ring dykes	**10**	Eighteen communities within the Red River Basin are protected with earth ring dykes which provide protection to 1997 flood levels plus 0.6 m freeboard. These dykes can be partially or completely closed during a flood. In addition, over 1,800 individual homes are now flood protected by ring dykes or have been moved onto elevated earth pads. These works protect up to 95% of the homes, businesses and farms in the basin.
		Floodwalls	**8**	There are several locations where floodwalls have been constructed to protect existing infrastructure located below FPL; these are typically for individual structures or properties and generally consist of a concrete wall extending several metres into clay for seepage control. Where the top of the wall is below FPL, a demountable wall may be erected on top of the permanent wall. The demountable wall may consist of prefabricated panels, structurally supported using posts or rakers.
	Channel Improvements	N	**NA**	Not practical or effective
	Bypass and Diversion Channels	Red River Floodway	**10**	The Red River Floodway was constructed in the 1960s to provide flood protection for the 1:160 year flood. It diverts water around the City of Winnipeg via a diversion channel with an original design capacity of 1,700 cubic meters per second (1,700 cms) or 60,000 cubic feet per second (60,000 cfs). There are four main components; i) an inlet structure, ii) the main channel, iii) an outlet structure and iv) the dykes (mentioned above). The channel is about 48 km long with a drop of about 5.5 m from the inlet to the outlet. The original base width ranged from 116 to 165 m; the channel was widened following the 1997 flood to increase the capacity to 4,000 cms equivalent to a 1:700 year flood event. Upgrades were also carried out at 8 bridge crossings to avoid obstructions at high flows.
		Portage Diversion Channel	**9**	A 30 km long channel designed to convey 708 cms (25,000 cfs) of flood flow from the Assiniboine River to Lake Manitoba (Fig. 1). This not only provides flood protection to the City of Winnipeg but also the City of portage la Prairie and communities between these two cities. The major components are a diversion structure to direct water into the channel, two gradient control structures and an outlet structure.
	Watershed Treatment	Generally not by design	**1**	The Commission created to carry out joint Canadian and American studies of flooding issues in the Red River Basin is known as the International Red River Task Force who reports directly to the International Joint Commission (IJC). The IJC is a binational organization that assists the Canadian and US Governments in managing water shared by both countries. The Task Force has looked at the possibility of storing flood water on farmlands and creating more wetlands within the Red River Basin. At issue recently was the question at to whether holding back a portion of the peak flow could reduce the risk to flood protection works already in place and if protection from rare floods is economically justified. In this regard, the construction of detention structure at St. Agathe Manitoba (about 50 km south of Winnipeg) was shown to be capable of significantly reducing river levels at the Floodway inlet by creating a temporary storage reservoir between St. Agathe and the US border. This alternative was not pursued further upon reaching the decision to expand the capacity of the Red River Floodway. Alternatives have also been considered which increase flood storage by using existing land bounded by roadways to create a series of small low-head reservoirs, controlled by gated culverts (micro-storage). It was concluded that " Large-scale micro-storage has some potential to reduce flood peaks on the Red River but it is likely to be impractical and costly. There are many obstacles to its effective and efficient implementation" (International Red River Basin Task Force, 2000). The Task Force also looked at the possibility of using wetlands (shallow depressions in the land) to retain water and reduce the flood peaks for large Red River flood events. Overall, it was determined that while wetlands restoration would provide local benefits associated with ecosystem restoration and wildlife habitat, it will have limited benefit in controlling major floods. The effects of wetland, farmland, and urban area drainage are also unclear; quickly draining these areas may in some cases provide a benefit, but may also result in local tributary peaks coinciding with the peak in the Red River (such was the case in 1997). Additional studies would be required to better evaluate this as a means of flood peak attenuation.

Category	Type	Used in Red River Basin? (Y/N)	Qualitative Rating of Effectiveness*	Comments
	Temporary Flood Barriers	Y	**6**	A variety of temporary flood protection barriers are used within the Red River Basin including the City of Winnipeg. These products include super sandbags, Hesco® barriers, water-filled geomembrane flood tubes, and sandbags. Other products including structural walls (Muscle Wall®) and Rapid Installation Barrier Systems (Ribs®) have been deployed on a trial basis (TREK, 2012, 2013). The Province alone has 50 km of flood tubes of which 22 km are in rapid response trailers. Sandbag dykes are commonly used and can be constructed over a variety of ground conditions and to heights up to about 2 m. Both the Province of Manitoba and the City of Winnipeg have sandbagging machines capable of producing large quantities of bags over short periods of time and which can be deployed to where they are most needed. In 1997, the City of Winnipeg alone produced about six million sandbags. These products have a limited capability as a primary line of defence but are well suited for secondary flood protection, to protect against overland run-off or providing additional freeboard.
	Channel Bank Erosion Protection	Y	**5**	Riverbank stabilization works are routinely constructed in urban areas, and to a lesser degree in rural areas, to protect critical infrastructure and properties. Since the root cause of many riverbank instabilities is scouring of the channel banks, erosion protection is typically applied as a preventative measure or as a component of stabilization works. Large diameter quarried rip rap is typically used. For example, rip rap is used to protect the river bank at the Floodway Inlet Structure where localized downstream water velocities and turbulence are significant. In this regard, erosion protection does not directly provide flood protection but is an important component in waterway management.
	Groundwater Flood Control	Y	**2**	Sump pumps often provide the primary means of preventing groundwater from entering basements. In some cases, large capacity pumps may be used to evacuate water providing the structure has been designed to accommodate the hydraulic pressures. Seepage cut-off walls are used on a very limited basis. The City of Winnipeg also subsidises the cost of installing backwater valves and sump pits to protect basements from flooding caused by overloaded sewers during high river levels. Both are now a requirement for new development.
Non-Structural Measures	Urban Redevelopment	Y	**2**	Both the Province of Manitoba and City of Winnipeg have adopted strategies whereby floodproofing of structures in flood prone areas is implemented; often this is considered based on the cost of providing secondary flood protection (e.g. sandbags) relative to the cost of permanent flood protection. Funding may be available to assist property owners.
	Property Relocation/Acquisition	Y	**1**	The most vulnerable structures south of Winnipeg were purchased by the Province and removed from high-hazard areas. The City of Winnipeg has generally adopted a strategy of providing enhanced flood protection for homes within the city (protected by the Floodway). The Province has identified up to 200 homes north of Winnipeg subject to ice jam floods as potential candidates for buy-outs (Winnipeg Free Press, 2009).
	Storm Water Management	Y	**1**	The current design philosophy in the City of Winnipeg has been to use temporary storage facilities (retention basins) that reduce the peak stormwater runoff. This provides more of a localized benefit and overall, has a limited impact on mitigating flood conditions along the Red River.
	River Flood Hazard and Inundation Mapping	Y	**7**	Significant improvements in databases have been made following the 1997 flood. A lidar-based digital elevation model has been prepared for the Red River Basin from the US border to Lake Winnipeg. This has greatly assisted in the preparation of hydrological and hydraulic models. About 70% of all residences and businesses have been geo-referenced with GPS and incorporated into the database (excluding structures within ring dykes).
	Floodplain Regulations	Y	**3**	Manitoba has introduced a Designated Flood Area Regulation; this provides elevation and inspection requirements for all new structures in flood prone areas. The City of Winnipeg has adopted the Designated Floodway Fringe Area Regulation (266/91) that regulates new construction or additions to structures within a designated floodway fringe area; floodproofing requirements are laid out based on the elevation of the building lot. Construction within the designated Floodway Zone is generally not permitted.
	Zoning and Land Use Bylaws	Y	**3**	Using a floodplain overlay, areas within the floodplain are subject to extra regulations.
	Subdivision Regulations	Y	**3**	If situated within the designated Floodway Fringe Zone, permanent flood protection measures such as dykes are required. Bank stabilization and erosion protection measures may be required if in close proximity to the river.
	Building Codes	Y	**2**	Backwater valves and sump pits/pumps are required for all new structures in the City of Winnipeg (under separate City By-Laws); the National Plumbing Code of Canada (NBCC) provides the appropriate criteria. NBCC would identify design codes applicable to the design of structural flood walls, however, there are no specific (general) requirements for structures located on flood plains. The Province requires an engineering assessment and design where flood protection works are near unstable slopes or shorelines with erosion concerns, for retaining (flood) walls, where a structural change to a building is required, and for all new foundations (in accordance with NBCC).
	Emergency Measures	Y	**10**	Manitoba has an emergency response plan that includes all municipalities. Each community is required to have an emergency response plan that takes an all-hazard approach. These plans are submitted to the Emergency Measures Organization (EMO) for review on a four-year cycle. All 198 communities have approved plans with designated emergency coordinators (which may be shared amongst smaller communities). The City of Winnipeg has an overall Emergency Preparedness Program that includes the planning and response to flood events. As part of this program, the City has EmergWeb, a website that can be fully activated in the case of a flood event; this site provides access to the most up-to-date emergency information including maps of affected areas, information on how to get assistance, information on how to volunteer, etc. The Geotechnical Emergency Response Team (GERT) may be implemented to provide technical advice related to emergency flood protection and inspection.
	Flood Proofing	Y	**3**	Under the Provincial Flood Proofing Program, financial assistance may be provided to property owners of flood prone buildings through the 2015 Individual Flood Protection Initiative. Under this program, acceptable measures are separated into structural works and earthworks. Structural works include raising the building onto a raised existing foundation or new raised foundation or moving the building to an area that is not flood prone. Earthworks includes raising buildings onto earth pads, dyking, terracing, or the construction of neighbourhood dykes. The City of Winnipeg requires that flood proofing measures must be incorporated in compliance with the Designated Floodway Fringe Area Regulation 266/91.
	Integrated Basin Flood Management Planning and Operation	Y	**10**	Integration has been provided by the formation of the International Red River Board (IRRB), The Red River Basin Commission (RRBC) and the International Water Institute (IWI), formerly the red River Basin institute. The IRRB is an advisory board to the International Joint Commission (IJC) and is co-chaired by representatives from the United States and Canada. It is tasked (among other things) to monitor the status of the IJC's recommendations pertaining to flooding along the Red River basin.

Category	Type	Used in Red River Basin? (Y/N)	Qualitative Rating of Effectiveness*	Comments
	Flood Monitoring, Forecasting and Warning	Y	**8**	Since 2002, Manitoba Water Stewardship has used a Mike-11 model for flood routing in the Manitoba portion of the basin. Improvements to hydrometric and climate monitoring networks have also been made. There is still a need for improved snow water equivalent, frost penetration and rainfall data. Following the 1997 flood, gauging stations were raised to withstand high water levels. The US national Weather Service (NWS) and Manitoba Water Stewardship have taken steps to increase public engagement in spring flood forecasts.
		Y	**10**	The City of Winnipeg developed a Flood Manual for use in forecasting requirements for mitigation works. It is a geographic information system (GIS)-based computer program that is linked to other GIS information containing records of sewer systems, property information, specific flood protection plans and information (e.g. reports and photos) on how properties were protected in 1997 and subsequent flood events. It is updated annually to incorporate new experience and changes in the system(s). On a web-based system, City engineers can input river flows and/or levels to predict impact areas and calculate the activities required to provide protection against the predicted levels (e.g. number of sandbags). It also provides the source of information to notify external agencies and property owners of river levels and actions required.
	Development Policies	Y	**NA**	The designated "Floodway" area (not to be confused with the Red River Floodway), is the portion of the flood risk area where the water is the deepest and most destructive. The remaining area is called the Floodway Fringe where waters are shallower and slower. In the 1970s, Canada and the Province of Manitoba (one of many including Alberta) signed a General Agreement respecting flood damage reduction (known as the Flood Damage Reduction program or FDRP). Under the terms of this 10 year agreement, the two governments agreed not to finance or engage in any projects within the designated floodway area but encourage suitable land use (e.g. agricultural). With respect to development within the Floodway fringe, it was agreed that financial assistance and disaster assistance would only be provided for undertakings that were adequately flood proofed. Although Federal participation in the FDRP has since been withdrawn, the general principles remain.
	Tax Adjustments	NA	**NA**	Not aware of any
	Flood Insurance	Y	**NA**	Up until 2015, standard residential insurance policies did not cover flood damage. Beginning in 2015 however, this coverage became available in the Red River basin albeit availability and premiums depend on the location relative to risk areas defined based on topographical mapping.
Other	Ice Mitigation	Y	**5**	Seven ice cutters and three Amphibex icebreakers are routinely used along the Red River north of Winnipeg to lake Winnipeg to mitigate against ice jams.

