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Case Study

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ASSESSING THE BENEFITS OF VARIOUS LEVELS OF FLOOD MITIGATION IN A HIGHLY DEVELOPED SETTING

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As demonstrated during the 2013 Flood, The City of Calgary is at risk of overland flooding from the Bow and Elbow Rivers. The City of Calgary (The City) mitigates this risk through emergency response measures that include deployment of temporary barriers in anticipation of a flood event. However, The City has limited time to respond as flood events develop and propagate quickly within the steep, mountainous topography upstream. In addition, the variability of rainfall distribution in the Rocky Mountains makes it difficult to predict, with certainty, whether mountain rainfall events will impact Calgary. To reduce the necessary response efforts during an emergency, The City has considered implementing permanent flood barriers for communities at risk. As much of Calgary's floodplain is developed and densely populated, constructing permanent flood protection within The City is a costly and challenging task, with little room to construct barriers and significant flood depths to protect against. Additionally, the dynamics of groundwater flooding in Calgary are not well understood.

As such, The City retained Associated Engineering (AE) to develop a better understanding of overland and groundwater flooding, propose mitigation measures for vulnerable areas in Calgary, assess the benefits and costs of mitigation measures, and identify the optimal level of service for these locations. This analysis was performed for river flood events between the 1:20 year and 1:1000 year return periods, considering economic, social and environmental impacts as part of a Triple Bottom Line (TBL) analysis. This analysis included the following steps:

1. Groundwater Modelling & Inundation Mapping

AE completed groundwater modelling and mapping as a part of this project to estimate groundwater inundation depths and extents during high river events. AE modeled groundwater movement due to high river levels using two-dimensional modelling. A two-dimensional modelling approach was selected because of the limited amount of geological information available and the large area to be covered as part of the study. The geological information indicated the presence of a silt layer overlying a gravel layer overlying bedrock. The stratigraphy and related conductivity values applied to the model were based on a desktop review of available information.

Review of the groundwater modelling yielded three major findings:

1. Surface water intrusion was found to be predominantly horizontal from the river bed and banks. Vertical migration of water from flooded areas was limited by the presence of a low conductivity silt layer. As a result, two wetting fronts were observed and it was found that complete groundwater saturation did not occur beyond the overland flooding extents.

2. In certain scenarios, groundwater was predicted to rise to surface despite the presence of proposed overland flood protection. This finding indicated that, in certain locations mitigation of overland flooding may require accompanying groundwater flood mitigation to be effective.
3. For cutoff walls to be effective in mitigating groundwater flooding, they would need to be installed to bedrock. Cutoff walls not installed to bedrock were found to be ineffective.

AE extracted the two-dimensional groundwater profiles from the model and used them to develop groundwater inundation mapping across The City. These results were used to identify locations where flooding was expected to reach affect basements or the ground surface. AE prepared groundwater surfaces for multiple return periods for the existing condition with no overland flood protection in place and for a scenario with overland flood protection in place.

2. Flood Vulnerability Assessment

The City provided AE with overland flood inundation surfaces for the high river events in question, as well as a list of critical infrastructure to consider protecting from flooding. AE assessed this critical infrastructure for vulnerability to both overland and groundwater flooding and used this information to identify areas to analyze for flood protection.

3. Flood Mitigation Designs

AE generated conceptual level flood protection designs to mitigate overland and groundwater flooding for the sites identified in the vulnerability assessment. To mitigate overland flooding, AE considered earth fill dykes, flood walls and semi-permanent barriers. These barriers are proposed on City owned land where space is available; however, some barriers require land acquisition of private property.

To mitigate groundwater flooding, AE considered seepage collection trenches and cutoff walls to bedrock as modelling showed that partial cutoff walls were relatively ineffective. For either solution, accompanying pump stations would be required to manage groundwater flows but the pumping capacities would vary depending on the proposed solution.

4. Estimation of Flood Damage and Benefits of Flood Protection

AE estimated damages related to overland and groundwater flooding as part of this study. These flood damage estimates included economic, social and environmental impacts.

Depth-damage curves developed as a part of the "*Provincial Flood Damage Assessment Study*" (IBI Group, 2015) contain unit area damage information. These curves were developed for numerous building types and separated into structure and content curves. AE amalgamated the depth-damage curves into residential, commercial and industrial categories and applied them to all properties in the study area.

Overland and groundwater flooding damage estimates were developed for buildings and their contents by applying modelled flood depths to the aforementioned depth-damage curves.

Socio-environmental factors were quantified such that a TBL benefit-cost analysis of proposed flood protection could be conducted. The social and environmental factors included in the analysis were related to safety impacts, traffic impacts, loss of business, aesthetic impacts, and impacts to riparian areas.

5. Triple Bottom Line Benefit-Cost Analysis of Proposed Flood Mitigation

A TBL Benefit-Cost Analysis was conducted to assess the merits of proposed flood mitigation projects considering economic, social and environmental impacts of flooding and impacts averted by the proposed flood mitigation. The aforementioned damages averted by proposed flood protection projects were considered to be benefits of flood protection.

The results identified areas where providing flood protection is cost-beneficial (i.e. benefit-cost ratio of greater than 1) and identified optimal levels of service for flood protection. This enabled the City to make informed decisions with regards to city-wide flood protection, local flood protection, and prioritization of the proposed improvements.