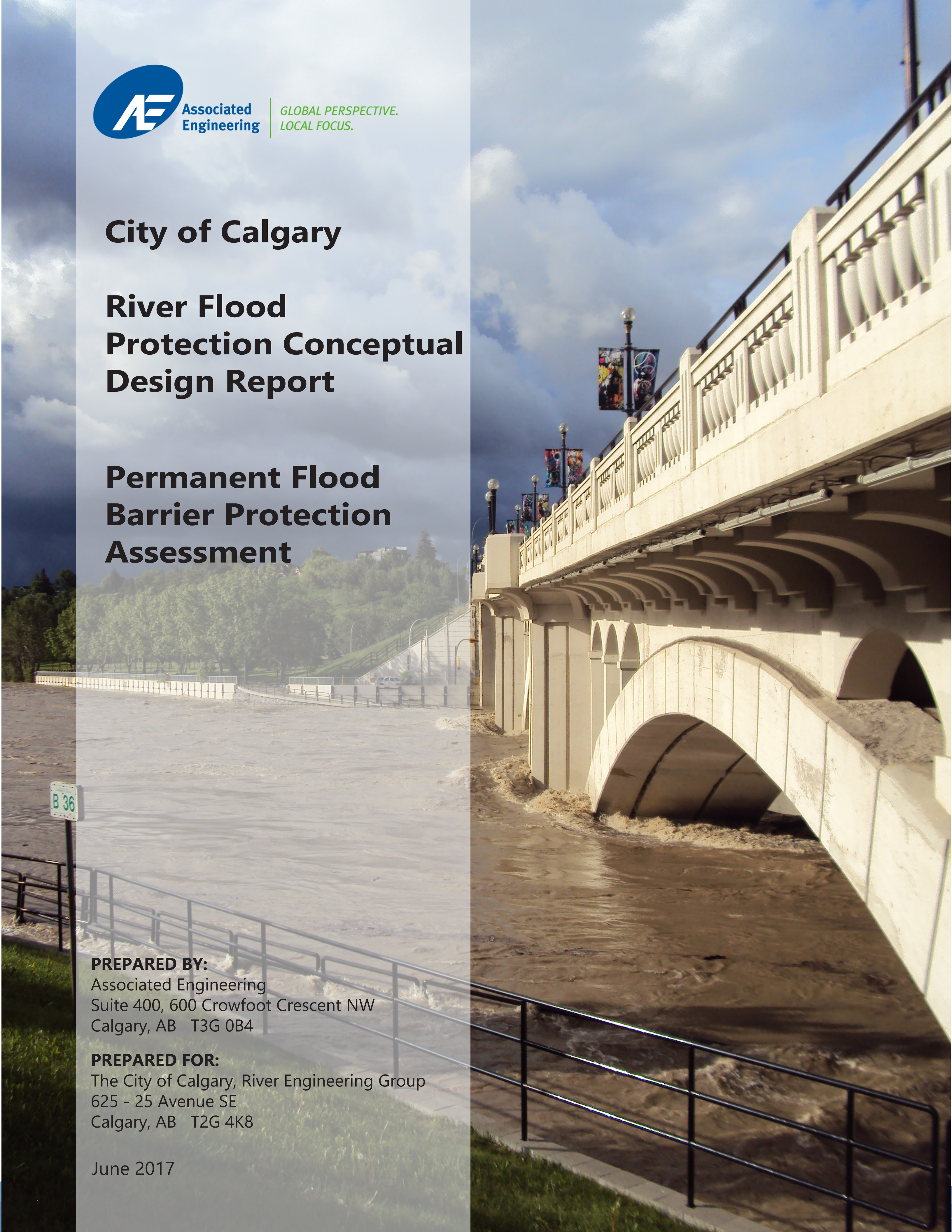

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City of Calgary

River Flood Protection Conceptual Design Report

Permanent Flood Barrier Protection Assessment

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INTRODUCTION

Portions of The City of Calgary are at risk of overland and groundwater flooding during river flood events. River flood events are caused by rainfall in the Rocky Mountains and are difficult to predict and respond to. As a result, The City has little time to implement emergency flood protection measures in response to high river levels. In an effort to reduce the risk of flood damage, The City of Calgary and Government of Alberta are evaluating watershed scale flood protection measures. The City is also investigating local flood protection measures (i.e., flood barriers) for communities that have the greatest risk of flooding.

This report summarizes the investigation of the merits of local, permanent flood protection measures; namely flood protection barriers and associated groundwater and stormwater management infrastructure.

TIMELINE

- **May 2013** - The City issued a request for proposal to review the existing flood defences and develop and prioritize additional conceptual level flood protection measures.
- **June 2013** - The City experienced severe flooding which was one of Canada's worst natural disasters.
- **August 2013** - The City created an Expert Panel on river flood mitigation. The Panel recommended investigation of local barriers and other flood mitigation concepts.
- **September 2013** - The City of Calgary retained Associated Engineering to undertake the "Calgary River Flood Protection Conceptual Design" project.
- **June/July 2014** - The Provincial Government was presented three possible large scale projects; the Springbank Off-stream Reservoir; the McLean Creek Dry Dam; and the Glenmore Reservoir Diversion to provide flood resilience for those along the Elbow River and into Downtown.
- **October 2015** - The Provincial Government announced it would move forward with the Springbank Off-stream Reservoir project to provide flood resilience for those along the Elbow River and into downtown Calgary.
- **January 2016** - The Bow River Working Group was established to investigate and advise on flood mitigation opportunities, including new reservoirs for the Bow River.
- **April 2017** - Six recommendations for Flood Mitigation Measures were proposed by City Administration and approved by City Council.