*(10-very effective, 1-ineffective) based on Experience in the Red River Basin

G

APPENDIX G: DEVELOPMENT OF FLOOD MITIGATION EVALUATION CRITERIA: DISCUSSION PAPER

Development of Triple Bottom Line Screening Criteria

Traditional economic analyses of flood mitigation alternatives have generally assumed a straightforward objective of maximizing the net benefits (total benefits minus total costs) that accrue to a project. Society however, has other goals besides economic efficiency. These goals or objectives are the results of outcomes that society desires and have more recently been described as triple bottom line objectives which include considerations of economic, environmental and social impacts. The purpose of triple bottom line evaluation is to account for these various goals in the evaluation process.

Description of Evaluation Criteria

For the purposes of this analysis, criteria have been subdivided into four basic categories as follows:

- Economic Efficiency
  - project costs
  - net benefits
  - project benefits
  - benefit cost ratio
- Disaster Prevention
  - reduces current losses
  - reduces future losses
  - potential residential loss of life
  - potential non-residential loss of life
- Environment Impact
  - biophysical, social, aesthetic
- Implementation
  - complexity
  - flexibility of integration with other measures
- Incidental Benefits, i.e., drought mitigation, low flow augmentation, recreation, etc.
- Prevents fraud and victimization.
- Promotes orderly development.

Economic Efficiency

Project Costs

Project costs are simply the estimated direct capital costs required to implement the various alternatives being compared. A common base is typically employed for the evaluation of economic costs, particularly as it relates to structural alternatives. All structural alternatives are usually designed to provide a 1:100 year flood protection level and a common discount rate of 4% is used by the Province of Alberta. The discount period is varied in accordance with the anticipated project life of these various alternatives.

Project Benefits

This evaluation incorporates a comparison of the costs and benefits which are measured in current dollar values. The present value of both benefits and costs is calculated on the basis of the real discount rate for provincial projects (4%) and the anticipated project life. Project cost estimates include the initial or capital cost plus the annual costs for operation and maintenance during the life of the project expressed in present value terms.

Project benefits are measured in terms of the reduction in flood damages to the existing development within the flood study area. Net benefits or present worth are also determined and represent the difference between project benefits and project costs expressed in the dollars of the day. Project benefits are based on the present worth of total damages averted and include direct, indirect, highways/utilities, and intangible damages.

Disaster Prevention

Reduces Present Losses

This equates to an immediate economic benefit in terms of floodplain damage reduction. For example, immediate relocation of dwellings within the flood study area would result in a significant reduction of potential existing damages. Conversely, flood zoning has no immediate effect on the reduction of potential damages in flood prone areas.

Reduces Future Losses

This criteria evaluates both structural and non-structural alternatives in terms of their ability to prevent future losses. The primary emphasis is on the provision of protection for those areas not yet developed. The greater the potential for preventing future losses, the higher the ranking in the scoring process.

Potential Residential Loss of Life

When flooding occurs in populated areas, there exists a possibility that human life could be lost, especially if people reside within the floodplain. This possibility is recognized and the potential estimated for consideration in the evaluation process. For any particular alternative, an absolute measure of risk can be estimated as 1% of the average annual number of floodplain residents exposed to flooding. However, for the purposes of this exercise, a qualitative approach is proposed to compare structural and non-structural alternatives. Alternatives are rated as high, medium or low with respect to potential for loss of life.

Potential Non-Residential Loss of Life

It is recognized that flooding may result in the loss of lives of those who are accessory to the event. Although it is not possible to describe this potential in quantifiable terms, the evaluation process provides for a relative rating of the objective from high risk to low risk. This is directly related to the characteristics of the alternatives proposed; i.e., no adjustment and flood regulations are perceived as representing high risk, whereas those measures which contain or divert the flood, i.e., dams and storage structures, would be rated as low risk. Alternatives such as dykes constitute the middle ground in that, although the design flood is contained, there is potential for failure and exceedence of the design flood and hence a medium level of risk.

Environmental Impact

Biophysical

For this current feasibility study, the environmental (biophysical) evaluation criteria consider the potential direct and indirect adverse impacts of a project on the existing biophysical conditions, and consider the following parameters:

- environmental sensitivities, including:
  - areas of natural vegetation;
  - fish and fish habitat;
  - species at risk or species of conservation concern and their habitat;
  - soil sensitivities and erosion potential;

  - historic resources and potential for discovery of unknown historic resources; and
  - designated areas (e.g., Parks and Natural Areas, Key wildlife and biodiversity Zones, Environmentally Significant Areas)
- restricted activity periods (i.e., time periods when construction activities are not permitted);
- required mitigation activities (i.e., standard practice, technically and economically feasible); and
- Municipal, Provincial and Federal regulatory requirements (i.e., approvals, authorizations, and compliance requirements).

Social

This entails social impact or social disruption other than that created by a flooding event and relates more directly to community disruption and distress brought about by such alternatives as relocation which may sever or significantly alter small insular communities, older established neighbourhoods and long standing residences, etc. An interesting sociological study of the removal of a town from a flood area was done in Shawnee Town in 1942 by Janes who lived there for several months during the project study. A remark from one of his interviews sums up the attitude to moving after the initial emotional response to the flood had subsided; "I am not going to move ... if you left most of the people around here to themselves, they would not think of moving."[1]

This parameter is expressed in relation to the number of homes (or businesses) dislocated or adversely affected by a particular alternative. As well, it considers temporary disruption during construction activities.

Aesthetics

Aesthetics, although somewhat subjective, may be analyzed (and quantified) with respect to certain visual experiences, common to high scenic quality in the landscape. Contributing visual experiences stem from interesting viewing opportunities and vistas, significant sight lines and spatial relationships which reflect the salient features (scenic attributes) of a given area.

This parameter involves a relative measure of the impact of a particular alternative on aesthetic quality including potentially improved aesthetics.

Implementation

The complexity or ease of implementation category entails a non-quantitative assessment of the relative difficulty of facilitating the various measures. Emphasis is placed on institutional implications and considers among other things:

- mechanisms already in place including existing statutory controls and processes;
- level of awareness;
- jurisdictional problems; and
- additional manpower and facilities required to implement.

Incidental Benefits

Certain alternatives may result in benefits non-related to flood damage reduction such as improved aesthetics and environmental quality, the provision or expansion of recreation opportunities, opportunities for local employment, etc. Again this is a relative measurement amongst the various alternatives.

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[1] Janes, R.W., *The Collective Action Involved in the Removal and Relocation of Shawnee Town, Illinois*, (Unpublished Ph.D. Dissertation, Department of Sociology, University of Illinois, 1942).

Prevents Fraud and Victimization

This objective relates to high profile measures or those alternatives which contribute to the overall level of awareness by conveying the potential problem to prospective floodplain purchasers.

Promotes Orderly Development

Essentially, this objective is intended to promote the orderly and efficient development of water and land use resources. This criteria evaluates the various alternatives in terms of their overall efficiency (economic, social and political) in contributing to orderly land use development.

Evaluation Procedure

Techniques for the evaluation of triple bottom line objectives fall into three categories:

1. monetary evaluation procedures;
2. non-monetary evaluation procedures; and
3. future options approaches.

Monetary evaluation procedures attempt to place approximate economic value on non-commensurables in the most uniform and least subjective manner possible.

Non-monetary evaluation techniques attempt to quantify non-commensurables but not in dollar values. These methods attempt to illustrate the relative effects of alternative projects on various social/aesthetic/environmental characteristics through the use of impact matrices.

The future options approach recognizes that society has broad multiple objectives that go beyond the objectives of water resource projects and that a complete trade-off analysis of all objectives is not possible. This approach attempts to develop contrasting sets of future options for comparison to add useful dimensions to the evaluation process.

A scoring matrix developed by the Ontario Ministry of Natural Resources for flood damage reduction studies is illustrated in **Exhibit 4.1**. For the purposes of flood damage reduction studies undertaken in Alberta for Alberta Environment by IBI Group, under the auspices of the Federal/Provincial Flood Damage Reduction Program, this scoring matrix was modified and is illustrated in **Exhibits 4.2A** and **4.2B.** A non-monetary evaluation technique was employed in which non-commensurables were quantified but not in dollar values.

Essentially, this method evaluated the relative effects of alternative management strategies on triple bottom line objectives through the use of a scoring matrix. The procedure required that qualitative values (ranging from very high to very low) were established for each specific objective to enable a measure of achievement for each alternative in relation to these objectives. For the most part, individual objectives were unweighted (each received an equal weighting in the evaluation). These measurements were then translated into numerical values between 1 and 5 and then summed to determine a relative ranking for each alternative. For ranking purposes,

1 = first, 2 = second, etc. Exhibits 4.2A and 4.2B detail the evaluation matrices for commensurable and non-commensurable objectives developed for the Fort McMurray Flood Damage Reduction Study.[2]

The scoring matrix employed by Saskatchewan Environment for flood damage reduction studies undertaken throughout the Province under the auspices of the Canada-Saskatchewan Flood Damage Reduction Program is illustrated in **Exhibit 4.3**.

For the purposes of the City of Calgary study, it is recommended that a non-monetary evaluation technique be employed in which non-commensurables are quantified but not in dollar values.

[2] IBI Group and Golder Associates Ltd.; *Flood Mitigation Options Assessment – Phase 1;* May 2016.

Ontario Ministry of Natural Resources - Scoring Matrix

FLOOD PLAIN MANAGEMENT ALTERNATIVES SCORING MATRIX

CATEGORY	MEASURE	COST TO FLOODPLAIN USER (RATED DIRECT HIGH SCORE TO INDIRECT LOW SCORE)	IMPLEMENTATION AND INFORMATION REQUIREMENTS		OBJECTIVES RELATED TO FLOOD LOSSES				SOCIAL, ECONOMIC, POLITICAL WELL-BEING		ENVIRONMENTAL IMPACT	FLEXIBILITY FOR INTEGRATION WITH OTHER MEASURES	TOTAL SCORE	RANK
			RELATIVE COMPLEXITY OF INSTITUTIONAL IMPLEMENTATION	DATA REQUIREMENTS	REDUCES PRESENT LOSSES	PREVENTS FUTURE LOSSES	PREVENTS FRAUD AND VICTIMIZATION	REDUCES RISKS (SAFETY AND ECONOMIC)	PROMOTES THE ORDERLY AND EFFICIENT DEVELOPMENT OF WATER AND LAND USE RESOURCES	MINIMIZES PUBLIC HEALTH DANGER FROM MALFUNCTIONING WATER SUPPLY & WASTE DISPOSAL SYSTEMS				
CATEGORY	MEASURE / WEIGHT	3	2	2	3	3	1	3	3	2	2	2		
MEASURES TO MODIFY THE FLOOD	STRUCTURAL FLOOD CONTROL	1 / 3	3 / 6	2 / 4	3 / 9	2 / 6	0 / 0	2 / 6	2 / 6	1 / 2	1 / 2	2 / 4	48	3
	WATERSHED TREATMENT	2 / 6	2 / 4	1 / 2	1 / 3	2 / 6	0 / 0	1 / 3	2 / 6	1 / 2	2 / 4	2 / 4	40	5
	METEOROLOGICAL MODIFICATION	0 / 0	1 / 2	0 / 0	0 / 0	1 / 3	0 / 0	1 / 3	1 / 3	1 / 2	1 / 2	1 / 2	17	10
MEASURES TO MODIFY THE DAMAGE SUSCEPTIBILITY	FLOODPROOFING	3 / 9	2 / 4	1 / 2	3 / 9	3 / 9	1 / 1	2 / 6	2 / 6	2 / 4	1 / 2	3 / 6	58	1
	FLOOD PLAIN REGULATIONS	1 / 3	1 / 2	1 / 2	0 / 0	3 / 9	3 / 3	2 / 6	3 / 9	3 / 6	3 / 6	3 / 6	52	2
	URBAN RENEWAL AND RELOCATION	1 / 3	1 / 2	2 / 4	1 / 3	2 / 6	0 / 0	2 / 6	2 / 6	2 / 4	2 / 4	2 / 4	42	4
	FORECASTING WARNING AND EMERGENCY MEASURE	1 / 3	2 / 4	1 / 2	2 / 6	2 / 6	0 / 0	2 / 6	1 / 3	1 / 2	0 / 0	2 / 4	36	6
MEASURES TO MODIFY THE LOSS BURDEN	FLOOD INSURANCE	2 / 6	1 / 2	1 / 2	0 / 0	0 / 0	1 / 1	3 / 9	1 / 3	0 / 0	0 / 0	2 / 4	27	8
	RELIEF/REHABILITATION	1 / 3	2 / 4	2 / 4	0 / 0	0 / 0	0 / 0	1 / 3	0 / 0	0 / 0	0 / 0	2 / 4	18	9
	TAX WRITE-OFFS	1 / 3	1 / 2	2 / 4	0 / 0	0 / 0	0 / 0	1 / 3	0 / 0	0 / 0	0 / 0	2 / 4	16	11
	PROTECTION FROM LOOTING	2 / 6	3 / 6	3 / 6	1 / 3	1 / 3	1 / 1	0 / 3	0 / 0	0 / 0	0 / 0	3 / 6	34	7

