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REPORT

Provincial Flood Damage Assessment Study – Town of Canmore: Damage Estimates

Prepared for Alberta Environment and Parks
by IBI Group and Golder Associates Ltd.
#103133 | March 2017

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March 22, 2017

Mr. Peter Brundin
Watershed Integration Specialist
Government of Alberta - Environment and Parks
Strategic Integration and Projects
Great West Life Building, 4th Floor
9920 - 108 Street
Edmonton, AB T5K 2M4

Dear Mr. Brundin:

PROVINCIAL FLOOD DAMAGE ASSESSMENT STUDY
- TOWN OF CANMORE DAMAGE ESTIMATES

Enclosed please find the final report for the aforementioned assignment. The report describes in detail flood damages for the Town of Canmore under a range of return frequencies from 1:2-year to 1:100-year. Damages were calculated employing updated curves and the Provincial Flood Damage Assessment Tool (PFDAT) developed specifically to assess damages within the Province of Alberta. The total damage amounts in this report represent potential risk and do not include an assessment of existing structural mitigation measures.

Should you have any questions or require additional information please do not hesitate to contact the undersigned.

Yours truly,

IBI GROUP

Stephen Shawcross
Director

David Sol
Senior Planner

SS/mp

cc: Andrew Wilson, Government of Alberta - Environment and Parks

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Alberta Government

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Executive Summary

Introduction

Background

Flood damage estimates are required for evaluating the cost effectiveness of projects designed to alleviate flood impacts. In 2014, IBI Group developed the Provincial Flood Damage Assessment Tool (PFDAT) for the Province of Alberta. The PFDAT enables the standardized calculation of flood damages for varying levels of inundation within a community.

Purpose and Scope

The purpose of this project is to use the PFDAT to develop community-specific damage models for different flood frequencies for the Town of Canmore. The scope is as follows:

a. Review of international best practices related to flood damage assessment.

b. Updating of residential, commercial, and industrial synthetic depth-damage curves to current economic values and local costs in Canmore.

c. Inventory of all structures located in the flood hazard area.

d. Application of the Provincial Flood Damage Assessment Tool to develop community-specific damages for different flood frequencies.

e. Preparation of a final risk assessment report for each community describing direct and indirect damage for various flood frequencies.

Best Practices Review

As part of the Provincial Flood Damage Assessment Study of 2015, IBI Group researched industry best practices related to flood damage assessment and provided a comprehensive summary of the findings. Best practices were identified and incorporated into the approach and project deliverables for the aforementioned project. Since that time the study team has continued to research and refine the methodologies, with particular emphasis on the monetization of intangible impacts, as well as indirect damages related to the cost of business interruption and residential dislocation. For the latter, additional damage functions have been developed that have been incorporated into the PFDAT model and run as stand-alone routines/outputs. Further analysis of the literature indicates that these refinements to the Provincial model are on the leading edge of best practices worldwide.

Methodology

Direct Damages

Damages for residential, commercial, and industrial units are estimated employing the updated synthetic depth-damage curves developed for general usage in Alberta in combination with community-specific property and flood elevation data.

The base of the property data is GIS building polygons provided by the Town. The area of these polygons was adjusted to reflect finished space and each building was coded for use class, structure type, presence of basement or underground parking, main floor elevation from grade, and elevation of grade at the building.

The source of flood elevation data for the Canmore study was the Canmore Flood Risk Mapping Study produced by W-E-R AGRA Ltd. in March, 1993. GIS cross-sections and bare-earth DEM elevations were provided by Alberta Environment and Parks. Golder Associates prepared flood elevation surfaces and inundation extent polygons for the purposes of damage estimation.

Indirect Damages

Indirect damages are additional costs beyond the physical damage to property that arise as a result of flooding. This includes residential displacement and business interruption. There is also an increasing awareness of the severity of intangible costs such as stress, anxiety, and community disruption. These costs have typically been acknowledged and applied as a percentage of direct damage. For this study, additional depth-damage functions were created for business interruption and residential displacement. Intangible costs were assigned per household with direct damage based on the results of willingness-to-pay studies.

Town of Canmore

Background

The Town of Canmore is located approximately 80 km west of Calgary in the Bow Valley of Alberta's Rocky Mountains. Canmore has been built up around the Bow River and Policeman's Creek, with a large portion of downtown Canmore and many residential buildings situated in the flood fringe. There are also a number of smaller mountain streams and creeks such as Cougar Creek that flow through Canmore that have caused damage to the town in the past.

History of Flooding

In recent years, Canmore has not experienced major flooding from high water on the Bow River. In 2013, Canmore was at the epicentre of an intense rain storm that overwhelmed tributaries. The majority of damage in Canmore in 2013 was caused by flooding of Cougar Creek, a steep mountain creek, which feeds into Canmore from the mountains to the northeast. Most of the damage on Cougar Creek was caused by debris flood on the alluvial fan where development had occurred over recent years.

The central area of Canmore is built on the low-lying floodplain between the Bow River and Policeman's Creek. Basement flooding due to the high water table in this area is an ongoing issue and the Town has implemented development regulations to prevent new buildings with space below the 1:100-year high groundwater level.

Floodplain Mapping

The 1993 Study mapped only the design-level flood (1:100-year). For the purposes of this study, inundation mapping was created to show areas where the flood elevation was higher than grade. The flood elevation was obtained by extending the 1993 cross sections and producing a surface between them. The grade elevation was obtained from the bare-earth digital elevation model provided by Alberta Parks and Environment. The results of this mapping is contained in **Appendix E**. The areas of inundation are determined by elevation only and do not consider existing mitigation, such as dykes.

Inventory of Buildings

Within the entire Canmore study area 1,456 buildings were classified (excluding accessory buildings such as garages and sheds). Of these, 1,268 were houses (single-family, duplex, townhouse, or mobile home). Only 7 were classified as apartment buildings. There were 182 non-residential buildings.

Damage Estimates

The flood damage estimates reflect total potential damages for the various return periods. Total damages are calculated based on flood elevations throughout the study area and do not account for mitigation measures in place. Canmore has protective dykes on both sides of the Bow River, as well as a controls at Policeman's Creek.

Mapping the flood elevations with the current ground elevation reveals that flooded areas are either directly connected to the water in the main channel or isolated. Isolated areas are those in which the flood elevation is modeled to be higher than the ground but there is no direct connection to the main body of water in the river channel. This could be behind a berm or just an area of lower elevation than surrounding lands. Unless isolated due to river and stormwater protections, these areas are subject to flooding as they are below the water level in the river and may flood from the stormwater system and/or not drain stormwater received.

Four zones were identified by mapping the flood elevations. These zones are illustrated in **Exhibit 1**. Zone 1 comprises all the flooding that is contiguous with the water in the main river channel. The other three zones are isolated from the main river channel within each reach. Zone 2 is the area behind the dyke on the west side of the Bow River. The map indicates that this dyke is not overtopped at a 1:100-year flood. Similarly, Zone 3 is behind the dyke on the east side of the Bow River. Finally, Zone 4 comprises the lands to the east on both sides of Policeman's Creek. The downstream portions of this zone would be protected by both control of the creek's inflow and the southern portion of dyke along the east bank of the Bow River.

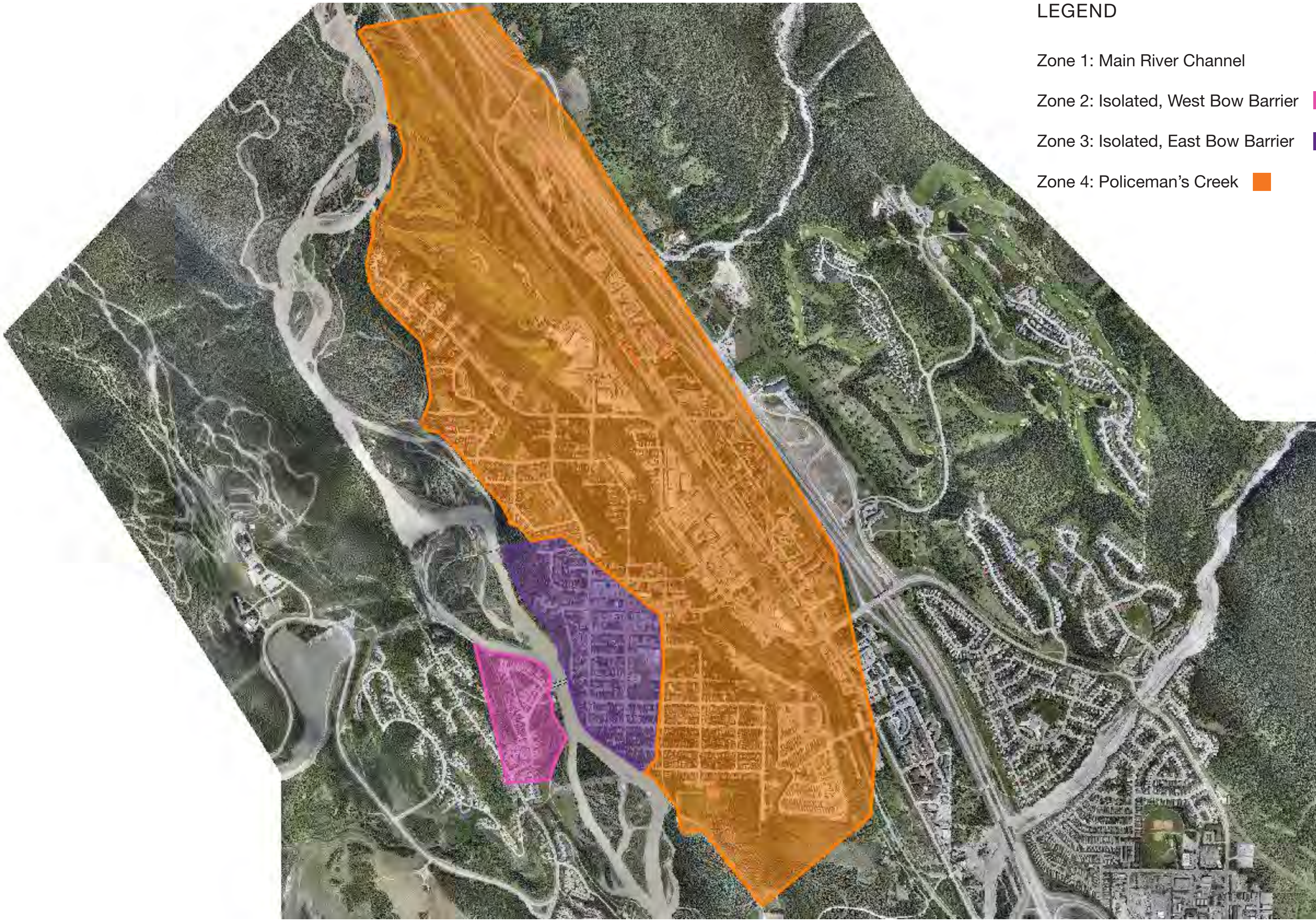
To reiterate, the potential damages were calculated based on the available flood elevations in relation to the building elevations. The zones were identified to enable assessment of each area in relation to existing or planned mitigation efforts. Detailed analysis of the effectiveness of these efforts is beyond the scope of this study.

Sewer backup or groundwater flooding is caused when the modeled flood elevation is below the ground surface, within 75 m of overland flooding, at the location of a basement. Sewer backup can occur when the river rises and enters the system or causes groundwater infiltration. High groundwater during a flood may also directly infiltrate basements through foundation walls or penetrations. Total potential damages are presented in **Exhibit 2**.