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METHODOLOGY

Associated Engineering was retained by The City in 2013 to evaluate flood risk and assist The City in developing a plan for future flood protection. Associated Engineering's scope of work was to:

- Review existing flood risk.
- Estimate the cost of flood damage.
- Develop conceptual flood barrier designs to protect from flooding for small to large floods.
- Conduct a Triple Bottom Line, Benefit-Cost Analysis to assess the merits of proposed flood barriers. The Triple Bottom Line Analysis is a method of evaluation which measures economic impact as well as environmental sustainability and social impacts.
- Assist The City in identifying barriers and protection levels that provide the greatest benefit for investment while working with, and accommodating other mitigation measures.
- Develop conceptual designs for selected projects.

Flood barrier projects were evaluated for different flood events in an attempt to identify the protection level, or level of service, with the maximum benefit/cost ratio. This represents the level of flood protection which yields the most benefit for each dollar spent. The level of service for flood barriers refers to a statistical return period in which a particular river flow occurs. For example, the 1:100 year return period corresponds to a flow of 2,020 m^3/s* in the Bow River upstream of the Elbow River, and has a 1% chance of occurring in any given year.

* Per the study Basin-Wide Hydrology Assessment and 2013 Flood Documentation prepared by Golder Associates Ltd. for The City and The Province in 2015

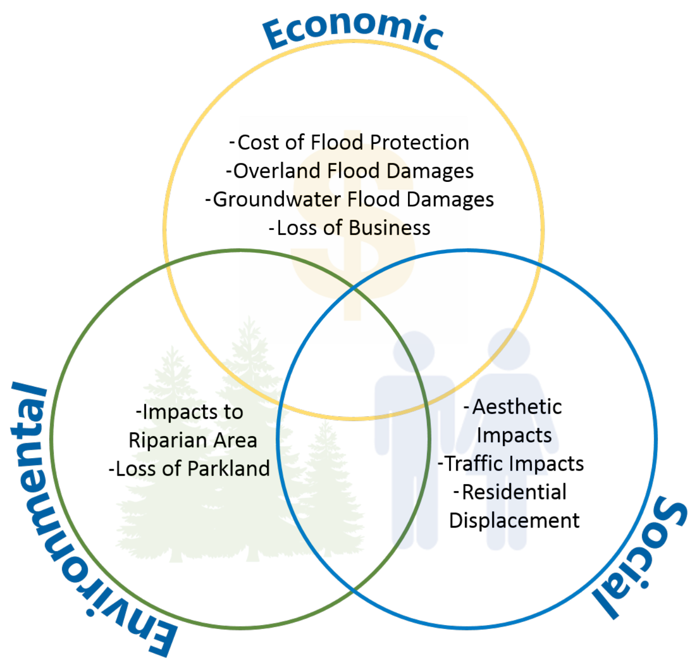

Figure 1 - Triple Bottom Line Analysis Considerations

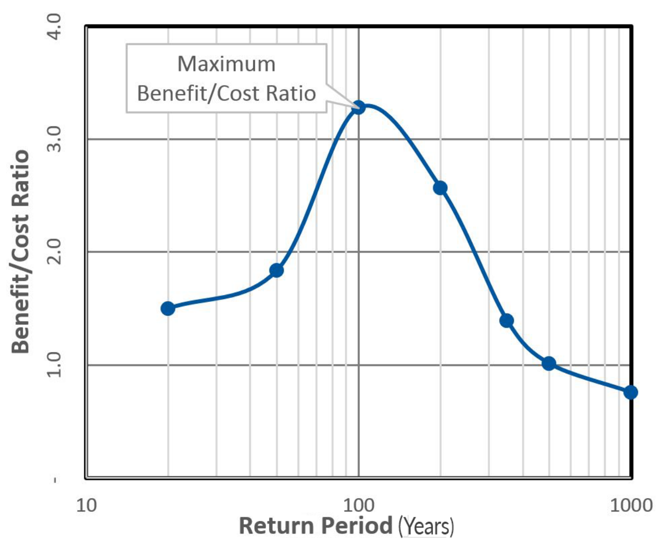

Figure 2 - Benefit Cost Ratio vs Return Period

EXISTING FLOOD RISK



Overland Flooding Risk

Although some structural flood protection exists currently, portions of The City of Calgary remain at risk of overland flooding during flood events.

In 1983, the 1:100 year return period flood hazard area of the Bow and Elbow Rivers was mapped by The Province and divided into Floodway and Flood Fringe regions. The Province, through the Water Act, restricts certain development in these regions. These restrictions are incorporated into The City's Land-Use Bylaw. New buildings within the Floodway are not permitted and buildings within the Flood Fringe must be constructed at or above the designated flood level. This flood hazard mapping is also referred to as regulatory mapping.

Floodway - The portion of the flood hazard area where flows are deepest, fastest and most destructive.

Flood Fringe - The portion of the flood hazard area outside the floodway that is inundated but with shallower flood depth and lower flow velocity.

Overland Flow - The portion of the flood hazard area that is inundated by shallow and fast moving overland floodwater.