Fort McMurray - Evaluation Matrix: Non-Commensurable Objectives

ALTERNATIVES	DISASTER PREVENTION				ENVIRONMENTAL IMPACT					
	REDUCES CURRENT LOSSES	REDUCES FUTURE LOSSES	POTENTIAL RESIDENTIAL L.-0.-L.*	POTENTIAL NON-RESIDENTIAL L.-0.-L.*	BIO-PHYSICAL	SOCIAL	AESTHETIC	IMPLEMENTATION	INCIDENTAL BENEFITS	RANK
1. Ice Control Structure	H	H	L	L	H	VL	M	M	M	3
2. Dyking Inside River	H	H	M	M	M	L	VL	L	M	2
3. Dyking Outside River	H	H	M	M	VL	L	VL	L	M	1
4. Channel Improvements	L	L	H	H	H	VL	M	L	L	8
5. Storage Crooked Rapids*	VH	VH	L	L	VH	VL	M	VH	H	4
6. Storage Clearwater	H	H	L	L	H	VL	H	H	M	5
7. Ring Road and Dyke**	L	M	M	M	L	L	M	M	M	6
8. Flood Zoning	VL	M	VH	VH	VL	M	VL	M	VL	9
9. Relocation	VH	VH	VL	VL	VL	VH	L	VH	H	1
10. Flood Proofing-Fill	H	H	L	L	L	H	H	VH	H	6
11. Flood Proofing-Foundation	H	H	L	L	L	H	H	VH	H	6
12. Flood Proofing-Seals & Cls.	M	M	L	L	L	H	H	VH	H	7
13. Flood Proofing-Seals & Cls.	M	M	L	L	L	H	H	VH	H	7
14. Downstream Blasting	VL	VL	VH	VH	L	VL	VL	VL	VL	8
15. Contingency Measures	L	L	L	L	VL	L	VL	M	VL	5

*L.-0.-L.: Loss-of-Life

Fort McMurray - Evaluation Matrix: Commensurable Objectives

ALTERNATIVES	ECONOMIC EFFICIENCY				
	PROJECT COSTS $1,000	PROJECT BENEFITS $1,000	NET BENEFITS $1,000	B/C	RANK
1. Ice Control Structure	81,700	52,802	-28,898	0.65	4
2. Dyking Inside River	28,500	46,112	17,612	1. 62	2
3. Dyking Outside River	20,000	46,112	26,112	2.30	1
4. Channel Improvements	N/A	N/A	N/A	N/A	N/A
5. Storage Crooked Rapids*	710,000	N/A	N/A	N/A	N/A
6. Storage Clearwater	87,300	52,802	-34,398	0.61	5
7. Ring Road and Dyke**	52,200	46,112	-6,088	0.88	3
8. Flood Zoning	N/A	N/A	N/A	N/A	N/A
9. Relocation	365,577	55,833	-309,743	0.15	10
10. Flood Proofing-Fill	332,581	63,048	-269,533	0.19	9
11. Flood Proofing-Foundation	309,487	63,048	-246,439	0.20	8
12. Flood Proofing-Seals & Cls.	137,392	31,681	-105,711	0.23	7
13. Flood Proofing-Seals & Cls.	112,419	31,618	-80,738	0.28	6
14. Downstream Blasting	N/A	N/A	N/A	N/A	N/A
15. Contingency Measures	N/A	N/A	N/A	N/A	N/A

* Medium Head

** Low Growth Scenario

FLOOD PLAIN MANAGEMENT ALTERNATIVES SCORING MATRIX

OBJECTIVES / ALTERNATIVES (WEIGHT)	ECONOMIC COSTS	ECONOMIC EFFICIENCY	REDUCES PRESENT LOSSES	REDUCES FUTURE LOSSES	PREVENTS FRAUD AND VIC.	SOCIAL DISRUPTION	POT. RES. LOSS OF LIFE	POT. NON-RES. LOSS OF LIFE	ENVIRONMENTAL IMPACT	IMPLEMENTATION	FLEXIBILITY OF INTEGRATION	PROMOTES ORDERLY DEVELOPMENT	TOTAL SCORE	RANK	OPTION 1	OPTION 2	OPTION 3
WEIGHT	3	3	3	3	2	3	3	3	3	2	2	2					
1. DYKING * 1:100 YEAR LEVEL	9	9	6	0	2	9	9	6	6	6	6	0	68	1	◀		
2. RELOCATION 1	0	0	9	3	6	6	6	9	0	2	0	2	43	5			
3. RELOCATION 2	0	0	3	3	6	6	6	6	0	2	0	2	34	8			
4. RELOCATION 3	3	3	0	3	6	6	3	3	6	0	2	2	37	6			
5. RELOCATION 4	0	0	9	3	6	6	6	9	3	2	0	2	46	4		◀	
6. FLOOD PROOFING	9	9	6	0	2	3	0	0	9	4	6	0	48	3	◀		
7. FLOOD PLAIN REGULATIONS	9	6	0	9	6	0	0	0	9	4	6	4	53	2	◀	◀	◀
8. NO ADJUSTMENT	9	0	0	0	0	0	0	0	9	6	0	0	24	9			
9. CONTINGENCY MEASURES	6	9	6	0	0	3	0	0	3	2	6	0	35	7	◀	◀	◀

APPENDIX H:
GROUNDWATER MODELLING FOR DAMAGE ESTIMATION

February 2, 2017

FLOOD MITIGATION OPTIONS ASSESSMENT - PHASE 2

Groundwater Flood Modelling

Submitted to:
City of Calgary
625 25 Ave SE
P.O. Box 2100 Station M
Calgary, Alberta, Canada
T2P 2M5

REPORT

Report Number: 1531394

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FIGURES

1.0 INTRODUCTION

The Bow and Elbow River floodplains in Calgary are underlain by a permeable alluvial aquifer. The groundwater levels in the alluvial aquifer may rise as the river water levels rise during river floods. Rising groundwater levels may cause basement flooding in the floodplain areas where there is no overland surface water inundation.

The City of Calgary (The City) retained IBI Group and Golder Associates Ltd. (Golder) to conduct the Flood Mitigation Options Assessment. This assessment includes two phases. Groundwater modelling was conducted during Phase 1 for updating the flood damage model. Additional groundwater modelling was conducted during Phase 2 for assessing the various flood mitigation scenarios.

Appendix C of the Phase 1 Study Report is a stand-alone report (or the Phase 1 groundwater report) describing the groundwater modelling completed in Phase 1. That report describes previous alluvial aquifer studies and available data, how the conceptual model of the alluvial aquifer along the Bow and Elbow Rivers was developed, details of the numerical model construction, groundwater flow modelling results for 20-, 100- and 500-year flood return periods, and a comparison between the groundwater simulation results and the available 2013 groundwater flood survey data.

The Phase 2 groundwater modelling followed the same methodology as that used in the Phase 1. However, modifications were made to the groundwater models developed in Phase 1 to simulate the effects of the various flood mitigation options on the maximum groundwater levels. This report documents the methodology and results of the groundwater modelling completed in Phase 2.

2.0 GROUNDWATER MODELLING METHODOLOGY

2.1 Cross-Section Modelling Approach

Similar to the groundwater modelling results of Phase I, the simulated maximum groundwater levels are expressed in a relationship of Delta H versus Distance. Delta H is the difference between the simulated peak of the groundwater level hydrographs at various locations offset from the rivers and the peak water levels of the river flood hydrographs. The distances for all delta H plots were calculated from the edge of surface inundation.

Groundwater simulations were conducted for the 20-, 100- and 500-year flood events. The simulated river flood peak discharges of these flood events are 275, 803 and 1,690 m^3/s in the Elbow River, and 1,230, 2020 and 2,920 m^3/s in the Bow River upstream of the Elbow River confluence (Golder, July 2015). The methodology for estimating the maximum groundwater levels for the other return periods was the same as that described in the Phase 1 report.

The Hillhurst cross-section model (see Figures 7 and 11 of the Phase 1 groundwater report) was modified when simulating mitigation options pertinent to the Bow River. The Mission cross-section model (see Figures 8 and 11 of the Phase 1 groundwater report) was modified when simulating mitigation options pertinent to the Elbow River.

In addition to the groundwater model developed in Phase 1, the following groundwater models were developed in Phase 2 to generate the groundwater level information for analyzing the various flood mitigation scenarios in Phase 2:

- **GW Model 1**: The effects of the permanent barriers placed along the Bow River on groundwater levels are simulated using the Hillhurst numerical cross-section model. During the Phase 1 work, it was found that the Delta H versus Distance relationships were very similar between the Hillhurst curve (i.e., the average 20-year curve shown in Figure 14 of the Phase 1 report) and the Mission curve south of the Elbow River (see Figure 16 of the Phase 1 report). Consequently, the Delta H versus Distance relationship developed using the GW Model 1 results were also used for the areas along the Elbow River where there are barriers. Using a single Delta H versus Distance relationship provides consistency when evaluating the mitigation effect of the barriers. This approach is considered appropriate in consideration of the limitations and approximation of the simplified modelling approach used in this study.

- **GW Model 2**: The effects of the Springbank Off-stream Reservoir along the Elbow River (SR1) on the downstream flood hydrographs and groundwater levels are simulated using the Mission-Eau-Claire numerical cross-section model.
- **GW Model 3**: The effects of one additional reservoir along the Bow River on the downstream flood hydrographs and groundwater levels are simulated using the Hillhurst numerical cross-section model.

Development of the above-mentioned models are described in the following sections.

2.2 GW Model 1 – Effects of Permanent Barriers along the Bow River

The Phase 1 Hillhurst cross-section model was modified to create GW Model 1. The permanent barriers were simulated in the numerical model by introducing no-flow cells along the river bank. This change allows the river water level to rise above ground surface without causing a simulated lateral flux of water through the numerical grid layer that overlies the alluvial aquifer.

Figure 1a shows the Hillhurst MODFLOW model cross-section with the permanent barrier in place. The Phase 1 model is identical except the barrier (shown in red in the figure) is not present. There is no discontinuity in the gray zone, which represents above ground surface areas.

The Bow River water level hydrograph used for GW Model 1 is the same as that used in Phase 1. Figure 2a presents the Phase 1 surface water elevation hydrographs for the Bow River used as river boundary conditions in the groundwater model.

2.3 GW Model 2 – Effects of SR1 on the Elbow River

The Phase 1 Mission cross-section model was modified to simulate the effects of SR1 on groundwater levels along the Elbow River. The original Mission cross-section included a low permeability silt lense immediately north of the Elbow River. To be more representative of the geologic conditions along the Elbow River downstream of the Glenmore Dam, this zone was modified to be gravel, consistent with the surrounding materials (see Figure 1b).

Removing the silt lense from the Mission cross-section makes the numerical model more consistent with the other cross-sections. In the Phase 1 report, the results of the model from the north side of the Mission cross-section containing the silt lense were not used, because it created anomalous Delta H versus Distance relationships, which were not considered representative of the conditions along most of the Elbow River.

The main effect of SR1 on the downstream flood hydrographs is lower flood peaks but longer durations than the existing conditions. Figure 2b presents the surface water elevation hydrographs for the Elbow River used as river boundary conditions in GW Model 2. The hydrographs in Figure 2b were derived based on the river flow hydrographs provided by The City and the rating curve between simulated water levels and discharges at the

Mission cross section, which was developed by Golder based on the latest HEC-RAS modelling results (Golder, July 2015).

2.4 GW Model 3 – Effects of Additional Reservoir on the Bow River

The Phase 1 Hillhurst cross-section model was modified to simulate the effects of one additional reservoir on the Bow River on groundwater levels along the Bow River. The effects of this additional reservoir on lowering downstream flood peak discharges were simulated, but the potential effects on the recession limbs of the flood hydrographs were not included in the simulation. Potentially longer flood recession limbs would result in slightly higher maximum groundwater elevations at further distances from the river. However, since the greatest groundwater level rises are closer to the edge of surface water inundation, where most of the groundwater damage will occur, the impact on the groundwater flood damage calculation by not including the potential effect of recession limbs, is considered to be relatively small.