Exhibit 2: Total Flood Damages by Return Frequency

Damage Category		Return Frequency, in Years					
		2	5	10	20	50	100
Zone 1	Direct Overland	$110,000	$136,000	$167,000	$189,000	$196,000	$215,000
	Indirect Overland	$39,000	$65,000	$90,000	$103,000	$107,000	$119,000
	Direct Sewer/Groundwater	$24,000	$63,000	$174,000	$352,000	$516,000	$603,000
	Indirect Sewer/Groundwater	$6,000	$15,000	$45,000	$89,000	$114,000	$114,000
	Subtotal	$179,000	$279,000	$476,000	$733,000	$933,000	$1,051,000
Zone 2	Direct Overland	$896,000	$1,475,000	$2,349,000	$2,622,000	$7,217,000	$8,067,000
	Indirect Overland	$258,000	$365,000	$721,000	$804,000	$2,177,000	$2,391,000
	Direct Sewer/Groundwater	$85,000	$175,000	$370,000	$820,000	$154,000	$72,000
	Indirect Sewer/Groundwater	$28,000	$77,000	$133,000	$318,000	$56,000	$28,000
	Subtotal	$1,267,000	$2,092,000	$3,573,000	$4,564,000	$9,604,000	$10,558,000
Zone 3	Direct Overland	$0	$466,000	$2,021,000	$3,081,000	$11,493,000	$15,444,000
	Indirect Overland	$0	$113,000	$487,000	$845,000	$3,646,000	$4,966,000
	Direct Sewer/Groundwater	$1,111,000	$3,904,000	$7,786,000	$16,277,000	$14,412,000	$12,910,000
	Indirect Sewer/Groundwater	$373,000	$1,333,000	$2,696,000	$5,661,000	$4,628,000	$4,115,000
	Subtotal	$1,484,000	$5,816,000	$12,990,000	$25,864,000	$34,179,000	$37,435,000
Zone 4	Direct Overland	$1,287,000	$3,955,000	$8,445,000	$12,209,000	$23,808,000	$29,491,000
	Indirect Overland	$257,000	$923,000	$2,023,000	$3,081,000	$6,362,000	$7,584,000
	Direct Sewer/Groundwater	$2,396,000	$6,223,000	$13,733,000	$26,880,000	$29,011,000	$30,615,000
	Indirect Sewer/Groundwater	$656,000	$1,675,000	$3,623,000	$6,937,000	$6,786,000	$6,660,000
	Subtotal	$4,596,000	$12,776,000	$27,824,000	$49,107,000	$65,967,000	$74,350,000
Infrastructure		$395,000	$1,041,000	$2,239,000	$3,122,000	$7,368,000	$9,180,000
Flood Fighting and Emergency Response		$138,000	$362,000	$649,000	$905,000	$1,709,000	$2,129,000
Total	Direct Overland	$2,293,000	$6,032,000	$12,982,000	$18,101,000	$42,714,000	$53,217,000
	Indirect Overland	$554,000	$1,466,000	$3,321,000	$4,833,000	$12,292,000	$15,060,000
	Direct Sewer/Groundwater	$3,616,000	$10,365,000	$22,063,000	$44,329,000	$44,093,000	$44,200,000
	Indirect Sewer/Groundwater	$1,063,000	$3,100,000	$6,497,000	$13,005,000	$11,584,000	$10,917,000
	Total	$8,059,000	$22,366,000	$47,751,000	$84,295,000	$119,760,000	$134,703,000

Canmore Flood Damage Zones



LEGEND

- Zone 1: Main River Channel
- Zone 2: Isolated, West Bow Barrier
- Zone 3: Isolated, East Bow Barrier
- Zone 4: Policeman's Creek

Source:

Average Annual Damages

The average annual damage (AAD) cost from flooding is a common performance indicator used to measure the level of potential flood damages. It expresses the costs of flood damage as a uniform annual amount based on the potential damages inflicted by a range of flood magnitudes. In other words, AAD are the cumulative damages occurring from various flood events over an extended period of time averaged for the same timeframe. The average annual damage is obtained by integrating the area under the damage-probability curve which depicts total damage versus probability of occurrence.

The unmitigated total potential flood damages amount to $17 million in average annual damages. Of this, approximately $200,000 occurs within Zone 1, $1.6 million occurs within Zone 2, $4.85 million occurs within Zone 3, and $10.45 million occurs within Zone 4. Overall, sewer backup or groundwater infiltration risk accounts for $9.8 million of the total AAD.

1 Introduction

1.1 Background

Flood damage estimates are required for evaluating the cost effectiveness of projects designed to alleviate flood impacts. In 2014, IBI Group developed the Provincial Flood Damage Assessment Tool (PFDAT) for the Province of Alberta. The PFDAT enables the standardized calculation of flood damages for varying levels of inundation within a community. This is accomplished by employing three sets of data: inundation damage curves; community-specific property data; and community-specific flood elevation data.

Use of the PFDAT permits comparative benefit/cost analyses of proposed flood mitigation measures to be performed within communities for which the community models have been developed.

The original Provincial Flood Damage Assessment Study can be found at the following link:

https://open.alberta.ca/publications/7032365

1.2 Purpose

The purpose of this project is to use the PFDAT to develop community-specific damage models for different flood frequencies for three Alberta communities – the Town of Canmore, the Town of Okotoks, and the Town of Whitecourt. This analysis is concerned with the Town of Canmore.

1.3 Scope and Deliverables

a. Review of international best practices related to flood damage assessment.

b. Updating of residential, commercial, and industrial synthetic depth-damage curves to current economic values.

c. Updating of adjustment indexes for use in the three flood prone communities.

d. Inventory of all structures located in the flood hazard area (privately, government and municipal owned).

e. Application of the Provincial Flood Damage Assessment Tool to develop community-specific damage models for different flood frequencies.

f. Preparation of a final risk assessment report for each community describing direct and indirect damage for various flood frequencies.

2 Best Practices Review

As part of the Provincial Flood Damage Assessment Study of 2015, IBI Group researched industry best practices related to flood damage assessment and provided a comprehensive summary of the findings. Best practices were identified and incorporated into the approach and project deliverables for the aforementioned project. Since that time the study team has continued to research and refine the methodologies, with particular emphasis on the monetization of intangible impacts, as well as indirect damages related to the cost of business interruption and residential dislocation. For the latter, additional damage functions have been developed that have been incorporated into the PFDAT model and run as stand-alone routines/outputs. Further analysis of the literature indicates that these refinements to the Provincial model are on the leading edge of best practices worldwide.

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. However, much of the recently published work is theoretical or academic in nature. In terms of monetary damage estimation practices, the diversity of the purposes combined with difference in the availability of data and resources mean that there are many different techniques currently employed.[1]

For direct damages, the use of synthetic depth-damage curves is the standard technique within flood risk management. Object-based approaches that assess individual building characteristics and flood exposure are the state-of-the-art but require large amounts of data and effort.

The PFDAT was originally developed to read a flood elevation table based on cross-section information, or reaches (HEC-RAS). The flood depth for each building was based on an average of the two cross-section values that bound the reach it was in. Golder and IBI have since developed a more detailed methodology that can accommodate newer modelling methods and enhance the use of cross-section tables. A GIS raster surface is created to assign a flood elevation to each building independently. In combination with accurate ground elevation data, this allows for the identification of flood areas that are either contiguous with the river channel flow or isolated. The identification of isolated areas allows assessment of the value of existing mitigations and/or the importance of stormwater management. Additionally, the creation of surface files for each event means they can be clipped at a distance relative to the edge of inundation for each event for the sewer backup option.

Indirect and intangible impacts are receiving greater attention and, in some cases, shown to be as significant as direct costs.[2] Despite this, there remains very limited useful data upon which to assess indirect or intangible damages and no consensus on methodologies.[3] This leaves a conspicuous 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 requires location-specific details that are not readily transferable. 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. There are, however, some general methods available that allow for the consideration of monetized indirect and intangible impacts. The methods and the incorporation of them into the PFDAT are detailed in Sections 3.6 and 3.7.

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1 Frank Messner, Edmund Penning-Rowsel, Colin Green, Volker Meyer, Sylvia Tunstall, and Anne van der Veen, *Evaluating flood damages: guidance and recommendations on principles and methods: Floodsite Report T09-06-01*, Helmholz

2 Joseph, Rotimi, David G. Proverbs, Jessica E. Lamond, and Peter Wassell. "The Costs of Flooding on Households." *Water Resources in the Built Environment*: *Management Issues and Solutions* (2014): 249-257.

3 Melanie Gall and Sönke Kreft, "Measuring What Matters?" *A suitability analysis of loss and damage databases for the climate change convention process*, Loss and Damage in Vulnerable Countries Initiative (2013).

3 Methodology

To allow for a consistent approach to the evaluation of flood mitigation alternatives, the Province has adopted a standard methodology for flood damage assessment. It is briefly summarized hereinafter. For a more detailed description of best practices, principles and guidelines, refer to the Alberta Government Bulletin contained in **Appendix A**.

3.1 Preamble

In a flood event, direct damages can occur both to buildings and infrastructure because of the inundation (hydrostatic effects) and action of the moving water (hydrodynamic effects).

Direct flood damages to residential dwellings includes both content and structural damages as well as the clean-up costs. Flood damages for commercial properties includes damage to inventory, equipment, and buildings in addition to clean-up costs. As with the residential component, these damages are generally calculated separately for contents and structures.

The commercial structures, due to the nature, range, and diversity of business activities, do not demonstrate the same uniformity in terms of damage per unit as residential structures. Consequently, categorization is a much more complicated procedure, and the grouping of similar functions for the purposes of estimating flood damages is done in order to maintain study costs within economic reason.

In a first principles approach, damages for residential, commercial, and industrial units are estimated employing the updated synthetic depth-damage curves developed for general usage in Alberta. On an ongoing basis, curves are indexed to current values employing Consumer Price, Household Expenditure, and Construction Cost indexes ratios that allow for the conversion of the original base year values to present day values.

Flood events also cause indirect damages. These damages generally include such things as:

- Costs of evacuation.
- Alternative accommodation during the flood event.
- Loss of wages and business income due to disruption of business establishments and transportation routes.
- Administrative costs.
- Flood fighting costs.
- General inconvenience.
- Stress and anxiety.

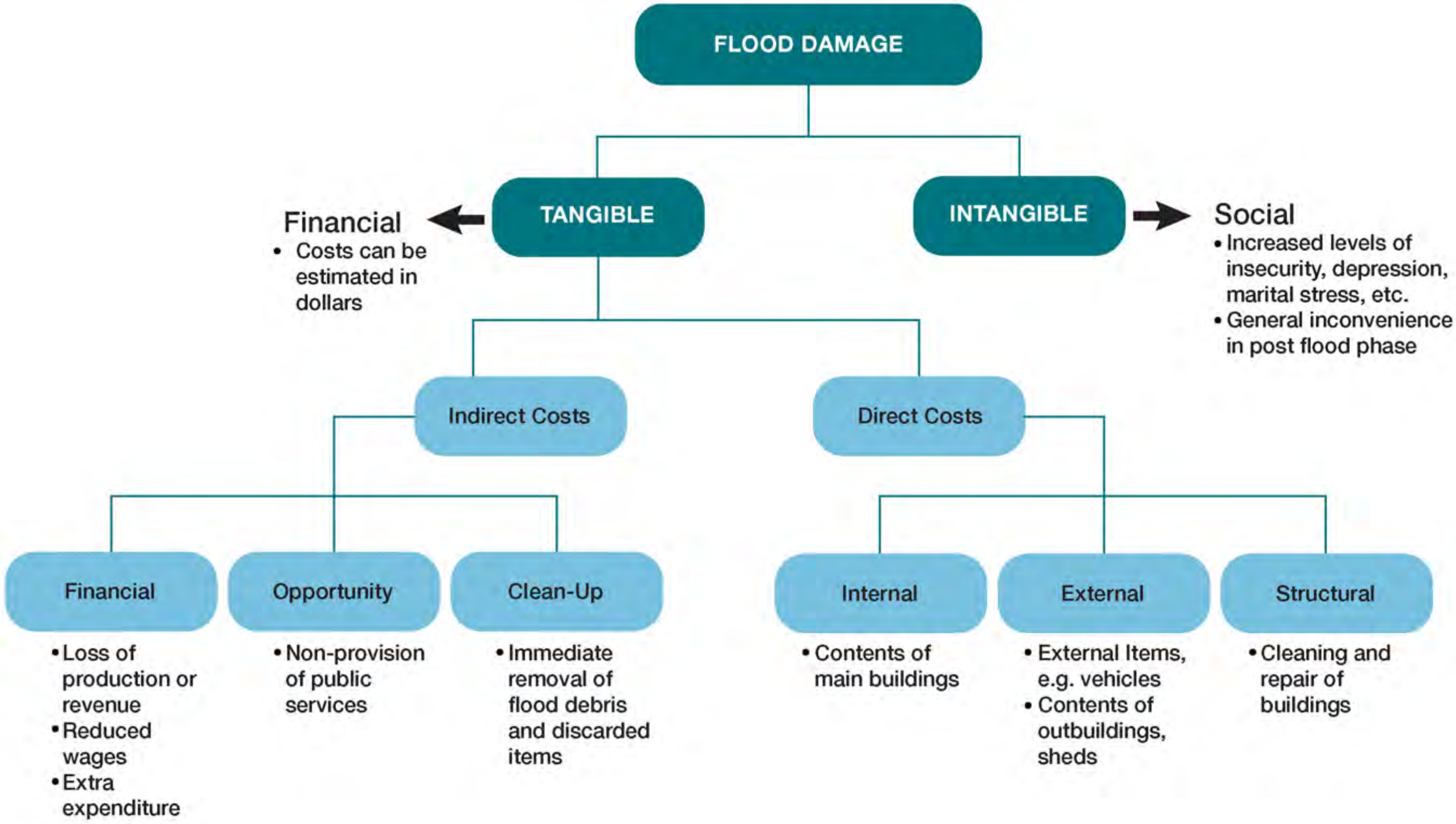
Finally, and most importantly, flooding may represent a threat to human life and well-being, not only for those residing directly within the floodplain, but also for those individuals who may work within the area as well as those volunteers and professionals who are involved in flood fighting activities (see **Exhibit 3.1**).