Since then, the specific areas of the flood hazard area mapping were updated by The Province in 1996. In 2015, The City and The Province had new flood maps created to better understand flood levels and hydraulics for emergency response planning. However, land-use continues to be defined by The Province's Flood Hazard Mapping. The Province is currently in the process of updating Flood Hazard Mapping.

For the Bow River, the most recent inundation mapping indicates that:

- Flooding of properties starts when flows exceed 920 m^3/s (1:10 year return period flood, 10% annual exceedance probability).
- Larger scale flooding of communities occurs when flows exceed 1,200 m^3/s (1:20 year return period flood, 5% annual exceedance probability).
- Widespread flooding of the downtown core occurs when flows exceed 2,020 m^3/s (1:100 year return period flood, 1% annual exceedance probability).

For the Elbow River, the most recent inundation mapping indicates that:

- Flooding of properties occurs when flows exceed 150 m^3/s (1:5 year return period flood, 20% annual exceedance probability).
- Widespread flooding of communities occurs when flows exceed 230 m^3/s (1:10 year return period flood, 5% annual exceedance probability).

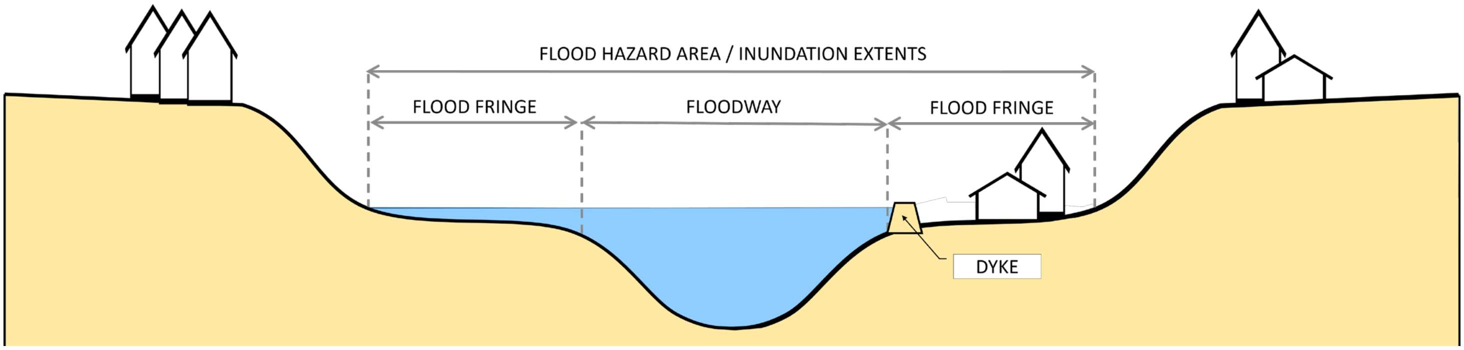

Figure 3 - Flood Hazard Area

Dyke: An engineered flood protection structure.

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Groundwater Flooding Risk

As a part of this study, Associated Engineering conducted groundwater modelling and inundation mapping across Calgary for various river levels. Using available geological information, Associated Engineering developed 2-dimensional groundwater models of representative locations across the City.

Associated Engineering used the groundwater modelling results to develop groundwater inundation mapping. The groundwater inundation mapping identified locations where groundwater was expected to reach the surface and/or may affect basements.

Geological data available at the time this study was conducted was limited and new data was costly to acquire. As such, the mapping produced cannot predict local groundwater conditions with certainty but it does provide a high level prediction of areas that may be prone to basement flooding and groundwater flooding to surface. This prediction is based on generalized river and floodplain geometry and subsurface soil characteristics. The City's ongoing work will include collection of additional subsurface information to continually improve their understanding of groundwater flooding.

The results of the modelling and mapping indicate that some communities are potentially at risk of groundwater flooding during flood events on the Bow and Elbow Rivers.

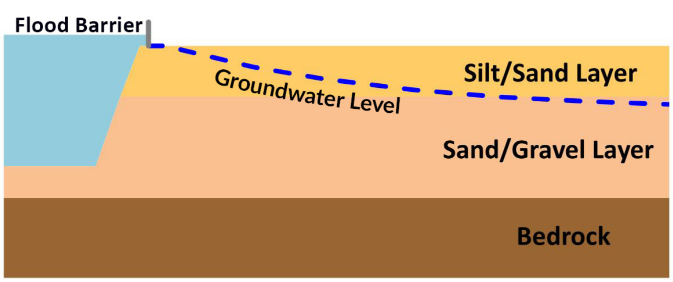

Figure 4 - Typical Subsurface

A permeable sand and gravel layer within floodplain areas allows groundwater to move inland during flood events. Groundwater can cause flood damage by seeping into basements or by inundating low areas.

The modelling yielded two major findings:

- Generally, a less permeable soil layer (i.e., silt) is present at the surface of floodplain areas. This prevents downward flow of groundwater from overland flooding. Groundwater flooding is primarily caused by horizontal flow from the riverbank and does not extend as far as the overland flooding extents.
- If a barrier is in place to block overland flooding, groundwater can rise to the surface. This finding indicates that in some locations, flood barriers should be evaluated with groundwater protection to address flooding.