Figure 2a presents the surface water elevation hydrographs for the Bow River used as river boundary conditions in the GW Model 3. The hydrographs in Figure 2a were derived based on the river flow hydrographs provided by The City and the rating curve between simulated water levels and discharges at the Hillhurst cross section, which was developed by Golder based on the latest HEC-RAS modelling results (Golder, July 2015). The flow hydrographs provided by The City did not include extension of the recession limbs of the hydrographs without the additional reservoir, which should be noted in interpreting the comparison shown in Figure 2a.

2.5 Approach for Applying the Cross-Section Modelling Results

The same approach used in Phase 1 was applied in Phase 2 to use the cross-section modelling results to estimate the maximum groundwater elevations associated with the various flood events and across the entire alluvial aquifer within Calgary. This approach is summarized below:

- Use the maximum groundwater level calculated at various distances from the edge of inundation to develop an approximate relationship between Delta H and Distance for each of the three flood return periods. Delta H is the difference between the peak river elevation and maximum groundwater elevation, and distance is measured from the edge of surface water inundation. Groundwater simulations were completed for the 20-, 100- and 500-year return periods. Groundwater surface results for other return periods were based on these three return periods, as discussed in the Phase 1 groundwater report.
- Use geospatial modelling tools to apply the Delta H versus Distance relationship to calculate a preliminary groundwater surface over the footprint of the alluvial aquifer. The calculation is based on the extent of surface water inundation and the maximum surface water elevation. At any location over the footprint of the alluvial aquifer that has no surface inundation, the nearest point of surface inundation is used to determine the maximum surface water elevation used in the Delta H versus Distance relationship.
- Apply consistency checks on the preliminary groundwater surface using geospatial modelling tools to constrain the preliminary groundwater surface to produce the final groundwater surface. The geospatial consistency checks included the following:
  - The groundwater surface was constrained to not fall below the long-term average (i.e., pre-flood event) river water level surface. To support this check, the long-term average river water surface elevations along the Bow and Elbow Rivers were estimated over the footprint of the alluvial aquifer based on the simulated river water levels using the HEC-RAS model.

- The maximum groundwater elevation at any location within the alluvial aquifer for a specific flood return period cannot be lower than the maximum groundwater elevation at the same location for the next lower flood return period.
- For all flood return periods, the calculated groundwater elevation was constrained not to be above ground surface. This constraint was generally needed for the areas immediately behind the permanent barriers. Because the groundwater modelling results were obtained only at one single cross section along the Bow River or the Elbow River, the relationships of Delta H versus Distance result in approximate estimation of the groundwater levels which may be above ground surface, particularly in the protected areas behind the permanent barrier.

The above-mentioned consistency checks were necessary due to the approximate and simplified nature of the groundwater modelling approach. This approach involved application of the simulation results from two cross-section models to estimate groundwater elevations over the entire alluvial aquifer in Calgary.

3.0 GROUNDWATER MODELLING RESULTS

3.1 GW Model 1 – Effects of Permanent Barriers along the Bow River

Figure 3a shows the Delta H versus Distance relationships for the Hillhurst cross-section models with a permanent barrier in place. For comparison purposes, the Phase 1 relationships are also shown in the figure. Note that for the 20-year flood event the river water level would not reach the base of the permanent barrier at the cross-section location. Therefore, the relationship for the 20-year flood event is the same for the conditions with and without the permanent barrier.

The Delta H versus Distance relationships derived in Phase 1 (existing conditions) and Phase 2 (potential mitigation measures in place at selected locations and for specified flood return periods) were used to calculate the maximum groundwater elevations in the alluvial aquifer as follows:

- Geospatial modelling tools were used to develop “influence polygons” behind barriers to delineate areas where maximum groundwater levels are influenced by the presence of a barrier. The influence polygons were defined by including the locations that were closer to the barrier than to the edge of surface water inundation beyond the barrier.
- A location was considered to be influenced by a barrier for a particular flood return period if the peak river water level was above the base of barrier but did not overtop the barrier.
- If the influence was determined to occur at a particular location, the Phase 2 relationship was applied over the influence polygon, using the barrier location as the edge of surface water inundation.
- If influence was determined not to occur at a particular location (e.g. the river water level was below the base of the barrier for a low return period, or the river water level overtopped the barrier for a high return period), the Phase 1 relationship was applied from the edge of surface water inundation.

Figure 3b shows how the maximum groundwater elevations, calculated using the Delta H relationships, decline moving away from the edge of surface water inundation. For comparison purposes, the Phase 1 maximum groundwater elevations are also shown in this figure. At first glance, it may appear that the groundwater levels for the condition with the barrier are actually higher than those for the condition without the barrier. It is important to recognize, however, that the distance axis refers to the distance from the edge of surface water inundation. Consequently, a distance of 100 m for 100-year return period curve of Phase 1 (without barrier) refers to a location that is actually further away from the river bank than the corresponding 100 m location of Phase 2 (with barrier), because the edge of surface water inundation for the condition without barrier is further inland.

As an illustration, Figure 4a shows the maximum groundwater surface (which is equal to surface water level if there is overland inundation) in the alluvial aquifer for the 100-year flood event calculated using geospatial modelling for the Bowness area and for the baseline condition (i.e., Scenario 0). The extents of surface inundation with and without the potential permanent barrier are also shown in this figure. The reduction in the maximum groundwater surface due to the barrier is illustrated in Figure 4b.

3.2 GW Model 2 – Effects of SR1 on the Elbow River

Figure 5a shows the Delta H versus Distance relationships for the Mission cross-section models using the Elbow River water level hydrographs (Figure 2b) with SR1 in place. For comparison purposes, the Phase 1 relationships are also shown in the figure. Note that for the 500-year return period the river water level overtops the river banks and inundates the entire alluvial aquifer at the Mission cross-section. Therefore, this figure has no result for the 500-year flood event.

During the 500-year flood event, approximately 70% of the alluvial aquifer extents along the Elbow River would be inundated by surface water. Along the upper reaches of the Elbow River, where the alluvial aquifer extent is narrow, the majority of the aquifer area would be inundated by surface water during the flood. In the area close to the confluence of the Elbow and Bow Rivers, where the alluvial aquifer is relatively wide, approximately 60% of the alluvial aquifer proximal to the Elbow River would be inundated by surface water during the flood.

For the Phase 1 results, the maximum groundwater level is closer to the peak river water level for lower return periods. However, for the Phase 2 results, this pattern is reversed and the 100-year flood Delta H result is smaller than the 20-year flood result. This is because the 100-year flood river water level hydrograph has the same peak as the 20-year flood when SR1 is in place, but the 100-year flood peak is of much longer duration (see Figure 2b). Consequently, the 100-year flood groundwater levels have more time to approach equilibrium with the peak river water level, resulting in smaller Delta H values for the higher return period.

Figure 5b shows how the maximum groundwater elevations, calculated using the Delta H relationships, decline moving away from the edge of surface water inundation. For comparison purposes, the Phase 1 maximum groundwater elevations are also shown in this figure. For both return periods, the peak river water levels are attenuated with the SR1 in place, resulting in lower maximum groundwater elevations.

Similar to the GW Model 1 result, the surface inundation with SR1 in place will be smaller, as shown on Figure 6a. This means that a distance of 100 m on these graphs refers to locations that are different distances from the river bank between the conditions with and without SR1.

As an illustration, Figure 6a shows the maximum groundwater surface (which is equal to surface water level if there is overland inundation) in the alluvial aquifer for the 100-year flood event calculated using geospatial modelling for the Mission area and for the baseline condition (i.e., Scenario 0). The extents of surface inundation with and without the SR1 reservoir are also shown in the figure. The reduction in the maximum groundwater surface is illustrated in Figure 6b.

3.3 GW Model 3 – Effects of Additional Reservoir on the Bow River

Figure 7a shows the Delta H versus Distance relationships for the Hillhurst cross-section models using the Bow River water level hydrographs with one additional Bow River reservoir in place. For comparison purposes, the Phase 1 relationships are also shown in this figure. The results for the condition with the additional reservoir (Phase 2) have smaller Delta H values than the condition without the reservoir (Phase 1). This is because the reservoir would result in lower flood peak water levels along the river (see Figure 2a).

Figure 7b shows how the maximum groundwater elevations, calculated using the Delta H relationships, decline moving away from the edge of surface water inundation. For comparison purposes, the Phase 1 maximum groundwater elevations are also shown in the figure. For all return periods, the peak river water levels are attenuated with the additional Bow River reservoir in place, resulting in lower corresponding maximum groundwater elevations at the edge of surface inundation (Distance equal to 0 m). The lower peak river water levels result in smaller surface inundation extents compared to the condition without the reservoir (refer to Figure 8a).

Similar to the results of GW Models 1 and 2, the smaller surface inundation extents for the condition with the reservoir in place mean that a distance of 100 m on these graphs refers to different locations. Consequently, although the Phase 2 groundwater elevations shown in Figure 7b for the 100-year and 500-year return period results are above the corresponding results for Phase 1, the actual locations corresponding to the same distance value are different.

For illustration, Figure 8a shows the maximum groundwater surface (which is equal to surface water level if there is overland inundation) in the alluvial aquifer for the 100-year flood event calculated using geospatial modelling for the Bowness area and for the baseline condition (i.e., Scenario 0). The extents of surface inundation with and without the additional reservoir upstream on the Bow River are also shown in the figure. The reduction in the maximum groundwater surface is illustrated in Figure 8b.

3.4 Effects of Barriers Versus Reservoirs

The simulated maximum groundwater level is influenced by the complex geometry of the inundation footprint, the maximum surface water levels, and the empirical relationships developed at a particular cross-section but applied throughout the Bow River alluvial aquifer. Although an understanding of alluvial aquifer flow dynamics was used to inform the development of the empirical relationships, there is, of necessity, some level of uncertainty in developing the relationships.

It is difficult to determine based on limited modelling analysis conducted in this study whether barriers or upstream reservoirs would result in lower groundwater levels. A comparison of the maximum groundwater levels where barriers are present along the Bow River (see Figure 4) with the maximum groundwater levels in the case of an upstream reservoir (see Figure 8), indicates that at least in the areas along the Bow River where the edges of surface inundation are similar, the additional reservoir would result in lower groundwater levels, especially for the simulated river hydrographs with no extended recession limbs.

Inclusion of the extended recession limbs is estimated to have more effect on the groundwater simulation results for the areas further away from the edges of surface water inundation. This is because having a longer recession limb allows for more time for the pressure pulse to move further inland from the edges of surface water inundation. The effect of not including the extended recession limbs is estimated to be small to negligible for the areas near the edges of surface water inundation, because the maximum groundwater levels in these areas are predominantly influenced by the peak river water levels.

The above commentary related to the groundwater effects along the Bow River is estimated to apply to the Elbow River.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The following conclusions are drawn based on the results of the groundwater flow modelling conducted in the Phase 2 study:

- The results of the groundwater modelling analysis were used to develop the Delta H versus Distance relationships, which were then used to facilitate the geospatial modelling. This approach is based on the results of limited groundwater modelling at two select cross-sections, and application of these results to the footprint of the alluvial aquifer along the Bow and Elbow Rivers throughout Calgary. This approach is inherently approximate.
- The magnitude of Delta H is strongly influenced by the shapes of the flood hydrographs and duration of high river water levels. Other factors affecting the Delta H versus Distance relationships are the hydrogeologic parameters (hydraulic conductivity and storage coefficient) and geometry of the alluvial aquifer in relation to the river location (notably the extent of the aquifer perpendicular to the river).
- The limitations of the modelling approach have been highlighted in this report. Relying on the results of a limited number of cross-sections for groundwater modelling necessitated the application of a series of quality assurance checks and modifications when estimating the groundwater elevation surfaces within the footprint of the entire alluvial aquifer in the city. These limitations should be considered when interpreting the groundwater surfaces generated in this study for the purpose of basement flood damage estimation.

4.2 Recommendations

The following recommendations are made based on the results of the groundwater flow modelling conducted in this study:

- The results of flood damage estimation have shown that basement damage is a relatively large fraction of the total flood damage for lower return periods of floods. Therefore, additional efforts should be spent to refine the groundwater modelling approach and to collect additional field data collection to support the model refinement and calibration.
- Model refinement should include a phased approach for developing a three-dimensional groundwater model to simulate spatially varying hydrogeologic parameters and changing aquifer geometry throughout the alluvial aquifer system. A three-dimensional modelling approach is particularly valuable for simulating conditions where there are hydraulic interactions between the Bow and Elbow Rivers.
- Data collection activities to be undertaken over time to progressively improve the groundwater model should include the following:

- Collect and compile aquifer lithology data to allow the development of a three-dimensional conceptual model of the alluvial aquifer geology.
- Collect hydraulic head response data so values of hydrogeological parameters can be estimated or calibrated. Datasets could include water level response data from slug tests, pumping rate and water level response data from pumping tests and planned dewatering programs, and river stage and groundwater level response data from controlled reservoir releases along the river systems.
- Since sewers can act as linear conduits to rapidly transmit changes in groundwater pressure, effort should be spent to better understand their importance in contributing to groundwater flooding. The survey data collected by the University of Calgary (see Phase 1 report) represent an initial data set that could be used in conjunction with City infrastructure engineering drawings to investigate this effect during the 2013 flood, for example.
- In addition to sewer backup, groundwater flooding can occur as water levels rise adjacent to basements during flood events, causing seepage through cracks in the foundations or wall. Survey data collected on building age, construction method and depth of excavation could be correlated to occurrence and severity of groundwater flooding.