3.2 Flood Elevations

Flood elevations are generally obtained by one of the following methods:

- Direct measurements taken during an actual flood event.
- High watermark surveys taken after the flood peak has passed.

Types of Flood Damage



- Recorded levels at Water Survey of Canada Hydrometric stations.
- Computed by numerical computer models that have been developed to simulate flows in river and stream channels and across floodplain (overbank) areas.

The source of flood elevation data for the Canmore study was the Canmore Flood Risk Mapping Study produced by W-E-R AGRA Ltd. in March, 1993 (See **Appendix B** for the 1:100-year flood hazard mapping from that study). The following flood water level information was contained in that report:

- Water levels at individual cross-sections for the1:10 and 1:100-year floods in the Bow River, as well as the 1:100-year flood in Policeman's Creek.
- Water profiles for the 1:2, 1:5, 1:20, and 1:50-year floods.
- Average hydraulic parameters for the 1:2, 1:5, 1:10, 1:20, and 1:100-year floods.

GIS cross-sections and bare-earth DEM elevations were provided by Alberta Environment and Parks. Golder Associates prepared flood elevation surfaces and inundation extent polygons for the purposes of damage estimation. The procedure is summarized as follows:

- The cross-sections were extended, where necessary, to fully cover the study area.
- Flood water levels for the various return periods were obtained from the cross-section shapefile attribute table.
- For the Bow River, only water levels for the 1:100-year flood were available in the cross-section shapefile attribute table. The cross-sections were identified by their locations and geometries shown on the flood frequency maps. The 1:10-year flood water levels were assigned as per the flood frequency maps. The 1:100-year flood water levels between cross-sections 6 and 29 in the shapefile attribute table were different from those in the flood frequency maps. The water levels in the shapefile were used.
- The flood water levels at individual cross-sections for the other return periods (i.e., 1:2, 1:5, 1:20 and 1:50 years) were calculated by adding or subtracting an amount equal to the difference in elevation from those of the 1:100-year or 1:10-year flood which was estimated based on the hydraulic parameter values in the 1993 study report. For example, the 1:10-year flood water levels at all cross-sections were lowered by 0.2 m to obtain the estimated flood water levels for the 1:5-year flood.
- For Policeman's Creek, only the 1:100-year flood water levels were available in the cross-section shapefile and flood frequency maps. The flood water levels for the other return periods were assigned by estimating the elevation difference between the water levels of the various return periods at the two Bow River cross-sections closest to the upstream and downstream ends of Policeman's Creek. The average of the two differences in elevation was used to estimate the water levels for the other return periods based on the simulated 1:100-year flood water levels for Policeman's Creek.
- For Cougar Creek, the 1:100-year flood flow was simulated to be contained within the Cougar Creek channel and not to cause any overland flooding. Therefore, the flood water level surface was not generated for Cougar Creek.

3.3 Floodway/Flood Fringe

The accompanying exhibits (see **Exhibit 3.2** and **Exhibit 3.3**) describe the criteria employed in defining the floodway/flood fringe and adjacent-to area. The floodway is typically defined as the area of deepest and fastest flows, with the flood fringe being that area within the overall floodplain which may suffer only shallow flooding and consequently may accommodate development with the provision that floodproofing measures are implemented.

Exhibit 3.2: Aerial View of Flood Hazard Area

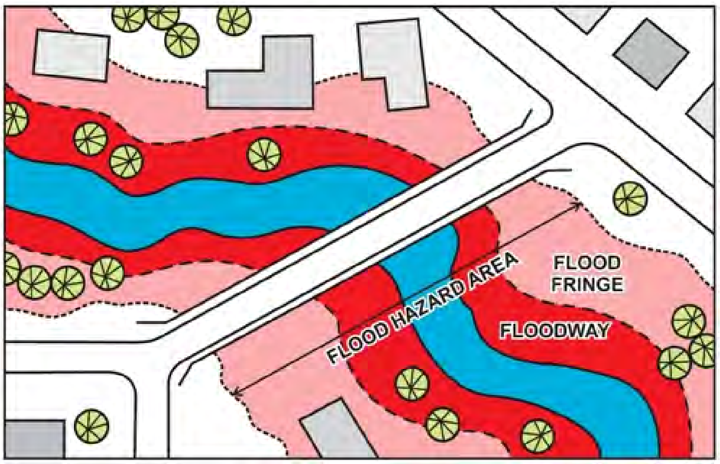
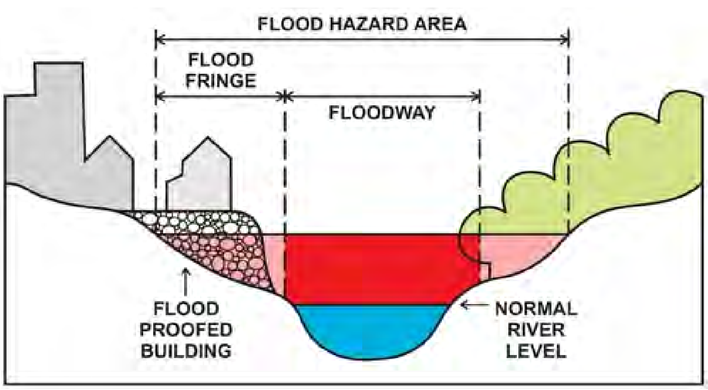


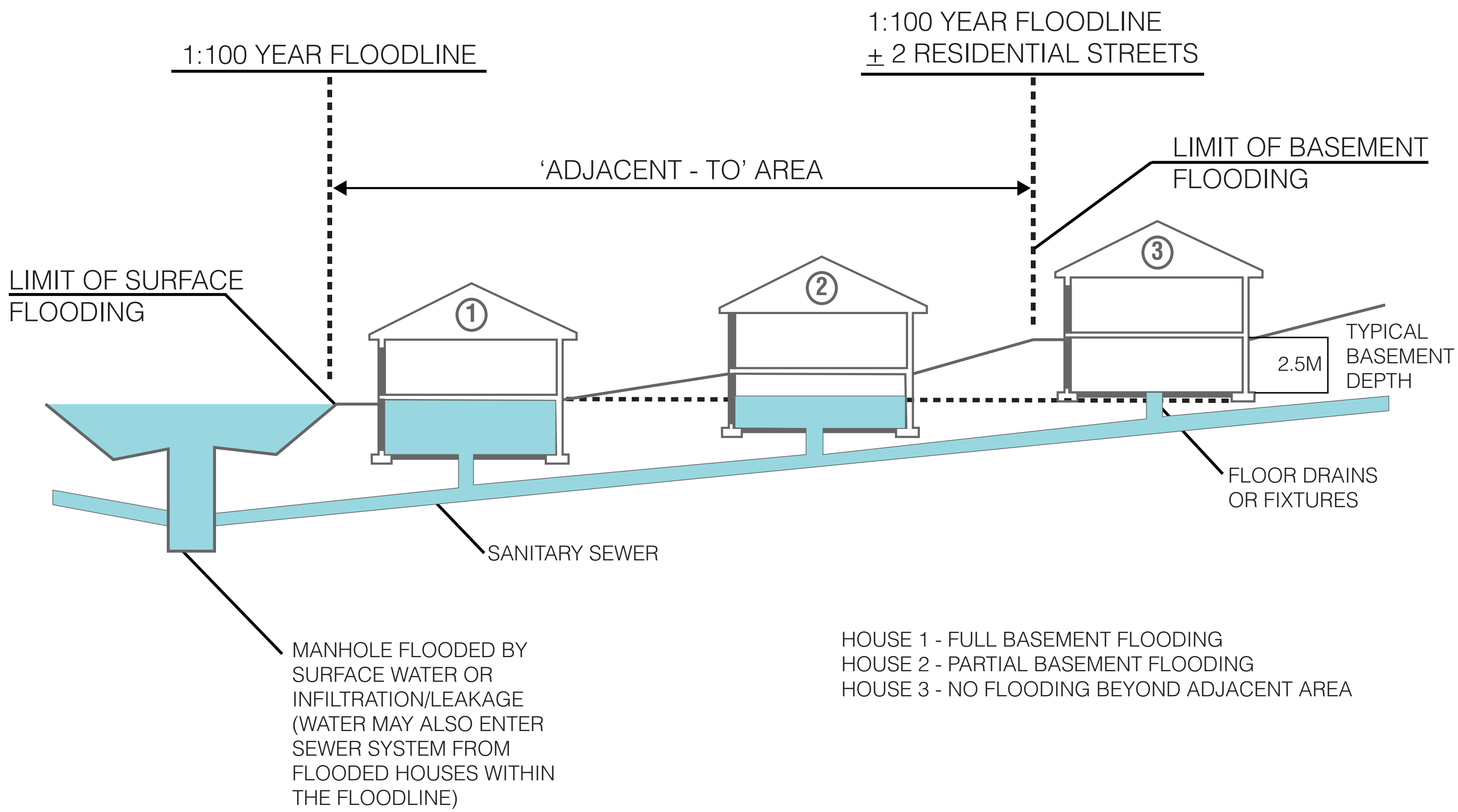
Exhibit 3.3: Cross-Section of Flood Hazard Area



3.4 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 overland inundation edge for each return period. Essentially, with the sewer backup condition, basements with floor elevations lower than the floodwaters will automatically suffer damages. **Exhibit 3.4** depicts this relationship.

Adjacent-To Area Definition Diagram



HOUSE 1 - FULL BASEMENT FLOODING
HOUSE 2 - PARTIAL BASEMENT FLOODING
HOUSE 3 - NO FLOODING BEYOND ADJACENT AREA

THE 'ADJACENT - TO' AREA IS THE AREA ADJOINING THE FLOODED SURFACE AREA IN WHICH BASEMENTS MAY BE FLOODED BY BACKED UP SANITARY SEWERS

3.5 Direct Damage Estimates

For the purposes of computing direct damage estimates for the study area all residential, commercial, industrial, and institutional structures within the identified flood hazard area are inventoried and damages computed employing the Provincial Flood Damage Assessment Tool (PFDAT) developed specifically for Alberta. The inventory was compiled using a combination of GIS mapping, assessment data, and field verification described below.