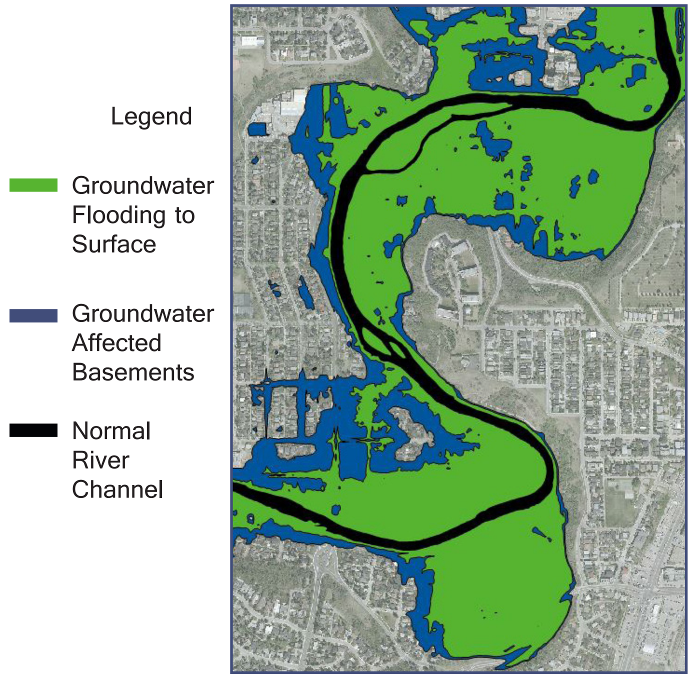

Figure 5 - Groundwater Inundation Mapping Example



Stormwater Flooding Risk

In floodplain areas, stormwater flooding can occur in two ways:

- When rainfall and runoff overwhelms the stormwater system.
- When rainfall occurs during a river flood event.

Stormwater flooding during a flood event occurs because river water backs up the storm system and prevents release of runoff to the river. The City's emergency response crews close the gates on the stormwater outfalls in anticipation of a flood event to stop river water from backing up the system, but this also stops stormwater from discharging to the river. If the rainfall is heavy enough when the gates are closed, flooding can occur in low lying areas. Construction of flood barriers will obstruct overland flow paths and require installation of additional gates on the stormwater system. This will reduce the risk of overland flooding but will not prevent stormwater flooding in these areas during flood events.

The risk of stormwater flooding depends on the probability of heavy rainfall occurring at the same time as a river flood event. It is important to recognize that river flooding in Calgary is primarily caused by rainfall in mountain areas, not local rainfall. Also, within the period of record there is only a few instances of river flooding. As a result, there are very few instances of heavy rainfall coinciding with river flooding in the City. Associated Engineering conducted a historical analysis as part of the "Northwest Inner City Drainage Study - Sunnyside Review". Based upon the findings of the historical analysis, and acknowledging the limitations of the record information, the City selected a 1:5 year return period rainfall event to be managed during flood events by proposed community drainage improvements within Sunnyside. This was also used as the basis for the Permanent Barrier Study.

Figure 6 - 2013 Flooding

Figure 7 - 2013 Flooding

Figure 8 - 2013 Flooding

FLOOD DAMAGE ESTIMATION

Associated Engineering estimated overland and groundwater flood damages within the City. These flood damages were used within the triple bottom line benefit-cost analysis.

Flood damages were first determined by evaluating the overland and groundwater flood depths at each property. AE then applied the flood depth to a depth-damage curve developed for the type of building on the property. The depth-damage curve represents an estimate of the potential damage to the building and contents based on a specific flood depth.

Associated Engineering used different depth-damage curves for residential, commercial and industrial properties. The depth-damage curves were derived from those used in the Provincial Flood Damage Assessment Study (IBI Group, 2015). Reduction of flood damages was then attributed to particular flood protection projects.

Damages were estimated for seven different return periods and plotted on a graph. The points on the line represent individual damage estimations, while the area underneath the line represents the Average Annual Damages, which are the average estimated damages per year based on the number of statistically predicted flood events.