Report Signature Page

This report is prepared and reviewed by the undersigned:

GOLDER ASSOCIATES LTD.

Prepared by:

Don Haley, M.Sc.
Associate, Senior Groundwater Modelling Specialist

Reviewed by:

Dejiang Long, Ph.D., P.Eng.
Principal, Senior Water Resources Engineer

DH/DL/ml/jlb

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Golder. (July 2015). *Bow River and Elbow River Hydraulic Model and Flood Inundation Mapping Update, Prepared for The City of Calgary, and Alberta Environment and Parks.*

IBI Group. (2016). *Flood Mitigation Options Assessment - Phase 1.* Calgary, Alberta: IBI Group.

FIGURES

Figure 1a: Modified Hillhurst Model Cross-Section

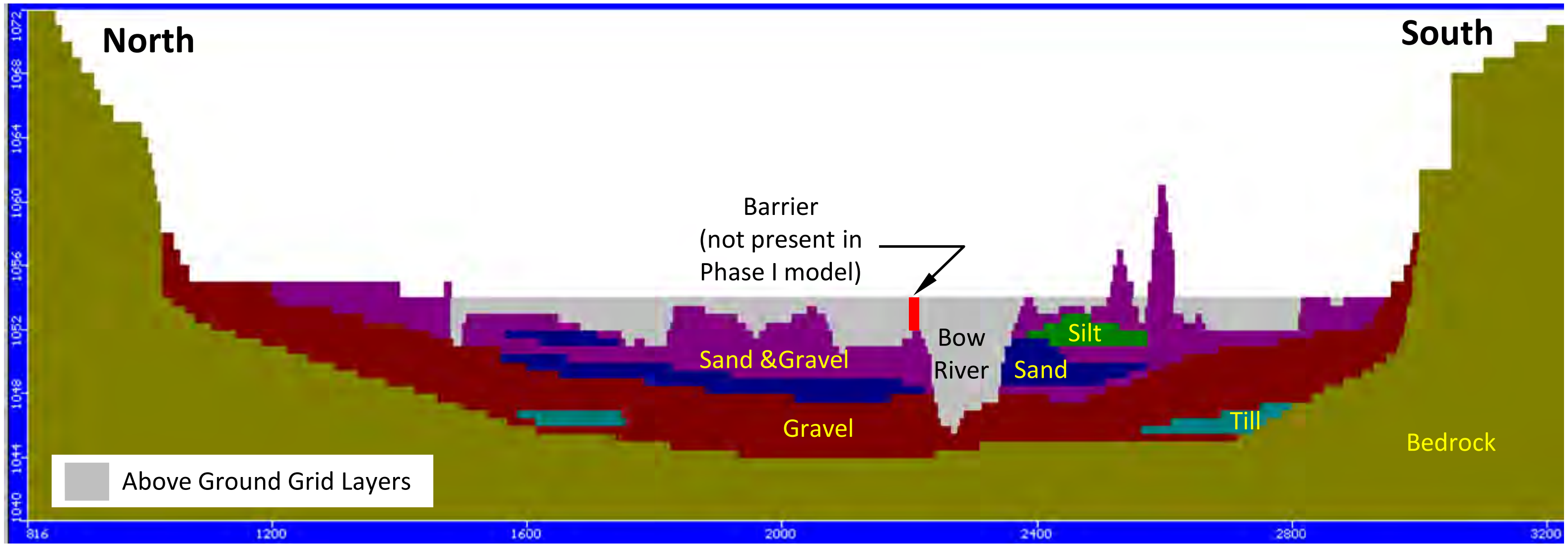
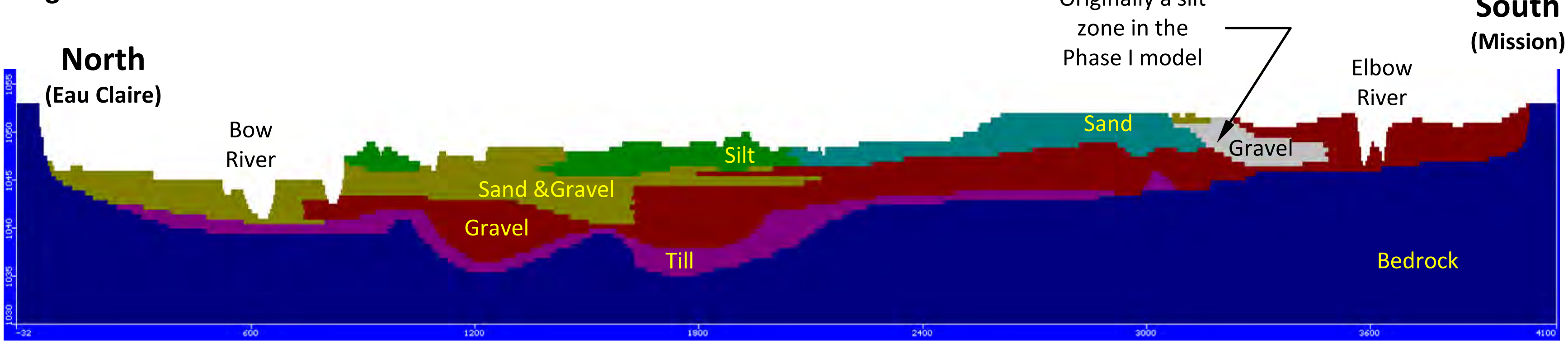


Figure 1b: Modified Mission Model Cross-Section



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	CHECK	DH	08/12/2016	
	REVIEW	DL	09/12/2016	

Figure 2a: Bow River Phase I (unmitigated) and Phase II (Additional Reservoir) Hydrographs

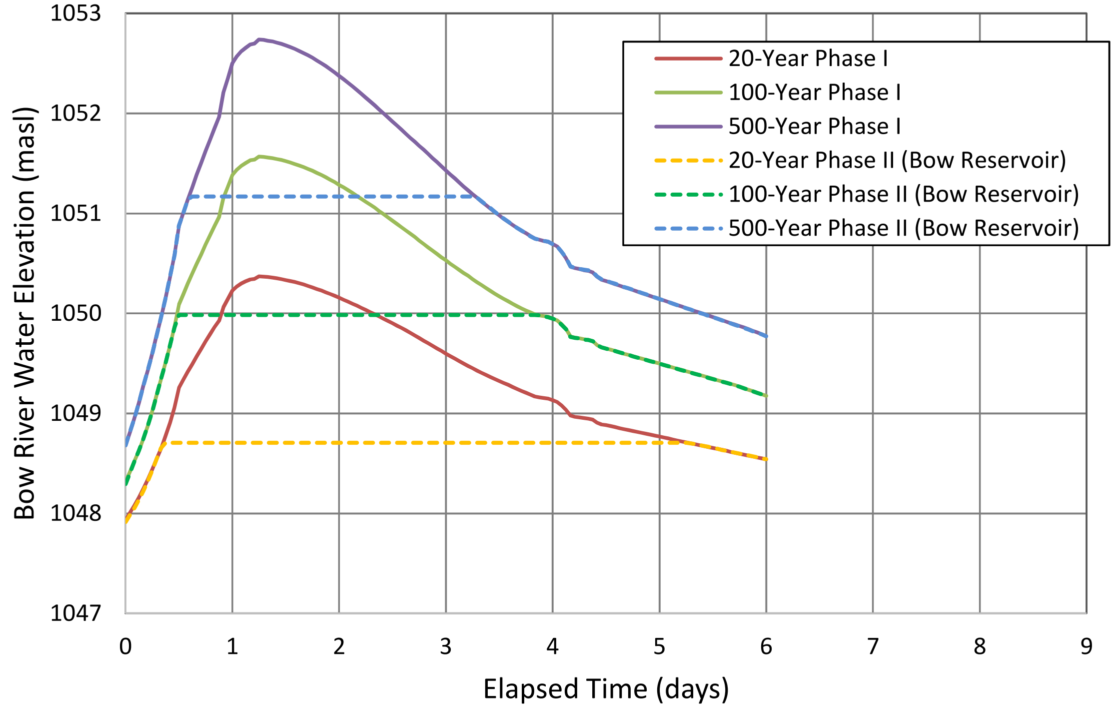
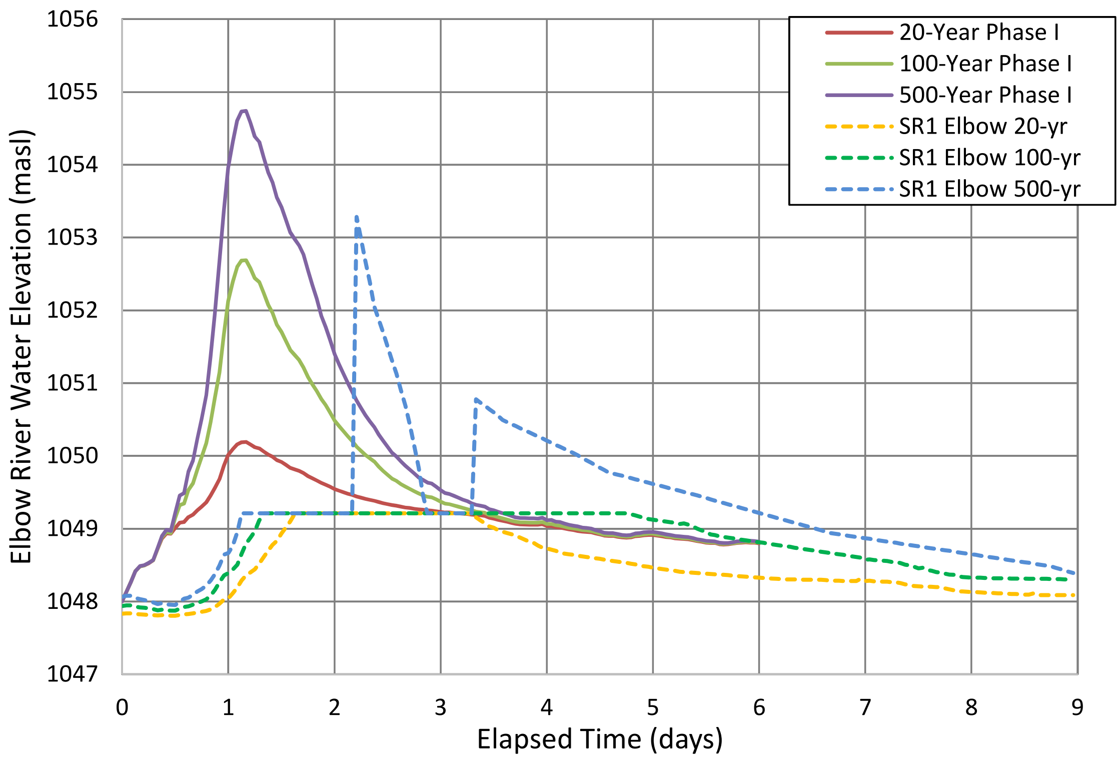


Figure 2b: Elbow River Phase I (unmitigated) and Phase II (SR1) Hydrographs



PROJECT

THE CITY OF CALGARY WATER RESOURCES

PHASE II FLOOD MITIGATION OPTIONS ASSESSMENT

TITLE

River Water Level Hydrographs

Golder Associates

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Figure 3a: Delta H versus Distance