3.5.1 Creation of the Building Inventory

Along with the depth-damage functions and flood elevation table, the building inventory is one of the major inputs for the PFDAT program. In addition to location and identifying attributes, the building inventory must, at a minimum, contain the following information for each building or parcel to be assessed:

- Use classification.
- Structural classification.
- Main floor area.
- Presence of basement or underground parking.
- Main floor elevation relative to grade.
- Elevation of grade at building.

3.5.1.1 Data Sources

Building footprint polygons and a 2013 orthophoto were obtained from the Calgary Regional Partnership's Open Data website. The Town of Canmore provided additional parcel shapefiles that contained the land use, number of titled units, assessed values, and gross square footage.

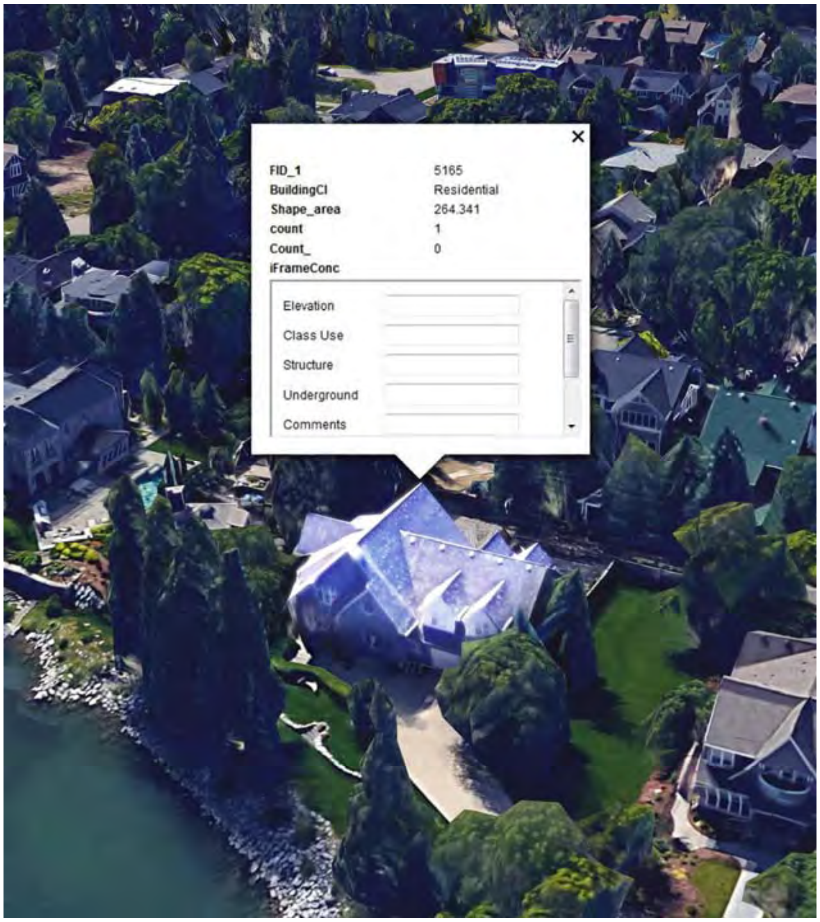
Additional building information was obtained using Google Earth street view and internet searches. A site visit was also undertaken in Canmore to verify data and assess buildings that were not visible using other methods.

3.5.1.2 Populating the Inventory Fields

First, the building footprint polygon layer was trimmed to the study area extent. Easily identifiable small accessory buildings or other not applicable structures were then removed. The costs for detached garages or other small accessory buildings such as tool sheds are built into the damage function for primary residential buildings. A new centroid point layer was created from the remaining building polygons, retaining the original shape's area as an attribute.

To facilitate the visual classification of buildings, IBI Group has developed a tool that allows entry of building attributes directly from Google Earth. The shapefile was converted to a KML file for importing into Google Earth Pro. In that file, one of the fields contains HTML code that creates a popup portal with the required fields when a user clicks on a building. The Google Earth tool is illustrated in **Exhibit 3.5**.

Exhibit 3.5: Building Classification Tool in Google Earth



The following fields were used for this study:

- *Elevation*: the height of the main floor from grade.
- *Class*: the use according to depth-damage curves. (See **Appendices C & D.**)
- *Structure*: the structure type according to the depth-damage curves.
- *Number of units*: the total number of residential dwelling units on the main and upper floors. This is used for the residential displacement function when a unit count is not available from assessment data.
- *Number of storeys*: the number of commercial floors. This is used for the business interruption function.
- *Basemen*t: Yes or No for the presence of a basement or underground parking.
- *Comment*s: this is for special notes relating to the building, such as the need for field verification. Some buildings were obscured or otherwise difficult to assess in this manner due to trees or shrubs, locations behind other buildings or on private roadways, or construction activity.
- *Reduction factor*: this value is to reconcile the areas of the building polygons with the building use areas that the damage curves were based on. The building polygons were created from aerial imaging and are thus not truly a 'footprint'. They would represent the roof coverage, including attached garages or carports.

Each building record was populated using street view. A map of properties that required physical verification was created to guide a physical survey and verification of buildings.

In addition to the identification of any necessary size reduction due to attached garages or other roof structures, the polygons for residential buildings with eaves were further reduced in GIS to account for that area of the shape that is not part of the building area. Adjusted building polygons were determined to be the best source of building area because a main floor area could not reliably be obtained from the gross floor areas in the tax assessment data. The main reason gross floor area could not be used is that multi-storey buildings in Canmore do not have a consistent distribution of floor area over each level. In other words, the main level area of a two-storey building is not half of the gross area.

3.5.1.3 Verification and Challenges

Throughout the process of creating the inventory, several challenges were encountered. These were primarily related to data accuracy and Canmore's unique variety of building styles.

In recent years, Canmore has experienced a high rate of redevelopment within the study area. The date of the imagery used to create the building polygons is unknown, but a number of parcels have been redeveloped since that time. Where a discrepancy is noted, the building area needed to be manually estimated via GIS. **Exhibit 3.6** illustrates an example of a redevelopment not represented in the GIS data set.

Exhibit 3.6: Example of a Redevelopment Not Represented in the GIS Data Set

Applying standardized structural classifications to all buildings in Canmore is challenging. The town has many unique building styles, particularly in terms of elevations. The town has restricted new construction according to a 1:100-year ground water elevation. Therefore, many new buildings do not have basements and the main floor is elevated above garages and other utility space. Examples of elevated buildings are shown in **Exhibit 3.7**. Extra time verifying and adjusting elevations and areas was required.

Exhibit 3.7: Examples of Elevated Buildings

3.5.2 Updating Stage-Damage Curves to 2016 Values

All synthetic depth-damage curves were updated to 2016 economic values using IBI Group's flood-specific methodology. As part of the 2015 Provincial Flood Damage Assessment Study, custom indexes were developed in recognition that existing commonly employed indexes were not sufficient to account for the specific type of damages caused by residential flooding. This custom index uses the Survey of Household Spending (SHS) to capture changes in content value more realistically than the Consumer Price Index (CPI), which measures goods of unchanging quality.

The original depth-damage curves were created using 2014 prices (see **Appendix D**). The SHS is annual but current-year results were not available. The 2015 survey was released January 27 2017[4]. The Alberta values from this survey were used to update the residential content damages. Specific spending categories were weighted according to the distribution of contents that comprise the depth-damage curves. Non-residential content values were adjusted using the CPI special aggregate "Goods" for Alberta.[5]

Structural curves were updated using current construction price indexes specific to the type of building, accounting for price changes in materials, labour, overhead and profit. Construction price indexes are published quarterly by Statistics Canada and currently available to the end of 2016. For both residential (building only) and non-residential construction, the Calgary price indexes indicate a reduction in costs compared to 2014.[6]

3.5.3 Updating Adjustment Indexes by Location

In addition to changes in time, there are regional variations across Alberta markets. Accordingly, IBI Group developed a spatial index for adjusting flood-specific residential contents costs throughout the Province. As with the adjustments between years, a flood-specific "basket of goods" and weighting were used.

Government of Alberta Treasury Board and Finance publish the Alberta Spatial Price Survey approximately every five years. The most recent survey was released in November 2016 containing prices from the spring of that year. The study compares the price of various goods across Alberta communities with a methodology similar to how the CPI compares goods across time. Canmore is one of the communities surveyed and the results from Calgary and Canmore were weighted and then indexed to produce a multiplier.

4 http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=3508
5 Statistics Canada Table 326-0021 Consumer Price Index, annual
6 Statistics Canada Table 327-0044 Price indexes of apartment and non-residential building construction, by type of building and major sub-trade group, quarterly & Table 327-0056 New housing price index, quarterly

Construction costs also vary between locations based on labour markets and material availability. However, there are no regularly published surveys for Alberta communities. Structural damages were adjusted according to the latest location factors from available sources including Alberta Infrastructure, the Alberta Disaster Recovery funding formula[7], and IBI Group's extensive industry experience in Alberta.

Exhibit 3.8 summarizes the combined spatial and temporal indexes used to apply the 2014 Calgary depth-damage curves to Canmore.

Exhibit 3.8: Canmore Indexes

Category	Index
Residential Contents	1.1042
Non-Residential Contents	1.0677
House Structure	1.1153
Apartment Structure	1.1373
Office Structure	1.1177
Retail Structure	1.1204
Industrial Structure	1.0982
Institutional Structure	1.0982

3.5.4 Infrastructure Damages

Infrastructure damages (such as highways, bridges, railroads, and utilities) are typically determined by the Municipality, or alternatively, a percentage of direct damages applied to represent potential damages to infrastructure. Without information on specific infrastructure risks, a value of 15% of direct overland damages was used for this study.

3.6 Indirect Damages

Indirect damages include such things as costs of evacuation, employment losses, administrative costs, net loss of normal profit and earnings to capital, management and labour, and general inconvenience. Indirect damages are best evaluated by developing a checklist of potential effects and methodically assessing each one. The checklist would logically include the amount of use and the duration of interruption of transportation and communication facilities, the number of workers and farmers depending on closed plants and the amount of business lost through a flood emergency. The magnitude of each effect may be estimated by interviewing those affected during recent floods and unit economic values may be assigned by market analysis, accounting for substitution and transactions that are merely delayed. Finally, the results may be summed to render a total value for indirect damages.

The complexity of the above evaluation process has led agencies to estimate indirect damages from direct damages based on percentages of direct damages. The ratios are chosen based on a review of the literature, empirical evidence, and expert opinion. For indirect damages that are associated with buildings, such as business disruption and residential displacement, another approach is to develop synthetic depth-damage curves.

[7] https://www.alberta.ca/estimated-residential-construction-cost.cfm

3.6.1 Loss as a Percentage of Direct Damages

Values can range from 10% to 45% for specific land use categories but are commonly calculated as being 20% of direct damages. The Canada-Saskatchewan Flood Damage Reduction Program uniformly applied an indirect damage calculation of 20% of all categories (combined) of direct damages. This figure is in keeping with guidelines developed by the U.S. Soil Conservation Services who in the past suggested the following ranges for indirect damages:

- Agricultural 5% to 10%
- Residential 10% to 15%
- Commercial/Industrial 15% to 20%
- Highways, Bridges, Railroads 15% to 25%
- Utilities 15% to 20%

3.6.2 Business Disruption Damage Curves

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

The major indirect loss results from disruption of business activities during the flood and restoration process. Estimating these tangible damages is described in the following sections. Other factors that may contribute to business losses are variable, such as the cost of loans vs. relief funds, or the relationship of the business to the specific location (foot traffic and attractions, among others) or to other affected services and suppliers.

3.6.2.1 Loss as Function of Productivity and Duration

Monetary business disruption losses can be 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 profits. Sales, profits, and expenses are components of value added, which is a better measure for the net of flows in a company[8].