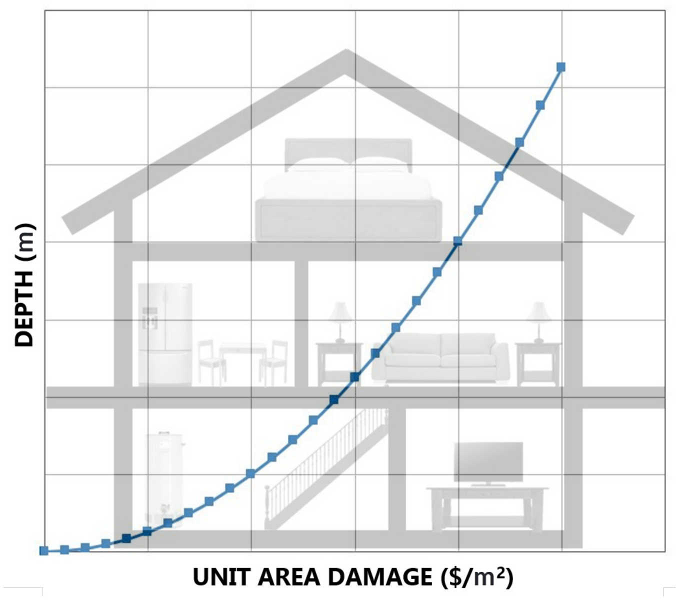

Figure 9 - Example Depth Damage Curve

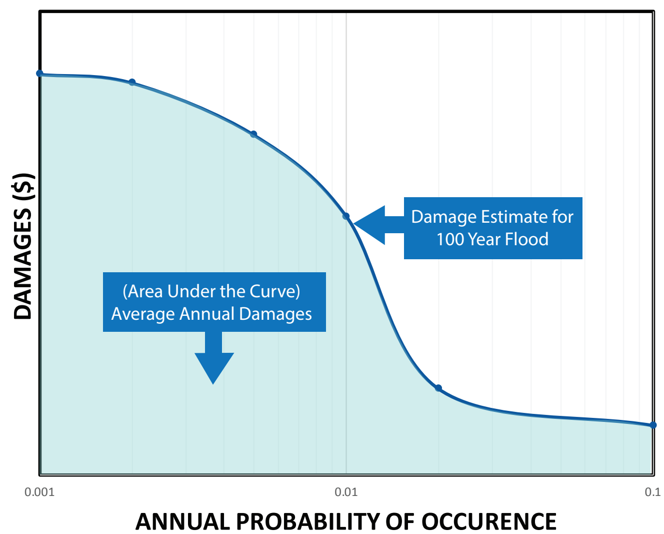

Figure 10 - Annual Probability of Occurrence

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Flood Barrier Protection

Associated Engineering developed feasible, high-level design concepts for flood protection barriers to support the triple bottom line analysis.

Overland Flood Protection

Flood barrier designs consist of dykes and concrete flood walls. Typically, dykes are the most cost effective and are therefore considered wherever there is sufficient space. Concrete flood walls are used where space is limited. To maintain pedestrian or vehicle access across barriers, operable gates or deployable barrier systems are considered.

Associated Engineering selected alignments for the flood barriers to avoid impacts to private land, existing buildings, existing utilities and to avoid construction in the Floodway. However, in some circumstances, private land impacts are necessary to accommodate the flood barriers.

Flood barrier design options were prepared at each location to several different design elevations; each design representing a different river flood return period. All design elevations include 0.5 m of freeboard. Freeboard refers to additional height above the anticipated water surface elevation and can be thought of as a factor of safety to account for waves, debris or changes to the river bed during a flood.

Figure 11 - Floodwall Example

Figure 12 - Dyke Example

Figure 13 - Dyke Example

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Groundwater Flood Protection

Groundwater flood protection design concepts consist of a groundwater collection system or cut-off walls to bedrock. Based on the modelling performed, typically, a groundwater collection system is more cost effective for low river flooding (e.g., 20 year flood), while cut-off walls are more cost effective for extreme river flooding. This, however, can change depending on the type of soils and subsurface conditions.

- **Groundwater Collection System** - Similar in concept to a weeping tile system, groundwater collection systems consist of buried, perforated pipes placed beneath the flood barriers. Perforated pipes intercept groundwater and convey it to an outfall which drains by gravity if river levels are sufficiently low, or is pumped to the river if the outfall gates are closed and/or river levels are high.
- **Cut-Off Walls** - Cut-off walls consist of interconnected steel sheet piles driven below ground that act as a physical barrier to groundwater flow beneath the barriers. Sheet piles would be driven down to bedrock to stop groundwater from moving inland. However, these walls would also impede groundwater on the land side from reaching the river during normal conditions (i.e., when a flood is not occurring). Smaller perforated pipes on the land side of the wall would convey groundwater to an outfall which would drain to the river by gravity.

Groundwater modelling was conducted to support design of the groundwater collection systems and cut-off walls.

In order to evaluate the projects within the triple bottom line analysis, AE designed the projects to varying extents. Each extent represented a different return period or level of service. As mentioned in previous sections, groundwater protection design concepts are based on limited subsurface information. Therefore, there is notable uncertainty in cost estimation and triple bottom line evaluations. Further investigation will be performed for proposed projects to validate findings relating to groundwater protection.

Figure 14 - Sheet Pile Wall Example

Figure 15 - Sheet Pile Wall Example

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Stormwater Flood Protection

Stormwater protection measures were considered for each flood barrier. Stormwater protection measures manage stormwater by storing and/or pumping runoff that cannot discharge to the river during a flood event. Estimated stormwater volumes are significant enough that a combination of storage and pumping is required.

Associated Engineering estimated rainfall runoff during a 1:5 year return period storm for each flood barrier. It was assumed that 20% of the peak flow would be stored reducing the pumping requirement to 80% of the estimated peak flow.

In order to estimate costs of stormwater pumping, Associated Engineering developed a cost versus pumping capacity curve from literature and validated it with recent projects.

Figure 16 - Slide Gate Example

Figure 17 - Flap Gate Example

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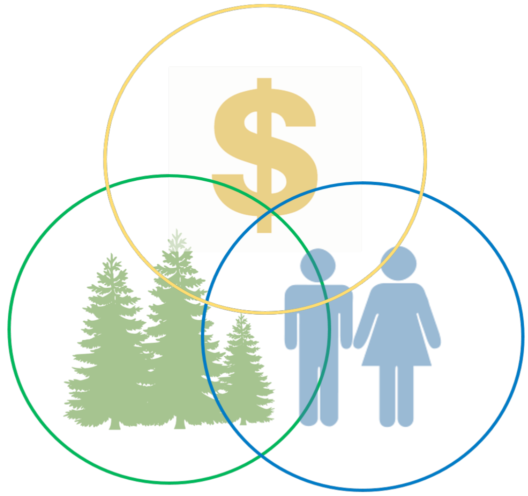
Triple Bottom Line Benefit/Cost Analysis



Associated Engineering conducted a triple bottom line analysis to identify flood barrier projects that are cost beneficial to determine the range of appropriate service levels. The triple bottom line analysis considered the economic benefits of reduced flood damages and the costs of flood barrier projects. The analysis also considered social and environmental factors such as traffic impacts, aesthetic impacts, loss of business income, administrative costs, loss of profit, inconvenience, displacement costs, loss of parkland and riparian areas.