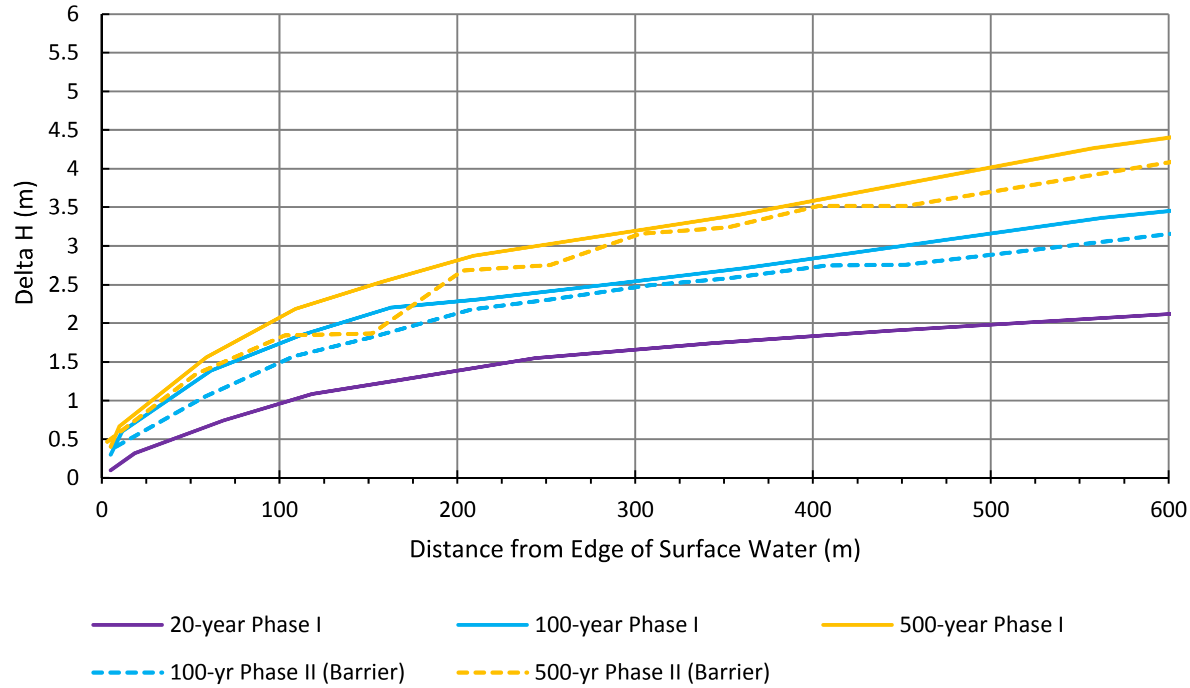
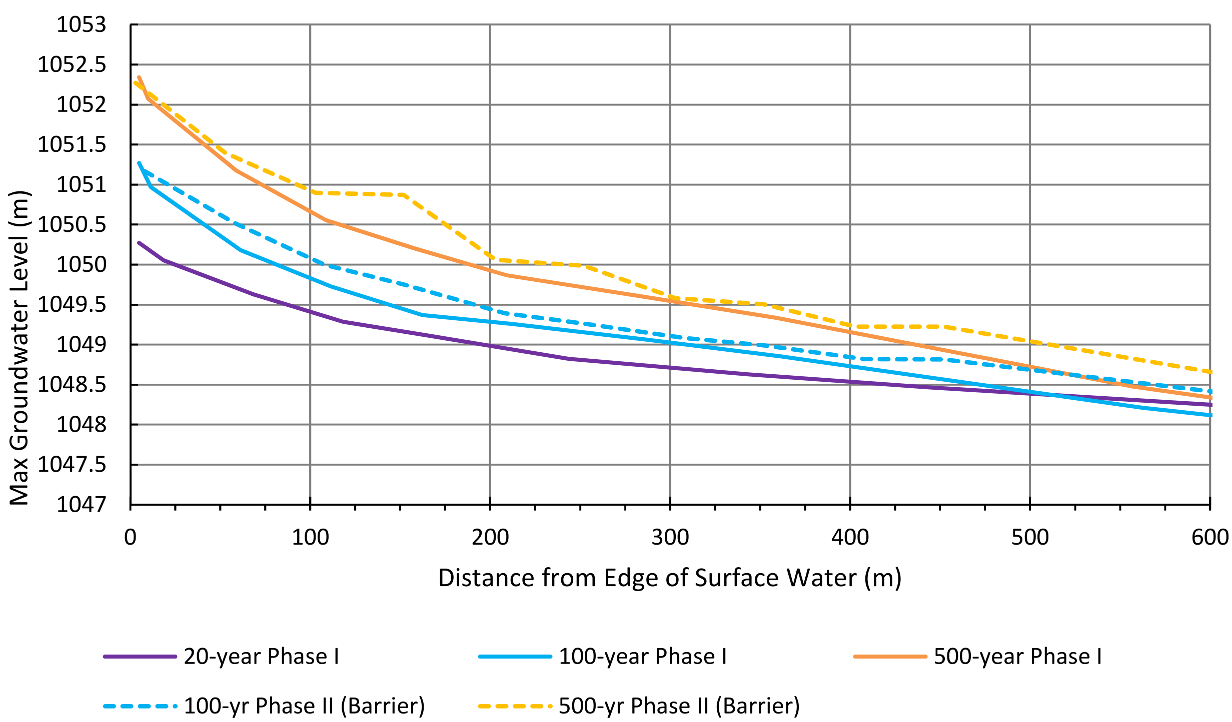


Figure 3b: Groundwater Level versus Distance



PROJECT

THE CITY OF CALGARY WATER RESOURCES

PHASE II FLOOD MITIGATION OPTIONS ASSESSMENT

TITLE

GW Model 1 Delta H and Groundwater Elevation versus Distance Relationships
(Barrier in Place – Hillhurst Section)

Golder Associates

PROJECT No. 1531394			FILE No.	15313942000A003
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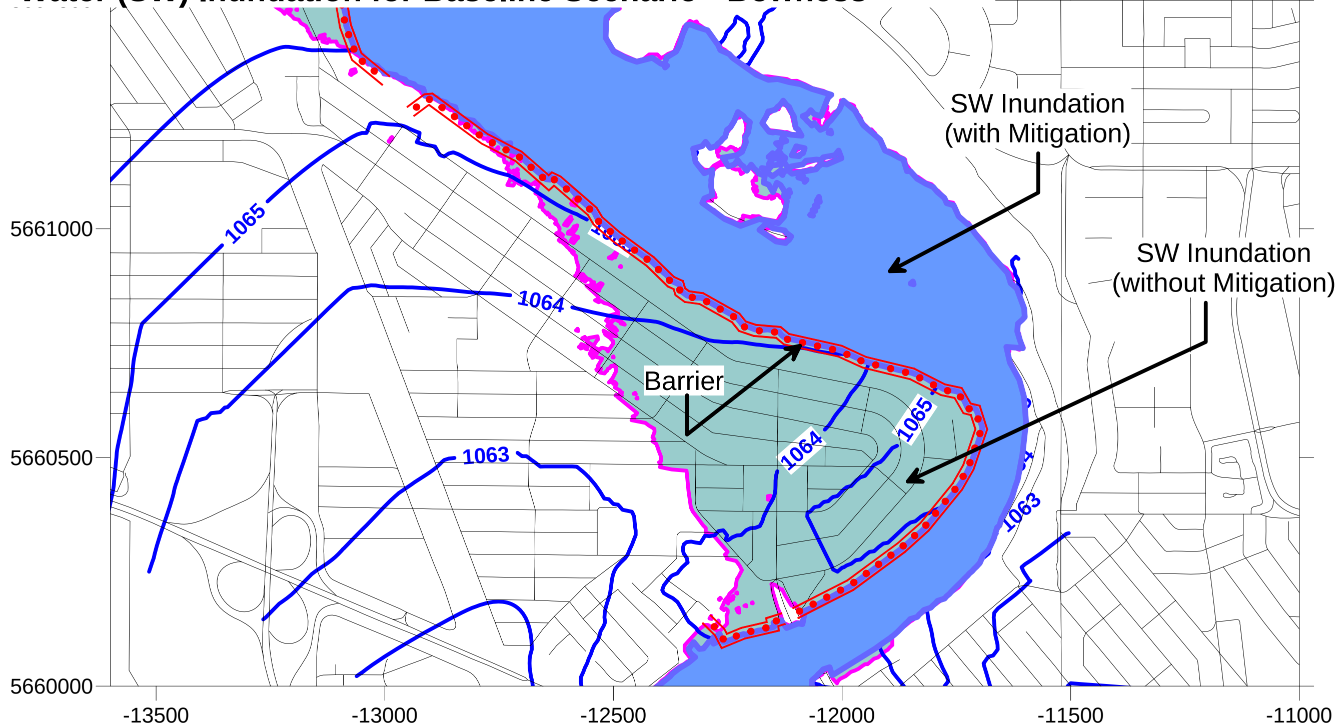
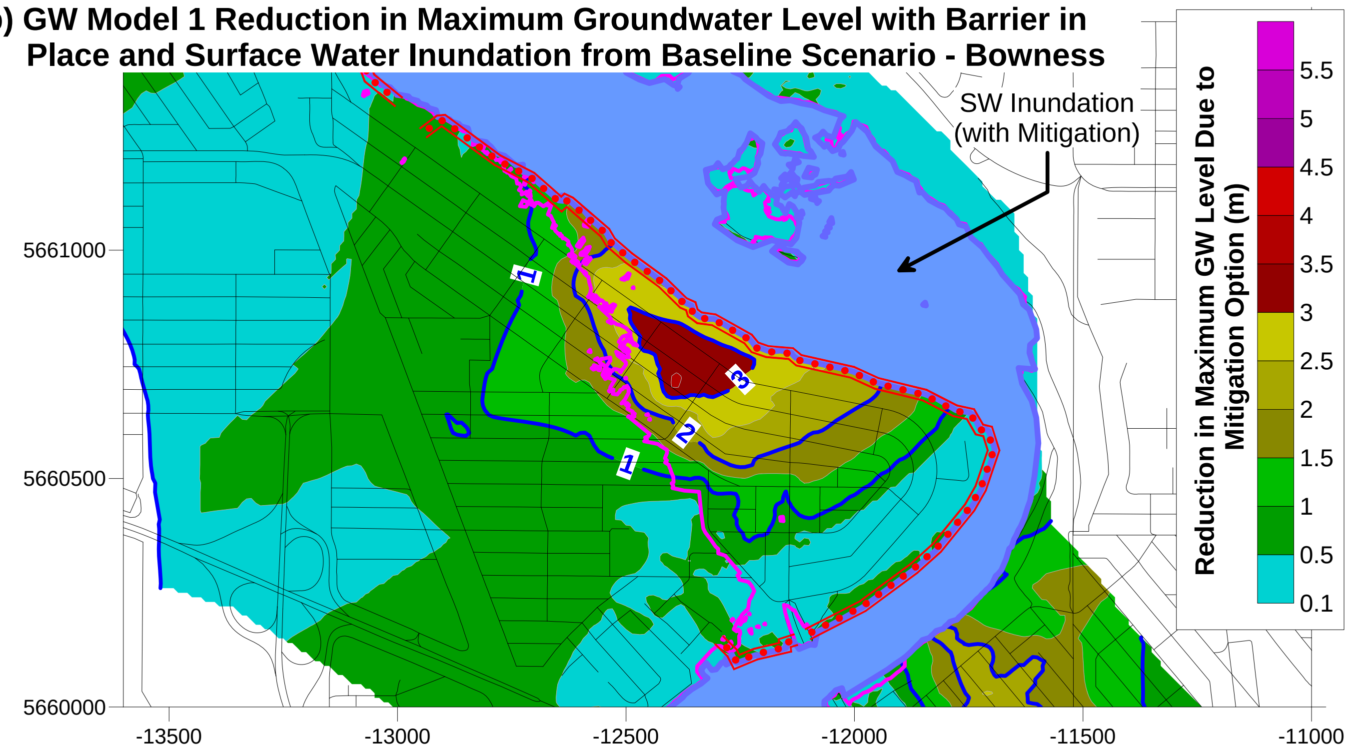
(a) GW Model 1 Maximum Groundwater Level Contours and Surface Water (SW) Inundation for Baseline Scenario - Bowness



(b) GW Model 1 Reduction in Maximum Groundwater Level with Barrier in Place and Surface Water Inundation from Baseline Scenario - Bowness



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PHASE II FLOOD MITIGATION OPTIONS ASSESSMENT

TITLE
GW Model 1(Barriers in Place) Maximum Groundwater Elevation and Reduction in Groundwater Elevation Due to Mitigation (100-year Return Period)

Golder Associates

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Figure 5a: Delta H versus Distance