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[9]. Labour productivity is the ratio between an industry's value added and hours worked. It thus allows loss to be measured by duration.

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 in response to 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

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8 FEMA, *Hazus-MH Technical Manual.*

9 Frank Messner, Edmund Penning-Rowsel, Colin Green, Volker Meyer, Sylvia Tunstall, and Anne van der Veen, *Evaluating flood damages: guidance and recommendations on principles and methods: Floodsite Report T09-06-01*, Helmholz Unweltforschungszentrum (UFZ), 2007.

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[10].

While the estimate based on the labour force survey is informative, it does not provide a readily repeatable method and may not accurately reflect actual loss. Offices do not operate like a factory and the temporary closure of offices would not cause shutdown of related production. Using only the hours from such a survey does not consider time made up or work otherwise caught up after the flood. On the other hand, small businesses such as retail and restaurants that suffered direct inundation of their buildings would certainly experience loss for a greater period of time than the survey would capture.

With productivity and restoration time assumptions detailed below, a business interruption depth-damage curve was created and applied to each commercial building in the study area.

3.6.2.1.1 Productivity Values

Statistics Canada provides hourly labour productivity per worker for various industry classifications at the provincial level.[11] 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 3.9**.

Exhibit 3.9: Daily Productivity per Square Metre

Classification		m^2 per Employee	Productivity $/hour	Operating Hours/Week	Productivity/ Day/m^2
A1	General Office	23	$52.94	45	$14.80
C7	Retail	33	$35.11	65	$9.88
I1	Restaurant	33	$23.48	80	$8.13
L1	Warehouse/Industrial	70	$66.50	65	$8.82

The General Office productivity value for Canmore was calculated as a weighted average based on the labour force composition of the town from the National Household Survey. The number of workers in each industry was multiplied by that industry's productivity value. The sum of those values was then divided by the total number of workers. Statistics Canada publishes productivity in chained base-year dollars. To express these in current dollars, the latest Implicit Price Deflator (provided quarterly).[12]

Productivity is not a measure applied to the public sector. Therefore, indirect damages associated with buildings identified as public (i.e., schools, government offices, and hospitals) should be considered as part of intangible impact evaluation.

3.6.2.1.2 Duration of Business Disruption

An effective business interruption period was estimated using the building restoration time along with assumptions about the maximum business interruption time and the percentage of partial recovery at that time.

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10 Statistics Canada publishes the productivity figures in a chained Fisher index, with 2007 as the base year.
11 Statistic Canada CANSIM Table 383-0033: Labour productivity and related measures by business sector industry and by non-commercial activity consistent with the industry accounts, provinces and territories
12 Statistics Canada CANSIM Table 380-0066 Price indexes, gross domestic product.

Building Restoration

Few methods of determining the average length of disruption have been suggested in the literature. Analysis of past events also indicates that restoration times vary greatly and are generally influenced by factors not directly attributed to flood damages such as additional improvements, changes, and pre-existing deficiencies. As with the direct damages, it is important to only consider the restoration to a previous state of operations.

One German study utilized telephone surveys among businesses in the Elbe and Danube catchments in 2003, 2004, and 2006 to determine mean interruption times. The study found that a water level of 20 cm led to a disruption of 16 days, and a depth of 150 cm led to a disruption of 59 days.[13] However, the specific types of industries surveyed in the study are unknown. In the United States, FEMA's Hazus model contains tables for flood restoration time by building type. For retail trade, depths of zero to 1.2 m of floodwater indicate a rather large range of restoration times of between seven and 13 months. As the flood depth range is rather large (1.2 m), it is assumed that a flood level of several centimetres could be recovered from in much less time. Furthermore, total reconstruction times are given and maximums range from 12 to 31 months. 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[14]. It is a simple linear function, equating to 45 days per 30 cm of water. This is a more reasonable estimate when applied to lower levels of flooding, such as a nine-day disruption for 6 cm of floodwater.

For each building type, an estimated average restoration time was determined. For standard office and retail buildings it was assumed to be 150 days per metre of flooding. Warehouse and industrial buildings were assumed to have a shorter restoration period of 100 days per metre.

Business Loss Adjustments

The actual duration of complete productivity loss is not necessarily equal to the building restoration period. A maximum business interruption time must be assumed at which point a business would have logically relocated rather than wait for an extended building restoration period. Additionally, there may be partial business recovery within the maximum interruption time. If a business' 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 loss of productivity decreases as the disruption time increases. The building disruption time variable was modified to produce a value for total business loss during the recovery process. Productivity days lost (L) for a building recovery period of n days was calculated as:

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

Where d is the maximum number of disruption days; and p is the percentage of the maximum recovered productivity. **Exhibit 3.10** illustrates the results of this method with the following assumptions for a building type:

- The maximum business interruption period (d) is 240 days.
- At 240 days, 20% of previous productivity (p) will have been recovered.

[13] P Bubeck and H Kreibich, "Natural Hazards: direct costs and losses due to the disruption of production processes." *Conhazwp1 final report*, GFZ, Helmhotz Centre Postdam, Postdam, Germany 1160 (2011).

[14] FEMA Benefit Cost Analysis Tool (v 4.5.5), 2009.

Exhibit 3.10: Building Restoration to Business Disruption Relationship

Building Restoration Days	Productivity Lost Days	Productivity/Building Loss Days
5	5	100%
151	132	87%
240	192	80%
300	192	64%

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, working remotely or at another office location. To account for this, the overall productivity loss for an office closure was reduced. In Canmore, no additional reduction due to office vacancy was considered.

In multi-storey buildings the impact on a retail business at ground level would be different than on an upper 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 that has not been directly flooded (upper floors, evacuated buildings with no damage, and parkade damage only). It is normally not feasible to classify uses in upper floors so the blended general office productivity values were used. The floor area of the upper floor was calculated by taking the gross tax assessment area and subtracting the main floor area.

3.6.2.2 Incorporation in Damage Model

The depth to productivity days lost estimates were combined with the daily productivity per square metre to create damage curves for each commercial use classification. To account for potentially different disruption times on upper floors, an additional curve is created for upper level office space. Costs associated with commercial buildings that are only evacuated (and not flooded) are not computed in the damage model.

3.6.3 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.

Residential displacement costs are not often explicitly estimated in flood damage assessments but the required assumptions are relatively straightforward. This section outlines the creation of depth-damage curves for the tangible costs of residential displacement. The intangible impact on houses is another aspect of displacement that is covered in Section 3.7.

3.6.3.1 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.

The following is an example of the assumptions made to estimate the costs per household:

- 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, and the costs associated with staying with friends and family is negligible.
- The remainder of households will spend up to 14 days in a hotel. Average daily hotel room costs are assumed to be $160.
- During the first 14 days, each individual will spend an extra $50 per day.
- The number of people per household is 2.4.[15]
- Households requiring alternate accommodation beyond 14 days will rent another unit of the same type. The average regional market rent for apartments and houses is assumed to be $1,200 and $1,800, respectively.
- A one-time moving expense of $500 per household is included for households requiring accommodation beyond 14 days.

3.6.3.2 Displacement Period

Displacement times can 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.

Data on unofficial secondary suites in Canmore was not available, but it is assumed that the majority of finished basements do not contain essential living spaces, such as kitchens, and a home with minor basement flooding will be largely inhabitable during its restoration. Basement flooding over 50 cm may affect electrical and mechanical equipment, and having an inspection completed can take longer than completing the actual repairs.

For multi-family 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. Re-entry of residents into multi-family buildings that only experienced flooded underground parking levels during the 2013 Calgary flood, ranged from a number of days to several weeks.[16]

It is recognized that as the number of buildings flooded increases, there may be issues with the availability of contractors, inspectors, and equipment. The estimated displacement duration considers the time to complete repairs plus general average expected delays including contractors, materials and equipment, and inspections for all return periods. Estimates are illustrated in **Exhibit 3.11**.

Exhibit 3.11: Estimated Average Residential Displacement Periods[17]

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
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

15 Town of Canmore 2014 Census https://canmore.ca/town-hall/census
16 IBI Group, *Provincial Flood Damage Assessment Study.*
17 Days due to underground parking and basement flooding are not added when main floor flooding occurs.

3.6.3.2.1 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 rental 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 that the full displacement costs for all households regardless of tenure was used.

3.6.3.2.2 Incorporation in Damage Model

The depth-displacement days estimates were 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, an additional curve is created for upper level units.

The damages were calculated on a per-unit basis, rather than for floor area. The total number of units in a multi-family building is not recorded in many 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 number of units was estimated during the visual classification. Costs associated with residential buildings that are only evacuated (and not flooded) are not computed in the damage model.

According to the 2014 Canmore Census, approximately 20% of residents were non-permanent. Non-permanent residents have a permanent place of residency outside of the town and are assumed to not require temporary accommodation in the event that their secondary residence is damaged. Accordingly, a 20% reduction factor was added to the residential displacement function.

3.6.4 Infrastructure Indirect Damage

Damage to infrastructure can have many secondary indirect impacts. This may include traffic delays and business loss due to interruption of services (water, electricity, gas). No object-based utilities damage model has been developed. Estimated as a percentage of direct damage, values in this category range from 10% to 25%. A value of 15% was used for this study.

3.7 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.[18] The intangible human impact of flooding is highly dependent on variables beyond the flood characteristics including an individual's prior health, income, family and community support, preparedness and experience, and a host of other social indicators or behaviours.

In 2015, The City of Calgary commenced an assessment of flood mitigations based on a Triple Bottom Line framework. This entailed an extensive literature review of intangible flood impacts and evaluation techniques. The impacts assessed included mortality, injury, disease, infection, exposure, mental health or quality of life, and environmental damage. A summary of the monetization method and the application of this value to Canmore is provided in the following section.

[18] Sue Tapsell, *Developing a conceptual model of flood impacts upon human health* (London: Middlesex University, 2009).

3.7.1 Public Health & Quality of Life

There is little evidence to characterize most intangible outcomes of specific flood events/contexts. Nonetheless, attempts have been 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 local context.

The available monetary values for all the impacts originate from various studies and contexts but in the end they are all assumptions based on willingness-to-pay surveys (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 to individually monetize impacts yielded values that were insignificant relative to the direct damages. In the simplest example, applying the recommended statistical value of life (in Canada this is approximately eight million in 2015 dollars[19]) directly to the 2013 Calgary flood, in which one person died within the city, equates to approximately 0.4% of the 1:100-year flood damage estimate. 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 this case are actually rather low.

The overall total impact on affected households, however, is obviously significant. There have been two WTP studies related to flooding conducted recently in the UK. The main objective of a comprehensive study by the Department for Environment Food and Rural Affairs on intangible effects was to determine a value to be used nationally for assessments.[20] There was also a research paper with a similar methodology published in 2015.[21]

In addition to a comprehensive 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 respondents whose residents were flooded was about £200 per household per year, or approximately $615 CAD in 2015 dollars. The 2015 study found a mean WTP value of £653 per household per year, or approximately $1,300. 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, the result 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 physical risk, worry, loss of services, community relations, or loss of enjoyment of the environment or historical assets.

To use a value from the UK is clearly a transfer in space and not Canmore-specific. However, unlike the other available data and methods which would be a transfer in at least space, scale, and/or time, this value 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. Doing so is beyond the scope of these guidelines, but the amounts can be adjusted for each at-risk community based on the available demographic data. The WTP studies include demographic

[19] Treasury Board of Canada Secretariat, *Canadian Cost-Benefit Analysis Guide: Regulatory Proposals*, (Government of Canada, 2007).
[20] Floyd, P., and S. Tunstall. "The appraisal of human-related intangible impacts of flooding." Report of Project FD (2005).
[21] Rotimi Joseph, David Proverbs, and Jessica Lamond. "Assessing the value of intangible benefits of property level flood risk adaptation (PLFRA) measures." *Natural Hazards* 79, no. 2 (2015).

profiles which, along with the evidence from the literature, can be used to make the initial judgements. Adjustments can be made according to the specific flood impact of the community. For example, two demographically similar communities may not experience equal impacts if one lost its school, community centre, and grocer to flooding while the other did not.