Observations

A benefit/cost ratio greater than one means that a project is cost beneficial. A benefit/cost ratio less than one means that a project is not cost beneficial. This means that it costs more to build than it would to pay for flood damages.

If the benefit/cost ratio is greater than one, the highest point on the benefit/cost ratio line is the point at which the greatest return is yielded for the investment.

In many cases, the benefits begin to taper off at higher return periods while costs increase significantly due to the increasing height and length of the flood barrier required. At these levels, increasing the level of service yields less incremental benefits.

Analysis

Associated Engineering analysed overland and groundwater flood protection projects separately, together and with stormwater flood protection projects. AE also considered the impacts of proposed upstream mitigation projects.

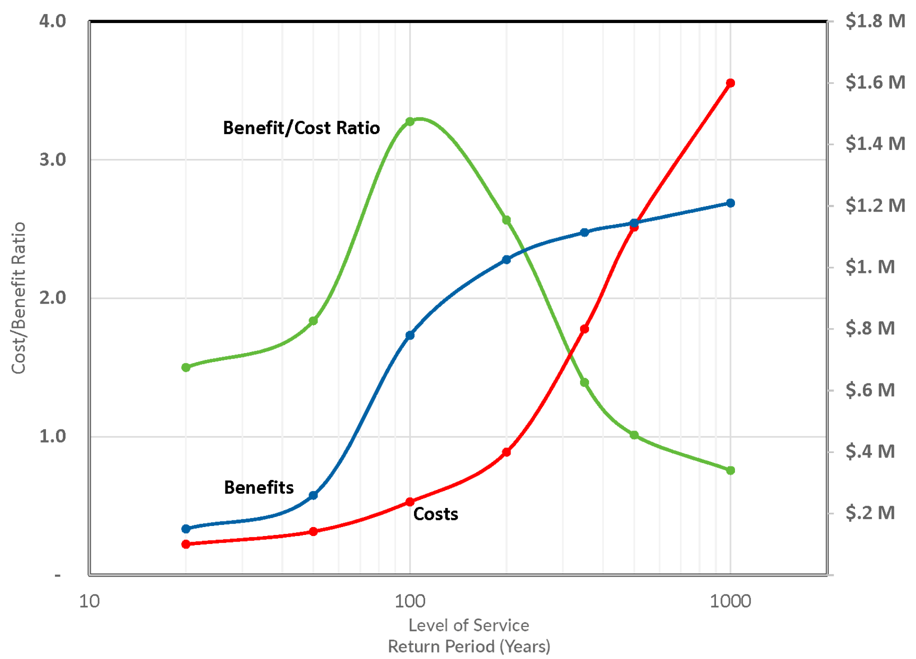


Figure 18 - Example Results of Triple Bottom Line Benefit-Cost Analysis

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Findings

Permanent Flood Barriers are technically feasible but they are costly. The barriers also require significant additional investment to protect from groundwater and stormwater flooding.

Not only are the barriers financially expensive, they also have large social and environmental costs. The flood barriers could obstruct river views and require easements over private land.

The triple bottom line analysis indicated that the investments with the highest benefit/cost ratios are generally located in Sunnyside, Inglewood, Downtown and Bowness. The analysis also revealed that groundwater and stormwater flood protection is not beneficial with the exception of a few communities.

It is noted that stormwater and groundwater design concepts and cost estimates have been based on limited information (e.g., subsurface conditions) and are somewhat uncertain. As such, these findings will be revisited and validated for proposed barrier projects.