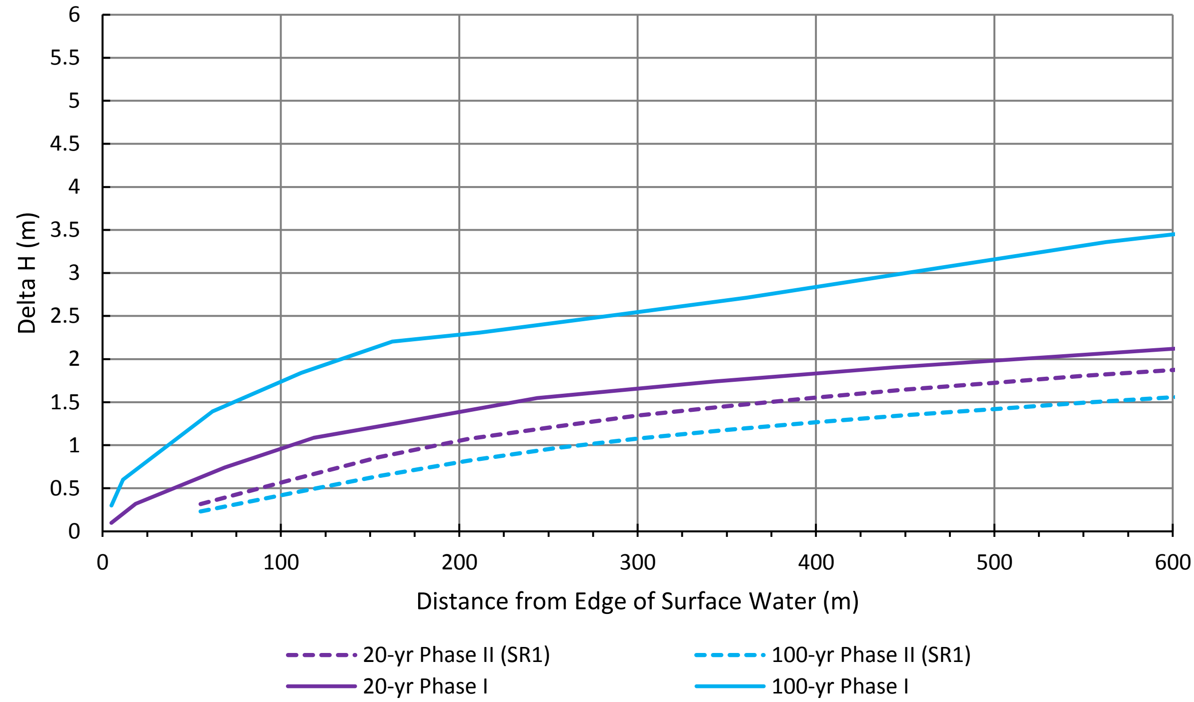
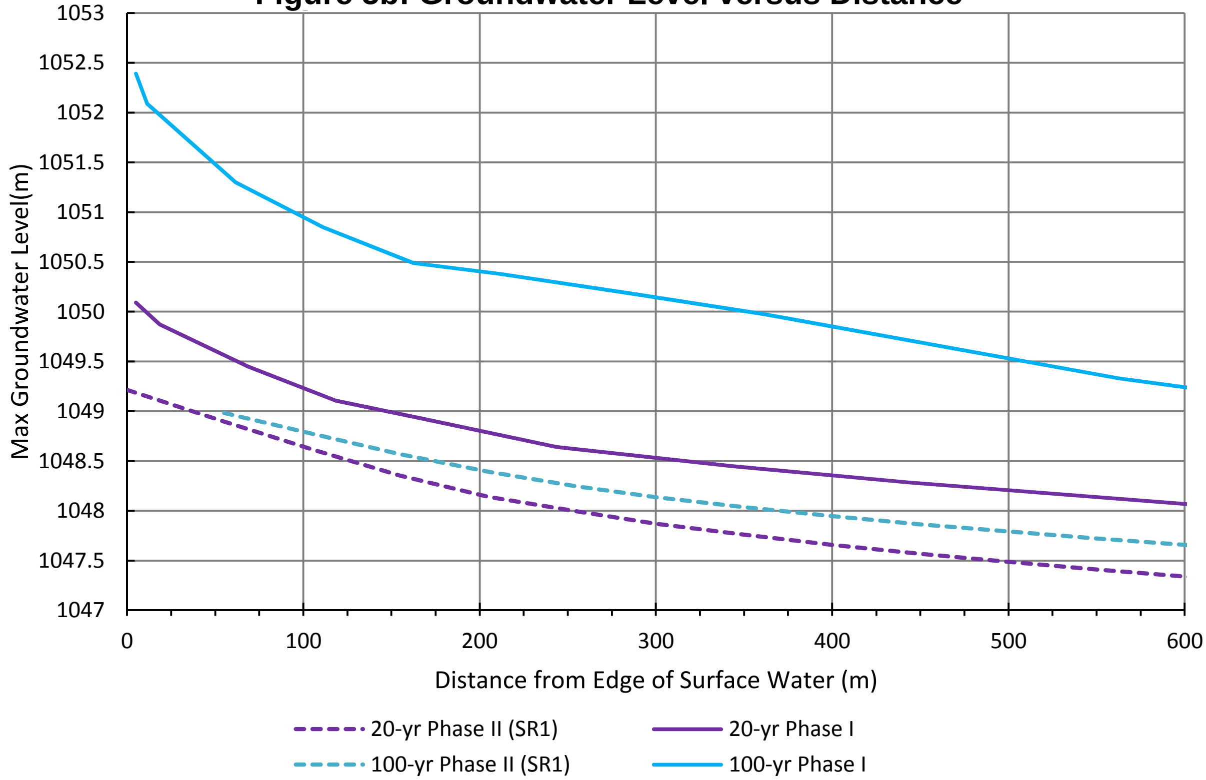


Figure 5b: Groundwater Level versus Distance



PROJECT

THE CITY OF CALGARY WATER RESOURCES

PHASE II FLOOD MITIGATION OPTIONS ASSESSMENT

TITLE

GW Model 2 Delta H and Groundwater Elevation versus Distance Relationships (Springbank Reservoir (SR1) – Mission Section)

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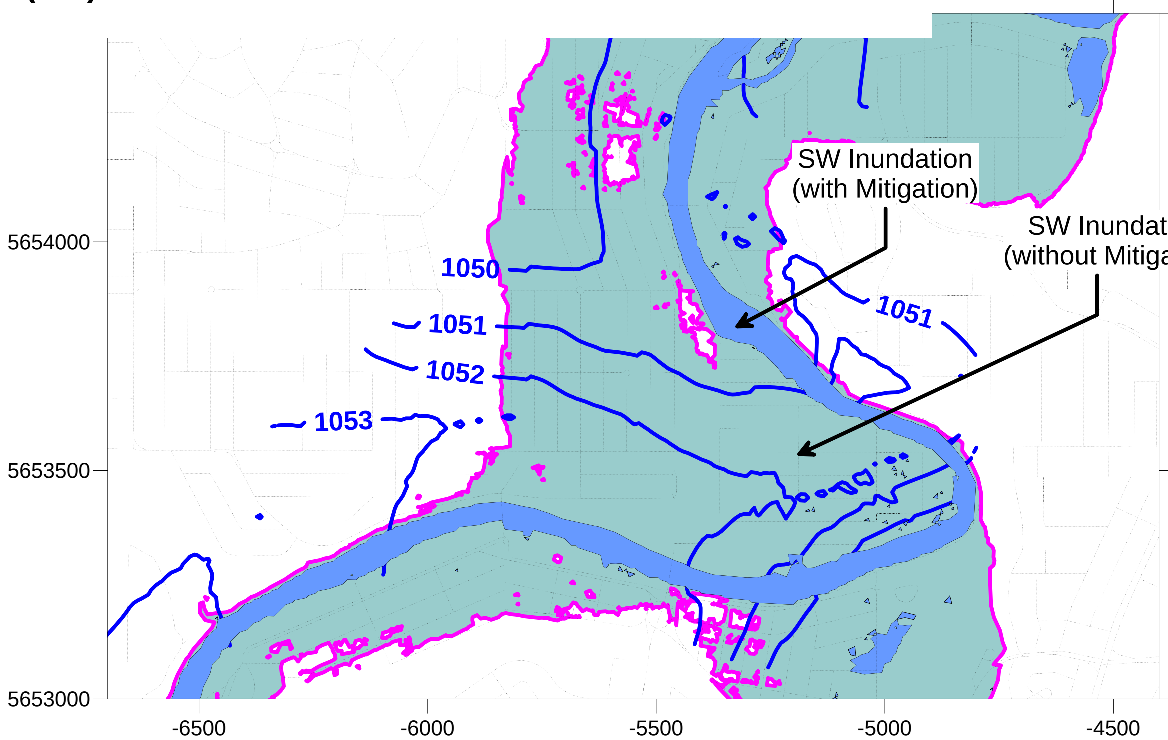
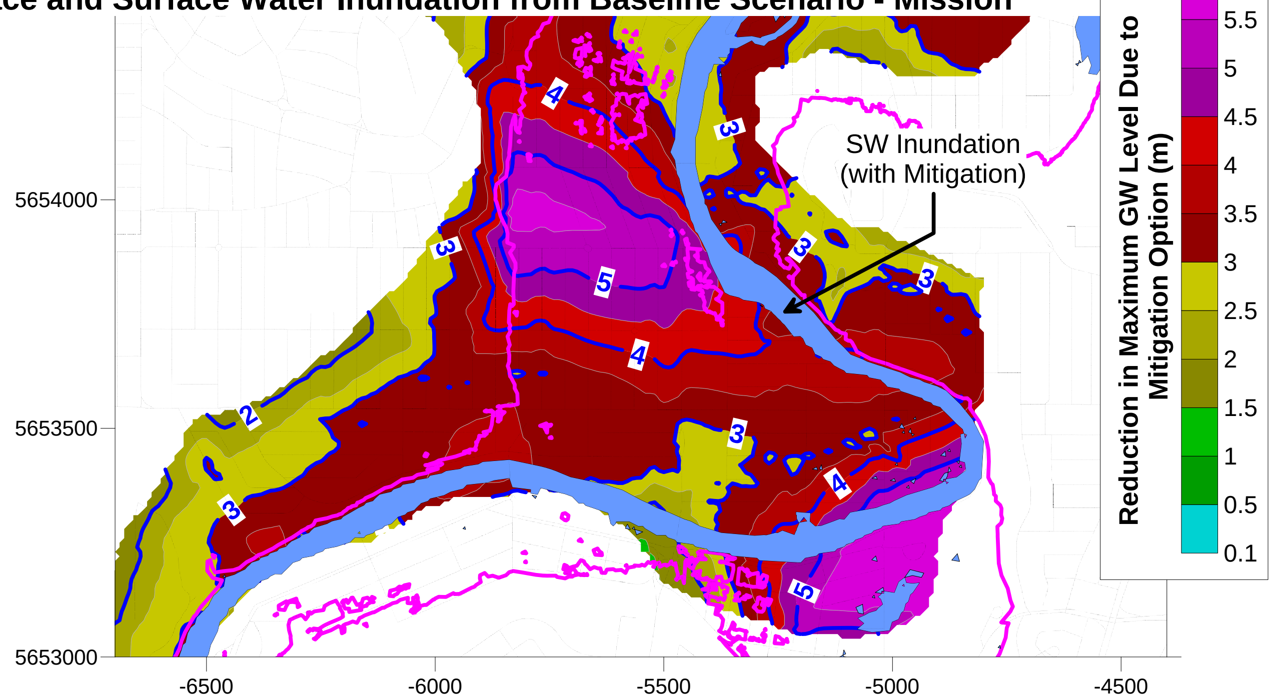
(a) GW Model 2 Maximum Groundwater Level Contours and Surface Water (SW) Inundation for Baseline Scenario - Mission



(b) GW Model 2 Reduction in Maximum Groundwater Level with SR1 in Place and Surface Water Inundation from Baseline Scenario - Mission



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THE CITY OF CALGARY WATER RESOURCES

PHASE II FLOOD MITIGATION OPTIONS ASSESSMENT

TITLE

GW Model 2 (SR1) Maximum Groundwater Elevation and Reduction in Groundwater Elevation Due to Mitigation (100-year Return Period)

Golder Associates

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Figure 7a: Delta H versus Distance