For Canmore, an average value of $1,000 CAD per household per household was used. For apartment households, the value was reduced to $700 for main floor units and $250 for upper floor units. This was applied to all households estimated to incur over $10,000 in direct damages. A 100-year net present value at 4% discount rate was applied to the annual value.

3.8 Total Damage Estimates

Total flood damages for each of the return floods (where available) are estimated employing the methodologies as previously described. These damages include direct damage to residential, commercial/industrial/institutional, utilities/infrastructure and highways, as well as indirect and intangible damages.

3.9 Average Annual Damages

The average annual damage (AAD) cost from flooding is a common performance indicator used to measure the level of potential flood damages. It expresses the costs of flood damage as a uniform annual amount based on the potential damages inflicted by a range of flood magnitudes. In other words, AAD are the cumulative damages occurring from various flood events over an extended period of time averaged for the same timeframe. The average annual damage is obtained by integrating the area under the damage-probability curve which depicts total damage versus probability of occurrence.

4 Town of Canmore

4.1 Background

The Town of Canmore is located approximately 80 km west of Calgary in the Bow Valley of Alberta's Rocky Mountains. Initially built on the coal mining industry, Canmore has more recently started to rely heavily on tourism as its main industry. Canmore's proximity to a number of natural parks and its abundant natural geography have made it a popular year-round tourist destination. Lending to Canmore's popularity as a tourist destination and traditional mining town are its location on the Trans-Canada Highway and the Canadian Pacific Railway. As Canmore is a popular and growing town, the construction industry also employs a significant portion of the labour force[22].

The permanent population in Canmore was 13,077, based on 2014 municipal census data, up 6.2% from its 2011 population of 12,317[23]. 2014 municipal census data indicated that the total number of dwellings at the time was 8,248.

While no permanent weather station exists in Canmore, the Kananaskis weather station is located less than 30 km away, and gives an approximation of local average climate conditions. Average summer temperatures in the area are around 14º Celsius, while average winter temperatures for the area hover around -5º Celsius[24]. Average annual precipitation in the Kananaskis area is 639 mm, with 404.6 mm falling in the form of rain, and 256.5 cm falling in the form of snow (translating to an equivalent 256.5 mm of melted precipitation)[25].

Canmore has been built up around the Bow River and Policeman's Creek, with a large portion of downtown Canmore and many residential buildings situated in the flood fringe. There are also a number of smaller mountain streams and creeks such as Cougar Creek that flow through Canmore that have caused damage to the town in the past.

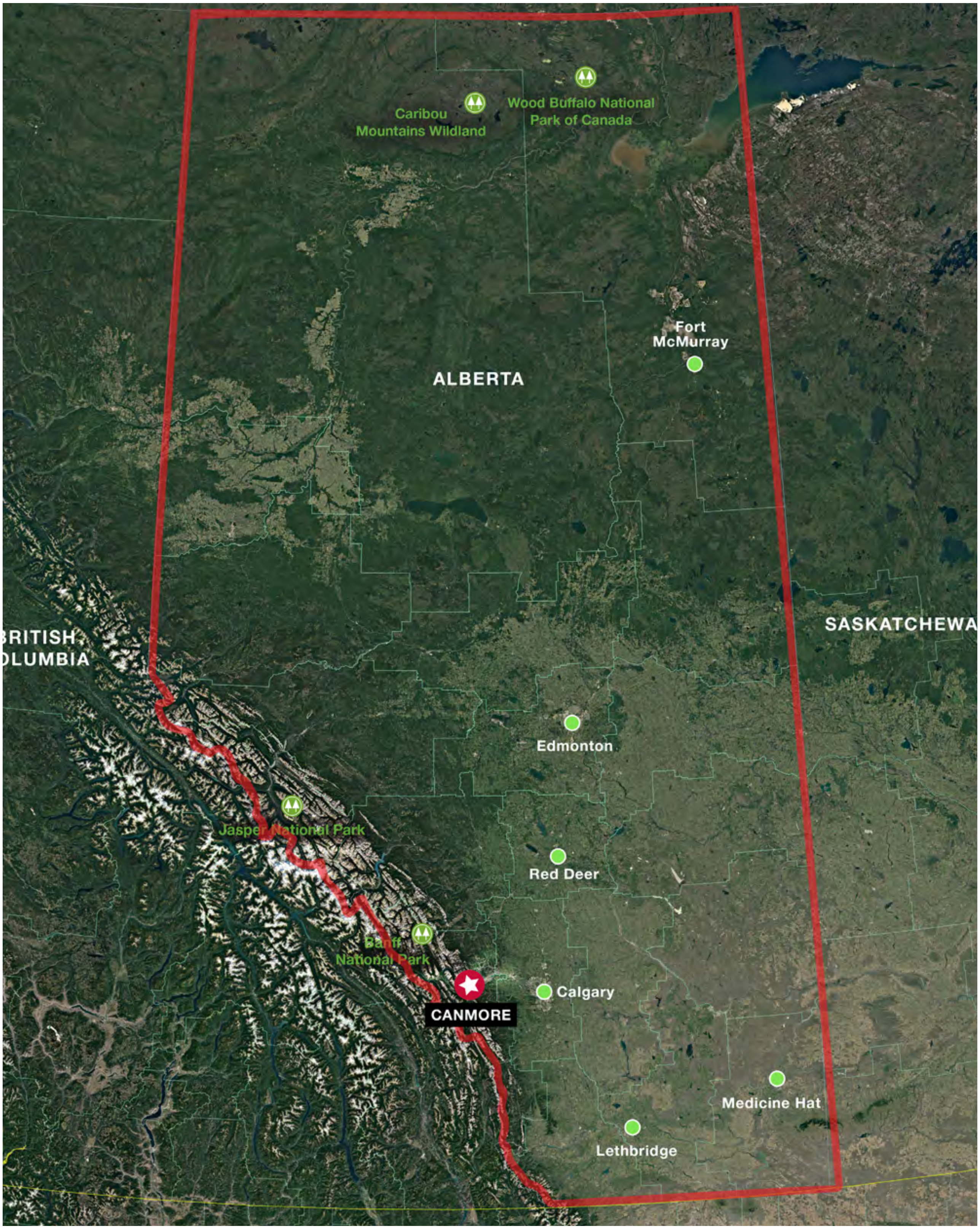
4.2 Context

Exhibit 4.1 depicts the regional setting within the Province of Alberta, while **Exhibit 4.2** locates the town in relation to the Bow River Watershed.

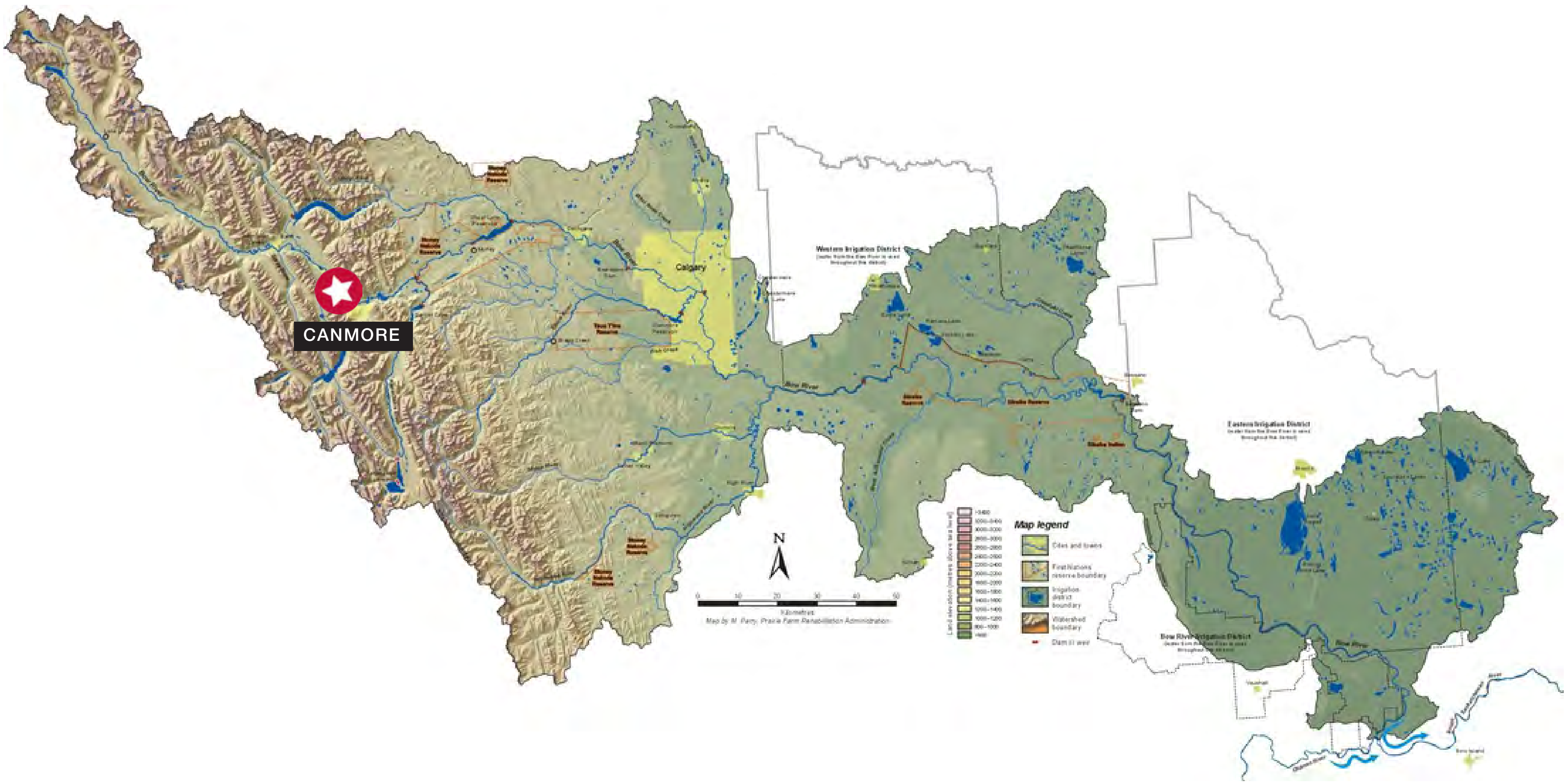
Exhibit 4.3 depicts the extent of the study area and **Exhibit 4.4** illustrates the extent of the 1:100-year flood water elevation surface. **Exhibit 4.5** illustrates the Provincial Flood Hazard Map.

22 "Town of Canmore Census," last modified 2014, http://canmore.ca/town-hall/census.
23 Ibid.
24 "Canadian Climate Normals," last modified 2016, http://climate.weather.gc.ca/climate_normals/index_e.html.
25 Ibid.