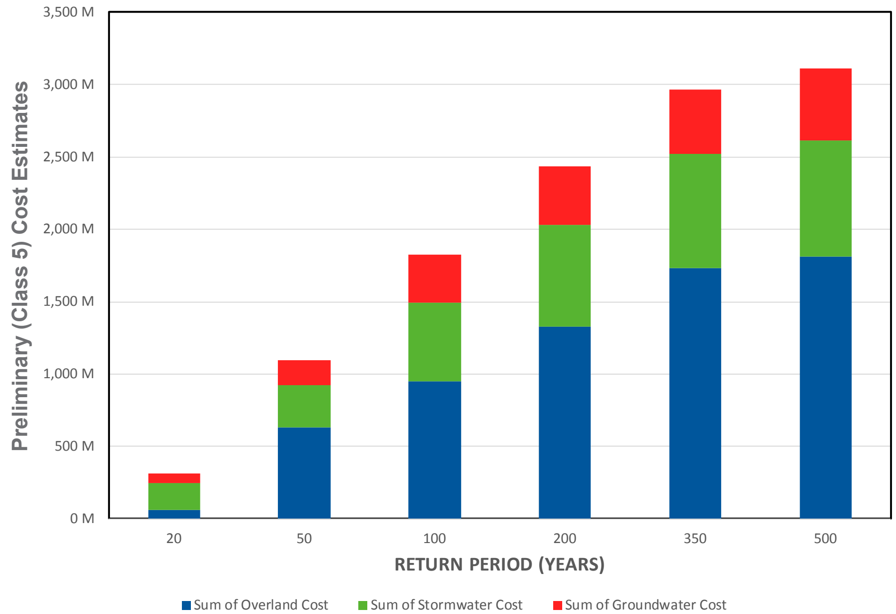

Figure 19 - Cost of City Wide Flood Protection vs Return Period

Figure 20 - 4 m High Flood Wall in St. Louis, Missouri

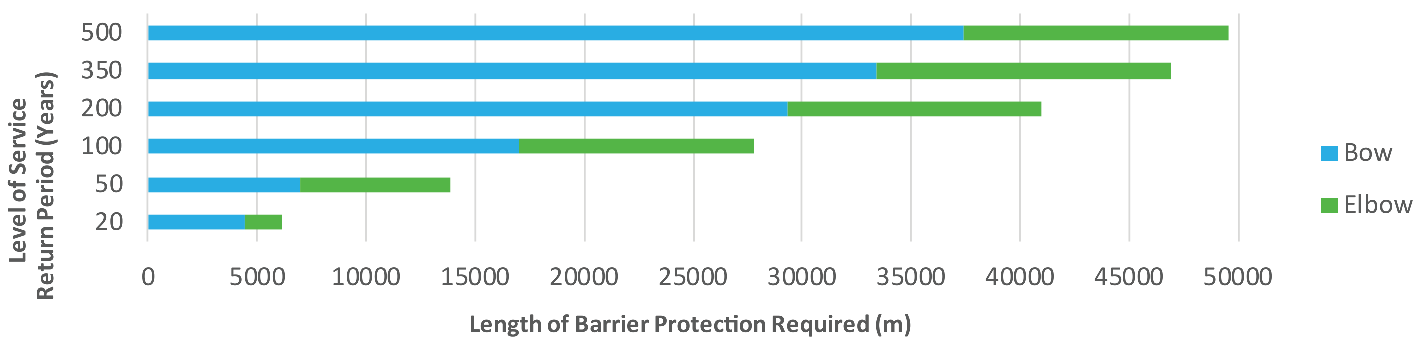

Figure 21 - Length of Barriers Required to Provide Various Levels of Service

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DECISION

In 2016, The City of Calgary undertook a Flood Mitigation Measures Assessment (FMMA) to provide a recommended direction on the future of Calgary's flood mitigation and resiliency. Findings from the "Calgary River Flood Protection Conceptual Design Study" contributed to this assessment.

The FMMA developed recommendations based on principles and priorities such as public safety, sustainable watershed management, beneficial investment, adaptability and flexibility, equitable protection on both the Bow River and Elbow River, community receptivity and shared responsibility.

The FMMA considered the following flood mitigation measures:

- Watershed-level structural flood mitigation including new reservoirs and revised operation of existing reservoirs upstream of Calgary;
- Community-level structural mitigation including permanent barriers; and
- Property level and policy-based mitigation measures.

Based on the results of the FMMA, it was recommended that a combination of the above be pursued. The following measures were recommended:

- Continue to support the development of The Province's Springbank Off-stream Reservoir project for the Elbow River. This project has a high benefit-cost ratio and, with The City's Glenmore Gates project, will mitigate a flood similar to what was experienced in 2013.
- Work with Council to advocate for an upstream reservoir and continuation of the Provincial TransAlta operational agreement for the Bow River.
- The above measures are most beneficial in terms of overall damage reduction, benefit-cost ratio, sustainability analysis, and citizen feedback. The upstream reservoir on the Bow River can also provide resilience to climate change and opportunities for drought and irrigation management.
- Develop and implement a funding plan for community level mitigation including permanent barriers that will complement an upstream reservoir and provide shorter term protection for communities at the greatest risk. The communities at the greatest risk are Sunnyside, Inglewood, Bowness, and Downtown. These barrier projects are referred to as "Complementary Barriers".
- Secure funding from multiple levels of government (i.e., municipal, provincial, federal).

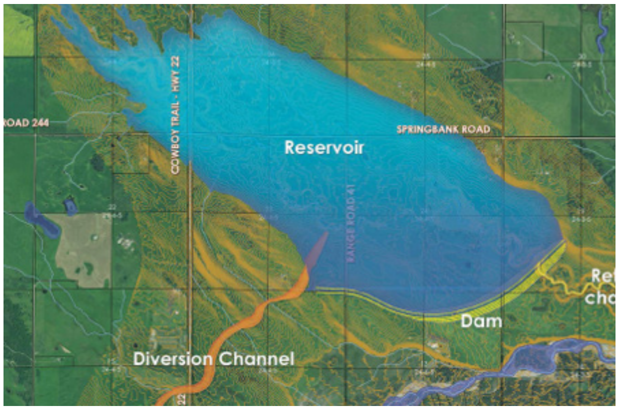

Figure 22 - Springbank Off-Stream Reservoir

Figure 23 - Ghost Dam

FLOOD PROTECTION
COMPLEMENTARY BARRIERS

In accordance with the recommendations from the FMMA, the complimentary barriers were assessed in greater detail. The conceptual designs take flood mitigation from the proposed Springbank Off-stream Reservoir project and operational changes made by TransAlta at the Ghost Reservoir into consideration.