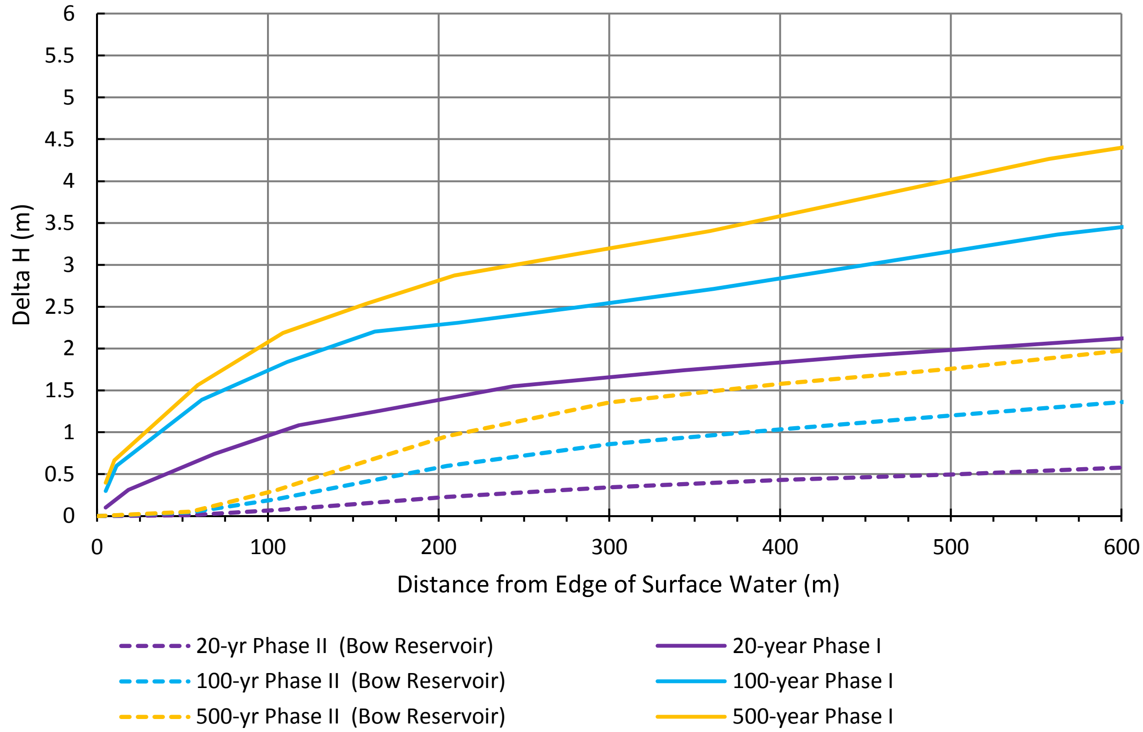
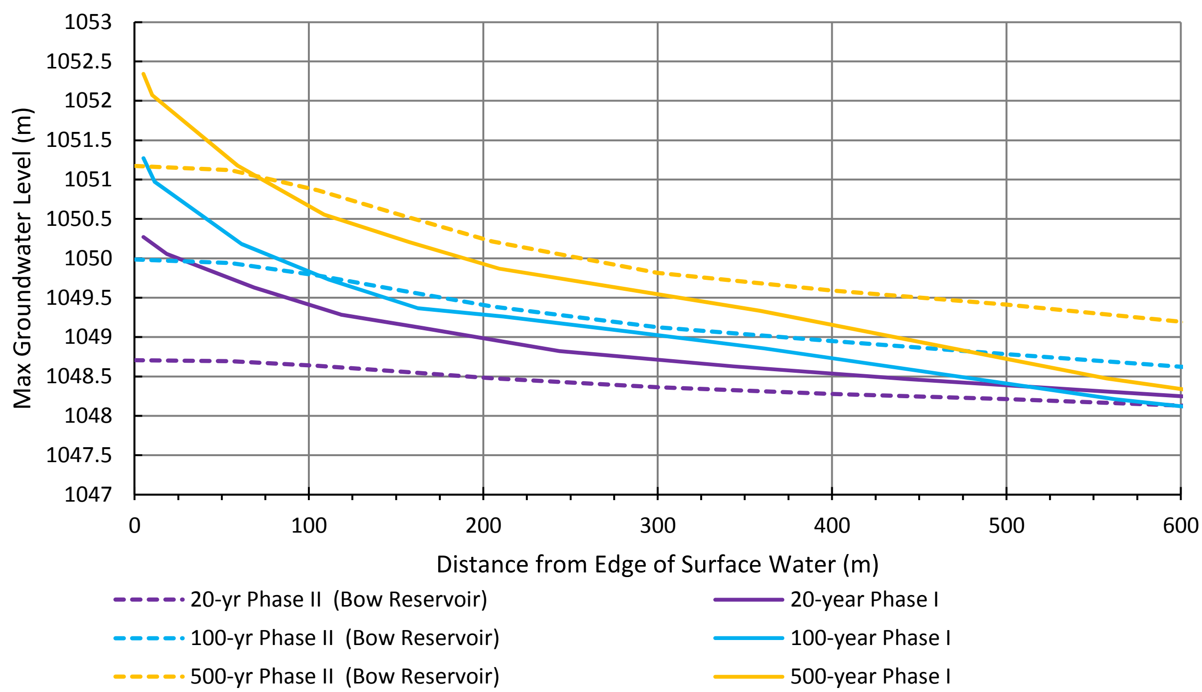


Figure 7b: Groundwater Level versus Distance



PROJECT
THE CITY OF CALGARY WATER RESOURCES

PHASE II FLOOD MITIGATION OPTIONS ASSESSMENT

TITLE

GW Model 3 Delta H and Groundwater Elevation versus Distance Relationships (Additional Reservoir on the Bow River – Hillhurst Section)

Golder Associates

PROJECT No.	1531394		FILE No.	15313942000A007
DESIGN	DH	05/12/2016	SCALE AS SHOWN	REV. 01
SURFER	DH	05/12/2016		
CHECK	DH	08/12/2016	**FIGURE 7**	
REVIEW	DL	09/12/2016		

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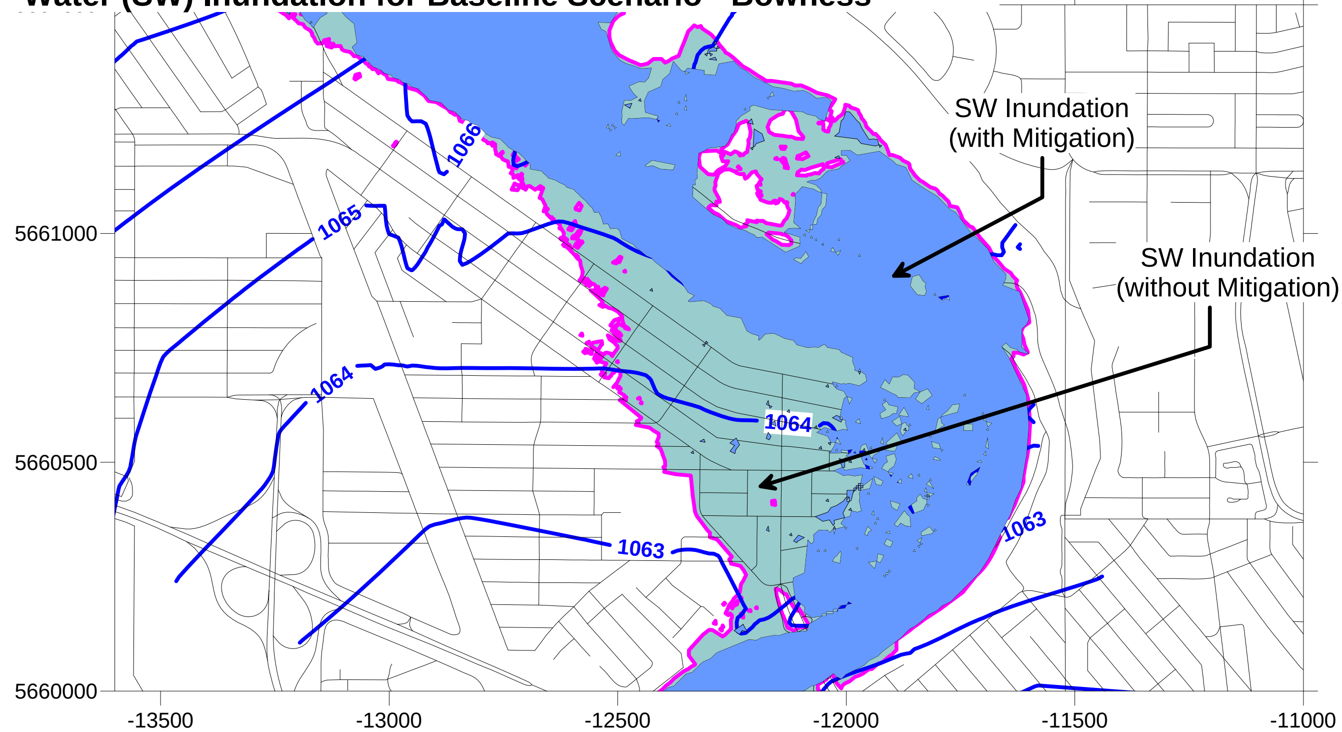
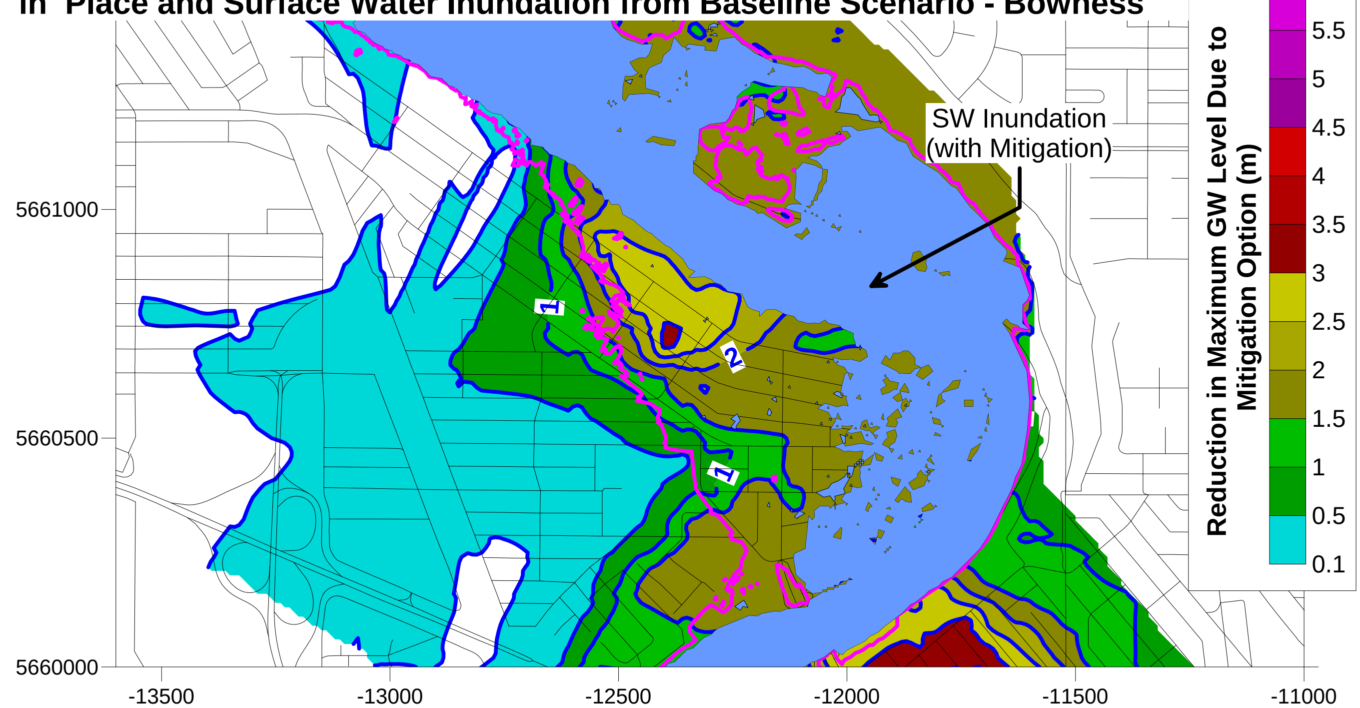
(a) GW Model 3 Maximum Groundwater Level Contours and Surface Water (SW) Inundation for Baseline Scenario - Bowness



(b) GW Model 3 Reduction in Maximum Groundwater Level with Bow Reservoir in Place and Surface Water Inundation from Baseline Scenario - Bowness



PROJECT

THE CITY OF CALGARY WATER RESOURCES

PHASE II FLOOD MITIGATION OPTIONS ASSESSMENT

TITLE

GW Model 3(Bow Reservoir) Maximum Groundwater Elevation and Reduction in Groundwater Elevation Due to Mitigation (100-year Return Period)

Golder Associates

PROJECT No.	1531394		FILE No.	15313942000A008
DESIGN	DH	05/12/2016	SCALE AS SHOWN	REV. 01
SURFER	DH	05/12/2016		
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REVIEW	DL	09/12/2016		

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For more information, visit golder.com

Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 44 1628 851851
North America	+ 1 800 275 3281
South America	+ 56 2 2616 2000

solutions@golder.com
www.golder.com

Golder Associates Ltd.
102, 2535 - 3rd Avenue S.E.
Calgary, Alberta, T2A 7W5
Canada
T: +1 (403) 299 5600

Golder Associates