Regional Setting



Location in Bow River Watershed



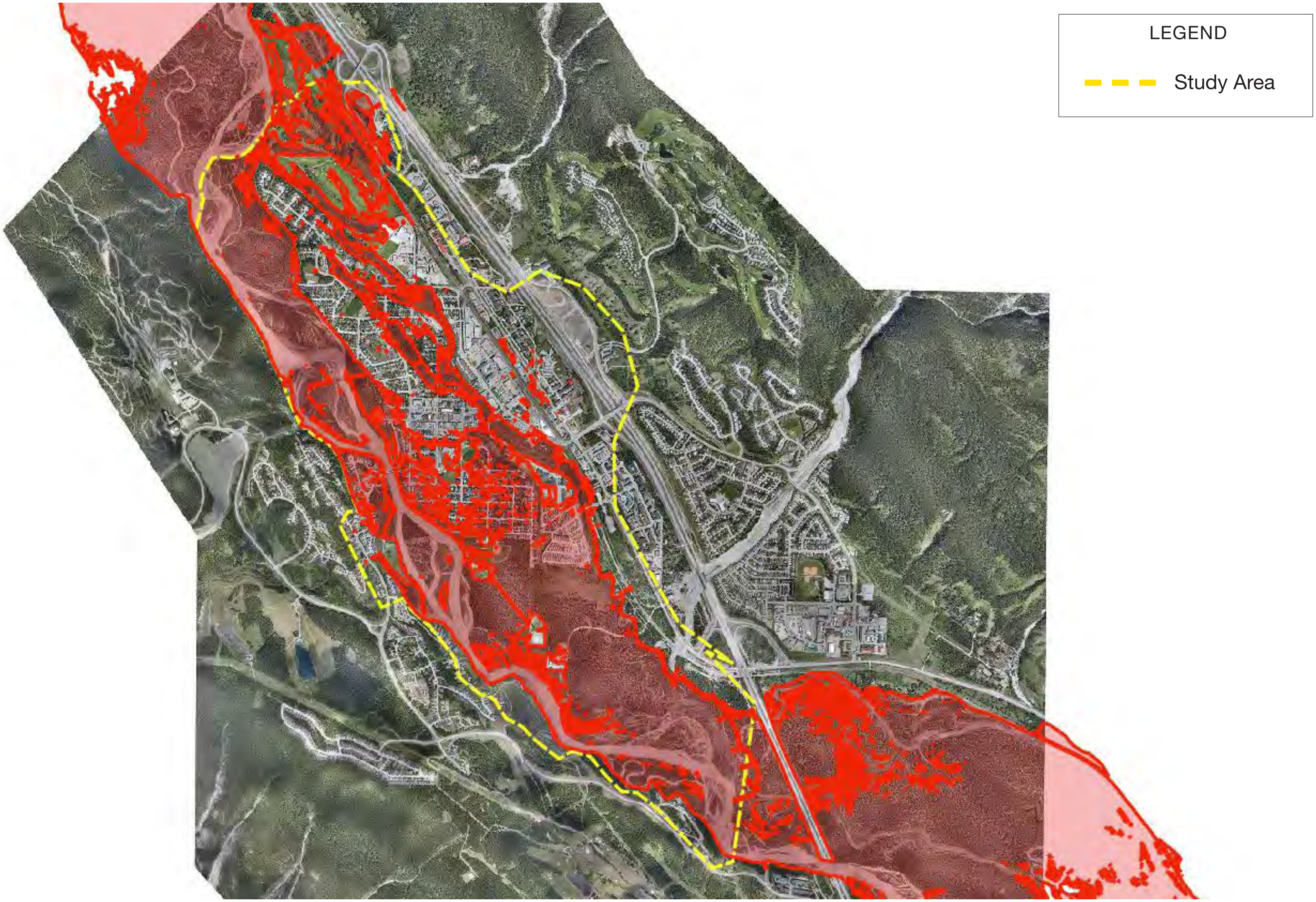
Canmore Flood Study Area - Aerial

IBI | Alberta

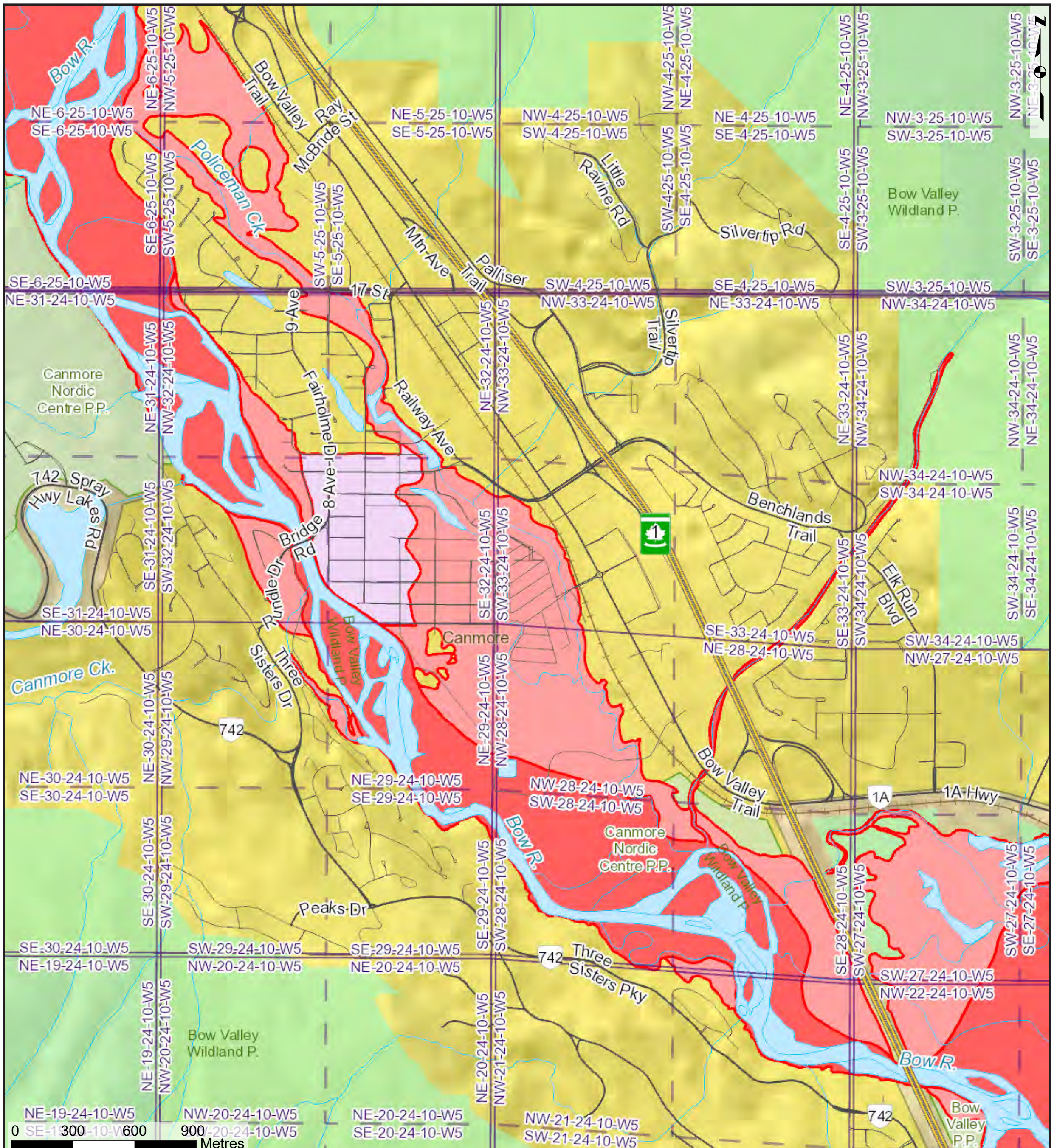
Provincial Flood Damage Assessment Study –
Town of Canmore: Damage Estimates
March 2017

EXHIBIT 4.3

Canmore 1:100-year Flood Inundation Extent



Provincial Flood Hazard Map



Legend

Floodway	Under Review	First Nation Boundary
Flood Fringe	855.09 m Cross Section and Design Flood Level	Municipal Boundary
Overland Flow (Flood Fringe)	Water Body	

Information as depicted is subject to change, therefore the Government of Alberta assumes no responsibility for discrepancies at time of use.
Cadastral data provided by Alberta Data Partnerships Ltd. (ADP)
Base Map Data provided by the Government of Alberta under the Alberta Open Government License. November, 2014
National Framework Data © Department of Natural Resources Canada. All rights reserved.
Alberta Road Network data provided by GeoBase ®
Alberta Environment and Parks

Flood Hazard Map

Projection:	Datum:
ALBERTA 10TM	NAD 83

maps.srd.alberta.ca/floodhazard/

4.3 History of Flooding

Flooding in the Bow River is caused primarily by a combination of spring rainfall and snowmelt runoff from the Rocky Mountains, with summer rainstorms having the potential to cause increases in river water levels, though to a lesser extent. High flow rates on the Bow River are most often observed in June and July.

A review by Alberta Environment of historic flood events of the Bow River in Canmore indicated that most recent flood events have peak discharges that correspond to return periods of less than five years[26]. The same review also found that ice-related flooding rarely occurs in Canmore, and that most flooding is the result of spring runoff. The Water Survey of Canada operated a hydrometric station on the Bow at Canmore from 1975 to 1985. During this period, the maximum recorded discharge was 267 m^3/s on May 25, 1981. This is less than a two-year peak flow discharge. Higher discharge values were estimated or calculated at the Banff station during the ten largest floods in Canmore, including a flood in 1923, with a discharge of 399 m^3/s. The station in Canmore was not in service during any of the ten largest floods[27]. See **Exhibit 4.6A/B** for historical flood photos.

In 2013, Canmore was cut off from neighbouring communities after experiencing flooding and associated mudslides that ended in the closure of the Trans-Canada Highway. The vast majority of damage in Canmore in 2013 was caused by flooding of Cougar Creek, a steep mountain creek, which feeds into Canmore from the mountains to the northeast. Most of the damage on Cougar Creek was caused by debris flood on the alluvial fan where development had occurred over recent years.

4.4 Floodplain Mapping

A Flood Risk Mapping Study for Canmore was conducted as part of the Canada-Alberta Flood Damage Reduction Program in 1993 (see **Appendix B**). This study was preformed to create flood risk maps for a 20 km reach of the Bow River from the Banff National Park boundary, through the Town of Canmore, to downstream of Dead Man Flats. At this time, potential groundwater flooding was not examined, with the study examining only surface flooding caused by open-water floods.

A 1:100-year flood has the potential to affect 50% of the Town of Canmore situated on the Bow River floodplain and areas adjacent to the existing dyke systems. These areas are subject to back-water and dyke breaching. The specific areas affected by the flood fringe are:

- Small portions of the floodplain along the Bow River between the Banff National Park boundary and the Canmore Golf Course.
- Large portions of the Canmore Golf Course.
- A number of buildings adjacent to Policeman Creek.
- Part of the town bounded by 9th Street on the north and 1st Street on the south and by the Bow River on the east and Policeman Creek on the west.
- The Rest Well Trailer Park.
- The portion of the town adjacent to the Rundle Canal dyke and the Mine dyke.
- Approximately 50% of the floodplain in the vicinity of the Transcanada Highway bridge.
- The Bow River and Three Sisters campgrounds.

[26] WER AGRA Ltd., *Canmore Flood Risk Mapping Study* (Canmore, 1993).
[27] ibid

Canmore Historical Flood Images - Flood of 1923

Canmore Historical Flood Images - Flood of 2013

The 1993 Study mapped only the design-level flood (1:100-year). For the purposes of this study, inundation mapping was created to show areas where the flood elevation was higher than grade. The flood elevation was obtained by extending the 1993 cross sections and producing a surface between them. The grade elevation was obtained from the bare-earth digital elevation model provided by Alberta Parks and Environment. The results of this mapping is contained in **Appendix E**. The areas of inundation are determined by elevation only and do not consider existing mitigation, such as dykes.

4.5 Inventory of Buildings

Within the entire Canmore study area 1,456 buildings were classified. Of these, 1,268 were houses (single-family, duplex, townhouse, or mobile home). Only 7 were classified as apartment buildings. Buildings with a commercial main floor and residences above were classified as according the commercial use and the residential unit count was only used for displacement costs. There were 182 non-residential buildings. **Exhibit 4.7** details the classification of the residential inventory in Canmore. As discussed, Canmore has many buildings that do not obviously fit the PFDA classification scheme. For example, some buildings with a raised main floor were classified as having basements even though the finished “basement” may be entirely above grade.