Downtown

Flood protection is planned for the downtown core to the 1:200 year return period. Projects are currently underway within West Eau Claire Park and at the south abutment of the lower deck of the Centre Street Bridge. A dyke is also proposed between Jaipur Bridge and Reconciliation (formerly known as the Langevin) Bridge.

- Average Height 1.2 m
- Average Width 8 m

Figure 24 - Downtown Barrier

Sunnyside

A dyke and concrete flood wall is proposed between the Peace Bridge and the Prince's Island Pedestrian (PIP) Bridge with a 1:20 year return period level of protection. This flood protection would fix an existing low spot at the PIP bridge, which is vulnerable to over-topping, and provide freeboard all the way to the Peace Bridge. The existing berm will be removed and replaced with a new earth fill dyke while the existing concrete flood wall to the east will be extended and integrated with the existing retaining wall at the PIP Bridge.

The dyke will be fitted with groundwater seepage mitigation. A groundwater collection system is proposed on the land side of the dyke and will discharge to stormwater pump stations proposed as part of the "Northwest Inner City Drainage Study - Sunnyside Review".

- Average Height 1.5 m
- Average Width 12 m

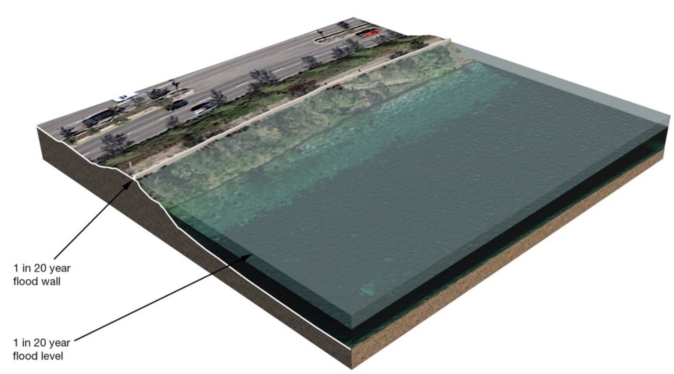

Figure 25 - Concrete Wall on Existing Barrier

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Bowness

Flood protection is planned for Bowness to the 1:20 year return period. A dyke is proposed behind the residential properties along Bow Crescent NW between the CP Rail Tracks and the playground at 6704 Bow Crescent NW.

Figure 26 - Bowness

A second dyke between approximately 64 Street and the Shouldice Bridge will provide additional flood protection in the community. Several sections of concrete flood wall will be necessary where properties are closer to the Bow River. Easements will be required to accommodate the flood protection.

- Average Height 1.1 m
- Average Width 9 m

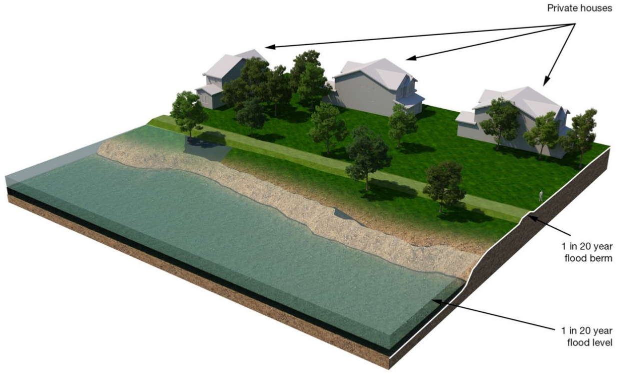

Figure 27 - Dyke Barrier

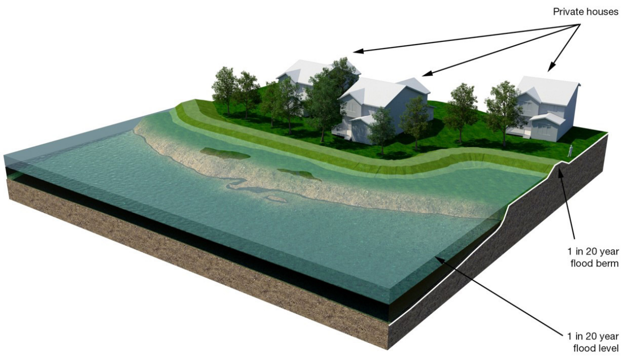

Figure 28 - Dyke Barrier

Pearce Estate Park

An dyke is proposed within Pearce Estate Park with a 1:20 year return period level of flood protection. The dyke will extend southeast from the CP Rail Tracks to high ground near the SoBow Condo Development. The berm would be integrated into the park area and would be considered in conjunction with the Bend in the Bow park rehabilitation project. This flood barrier would protect the park and provide a platform for emergency barrier placement, to provide greater protection to the community of Inglewood.

- Average Height 0.8 m
- Average Width 7 m

Figure 29 - Pearce Estate Park

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WHAT'S NEXT

- City administration presented recommendations to the Standing Policy Committee on Utilities and Corporate Services on March 22, 2017. All recommendations were subsequently approved by City Council on April 10, 2017.
- Presentation and related documents are available at www.calgary.ca/floodinfo and agendaminutes.calgary.ca.
- Recommendations included that Administration shall develop an implementation and funding plan for community level flood mitigation.
- Development of the implementation plan is currently underway and funding is being secured from provincial, federal, and municipal sources.
- Further communication on the implementation plan and community engagement for complementary barriers will take place in fall/winter 2017.

Stay tuned for possible engagement sessions!

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