Exhibit 4.7: Residential Building Inventory Classification

Class	Total	One Storey	Two Storey	Split-Level	Basement
A	303	41	251	11	192
B	706	222	365	119	545
C	134	76	51	7	80
D	125	125	0	0	0
M	7	n/a	n/a	n/a	4

Up to the 1:100-year flood, it is primarily residential buildings at risk of overland flooding. Canmore’s commercial core has a slightly higher elevation than the surrounding lands. During a 1:100-year flood, it is estimated that 393 buildings will be impacted by overland flooding. A further 324 are at risk of sewer backup or groundwater infiltration. Residential buildings account for nearly all the estimated flood damages.

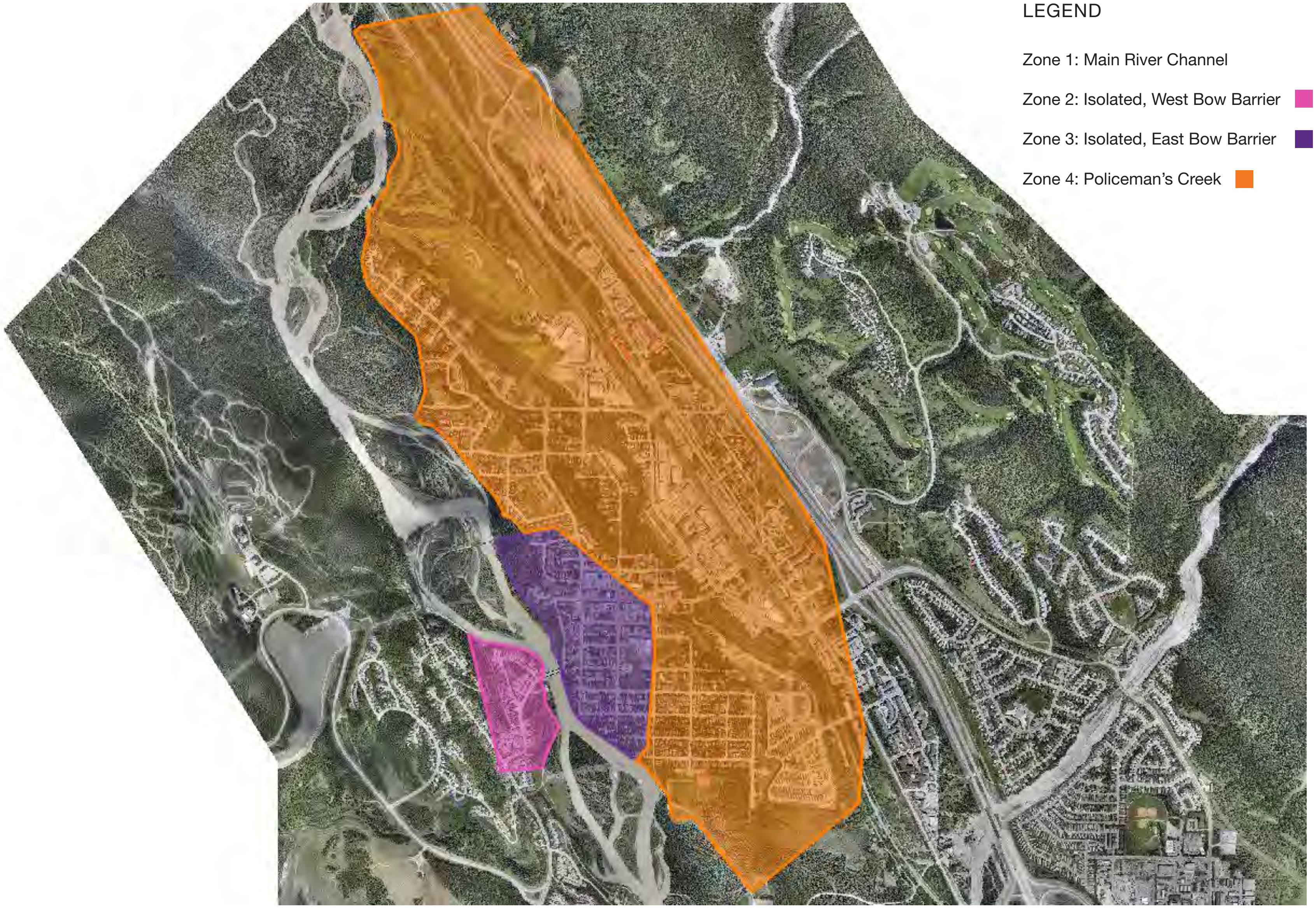
4.6 Direct Damage Estimates

The flood damage estimates reflect total potential damages for the various return periods. Total damages are calculated based on flood elevations throughout the study area and do not account for mitigation measures in place. Canmore has protective dykes on both sides of the Bow River, as well as a controls at Policeman’s Creek.

Mapping the flood elevations with the current ground elevation reveals that flooded areas are either directly connected to the water in the main channel or isolated. Isolated areas are those in which the flood elevation is modeled to be higher than the ground but there is no direct connection to the main body of water in the river channel. This could be behind a berm or just an area of lower elevation than surrounding lands. Unless isolated due to river and stormwater protections, these areas are subject to flooding as they are below the water level in the river and may flood from the stormwater system and/or not drain stormwater received.

Four zones were identified by mapping the flood elevations. These zones are illustrated in **Exhibit 4.8**. Zone 1 comprises all the flooding that is contiguous with the water in the main river channel. The other three zones are isolated from the main river channel within each reach. Zone 2 is the area behind the dyke on the west side of the Bow River. The map indicates that this

Canmore Flood Damage Zones



LEGEND

- Zone 1: Main River Channel
- Zone 2: Isolated, West Bow Barrier
- Zone 3: Isolated, East Bow Barrier
- Zone 4: Policeman's Creek

Source:

dyke is not overtopped at a 1:100-year flood. Similarly, Zone 3 is behind the dyke on the east side of the Bow River. Finally, Zone 4 comprises the lands to the east on both sides of Policeman's Creek. The downstream portions of this zone would be protected by both control of the creek's inflow and the southern portion of dyke along the east bank of the Bow River.

To reiterate, the potential damages were calculated based on the available flood elevations in relation to the building elevations. The zones were identified to enable assessment of each area in relation to existing or planned mitigation efforts. Detailed analysis of the effectiveness of these efforts is beyond the scope of this study.

Sewer backup or groundwater flooding is caused when the modeled flood elevation is below the ground surface, within 75 m of overland flooding, at the location of a basement. Sewer backup can occur when the river rises and enters the system or causes groundwater infiltration. High groundwater during a flood may also directly infiltrate basements through foundation walls or penetrations.

4.6.1 Overland Flooding

Direct flood damages by return period are detailed in **Exhibit 4.9**.

Exhibit 4.9: Direct Overland and Isolated Damages

Damage Category		Return Frequency, in Years					
		2	5	10	20	50	100
Residential	Direct Zone 1	$0	$0	$0	$0	$0	$0
	Direct Zone 2	$896,000	$1,475,000	$2,349,000	$2,622,000	$7,217,000	$8,067,000
	Direct Zone 3	$0	$466,000	$2,021,000	$3,081,000	$11,493,000	$15,444,000
	Direct Zone 4	$1,287,000	$3,948,000	$8,417,000	$12,172,000	$23,747,000	$29,403,000
	Subtotal	$2,183,000	$5,889,000	$12,787,000	$17,875,000	$42,457,000	$52,914,000
Non-Residential	Direct Zone 1	$110,000	$136,000	$167,000	$189,000	$196,000	$215,000
	Direct Zone 2	$0	$0	$0	$0	$0	$0
	Direct Zone 3	$0	$0	$0	$0	$0	$0
	Direct Zone 4	$0	$8,000	$28,000	$36,000	$61,000	$88,000
	Subtotal	$110,000	$144,000	$195,000	$225,000	$257,000	$303,000
	Total	$2,293,000	$6,033,000	$12,982,000	$18,100,000	$42,714,000	$53,217,000

Total potential overland damages for both isolated and inundated areas for the 1:100-year flood amount to $53 million. As indicated, there are no overland inundation damages for residential properties in Zone 1, outside the isolated areas. Non-residential damages in this zone are also limited to some utility buildings.

Modeled elevations indicate damages for the more frequent events are occurring at the southeast corner of the study area adjacent to Policeman's Creek in Zone 4. Additionally, properties behind the existing barriers along the Bow River in Zones 2 and 3 would be at considerable risk if these barriers were not in place or not supplemented with stormwater controls.

4.6.2 Sewer Backup/Groundwater Flooding

Damages due to sewer backup and/or groundwater flooding are detailed in **Exhibit 4.10.**

Exhibit 4.10: Direct Sewer Backup/Groundwater Damage

Damage Category		Return Frequency, in Years					
		2	5	10	20	50	100
Residential	Direct Sewer/Groundwater	$34,306,000	$38,200,000	$40,815,000	$40,677,000	$37,176,000	$35,129,000
Non-Residential	Direct Sewer/Groundwater	$1,854,000	$3,261,000	$3,311,000	$3,653,000	$6,917,000	$9,070,000
	Total	$36,159,000	$41,461,000	$44,127,000	$44,330,000	$44,093,000	$44,199,000

Despite the redevelopment of many properties above the estimated 1:100-year groundwater level, significant flood potential remains. The sewer backup/groundwater flooding condition from higher frequency events is projected to cause considerable damage, and at the 1:2 year and 1:5 year return periods constitutes 94% and 87% of total damages respectively. For buildings with basements, this result assumes typical finishing and damages for those units within the flood hazard area without adjustments. In other words, no allowance is made for actual use or employment of sump pumps and backflow preventers.

High groundwater levels is a known issue within the study area. Anecdotally, it has been reported that basements within the Canmore flood hazard area start flooding at 240 m^3/s, which is actually below the 1:2 year return period.[28] The Town of Canmore has produced estimates of 1:100-year groundwater elevations as part of the development guidelines. These elevations are indicated on **Exhibit 4.11**. The modeled groundwater surfaces for this study were found to be consistent with this information for the 1:100-year flood event. .

Properties affected by the more frequent floods are likely to have implemented protective or adaptive measures. For example, a recent survey (April, 2016) commissioned by the City of Calgary found that 50% of households at risk of flooding had sump pumps, 27% had a backup generator, and 29% had some form of private flood mitigation measure.

More research is required to determine the incidence of sewer backup and/or groundwater flooding. However, the results of the sewer backup model indicate that the Town's development restriction has the potential to mitigate a substantial amount of damages over time.

When considering mitigation measures, it will be prudent to survey residents and businesses within the flood hazard area to determine incidence of flooding and damages, along with measures employed to ameliorate the damages. Average annual damages should be adjusted accordingly prior to benefit/cost analysis of potential mitigation alternatives.

For the purposes of this study, a second scenario is presented with reduced groundwater damages for the more frequent events to reflect an assumed level of mitigation or adaptation. The 1:2, 1:5, and 1:10-year groundwater damages were reduced by 90%, 75%, and 50% respectively, as indicated in **Exhibit 4.12**.

Exhibit 4.12: Adjusted Sewer Backup/Groundwater Damages

Damage Category		Return Frequency, in Years					
		2	5	10	20	50	100
Residential	Direct Sewer/Groundwater	$3,431,000	$9,550,000	$20,408,000	$40,677,000	$37,176,000	$35,129,000
Non-Residential	Direct Sewer/Groundwater	$185,000	$815,000	$1,656,000	$3,653,000	$6,917,000	$9,070,000
	Total	$3,616,000	$10,365,000	$22,063,000	$44,330,000	$44,093,000	$44,199,000

It is important to note that the Sewer/Groundwater damages include only properties with a modelled flood elevation and finished space below grade. If a building in Zone 2, for example, had a modeled flood elevation above grade the damages would be calculated at that grade and presented as overland isolated flooding. If, however, that building was protected from overland flooding by a dyke, it may not actually receive overland damages but it would still be a risk for sewer backup or groundwater flooding. The effects of hydraulic pressure of high water against a dyke on groundwater levels behind it have not been modeled for this location.

[28] Sandford, Robert William, and Kerry Freek. *Flood forecast: climate risk and resiliency in Canada*. Rocky Mountain Books Ltd, 2014. pg. 34

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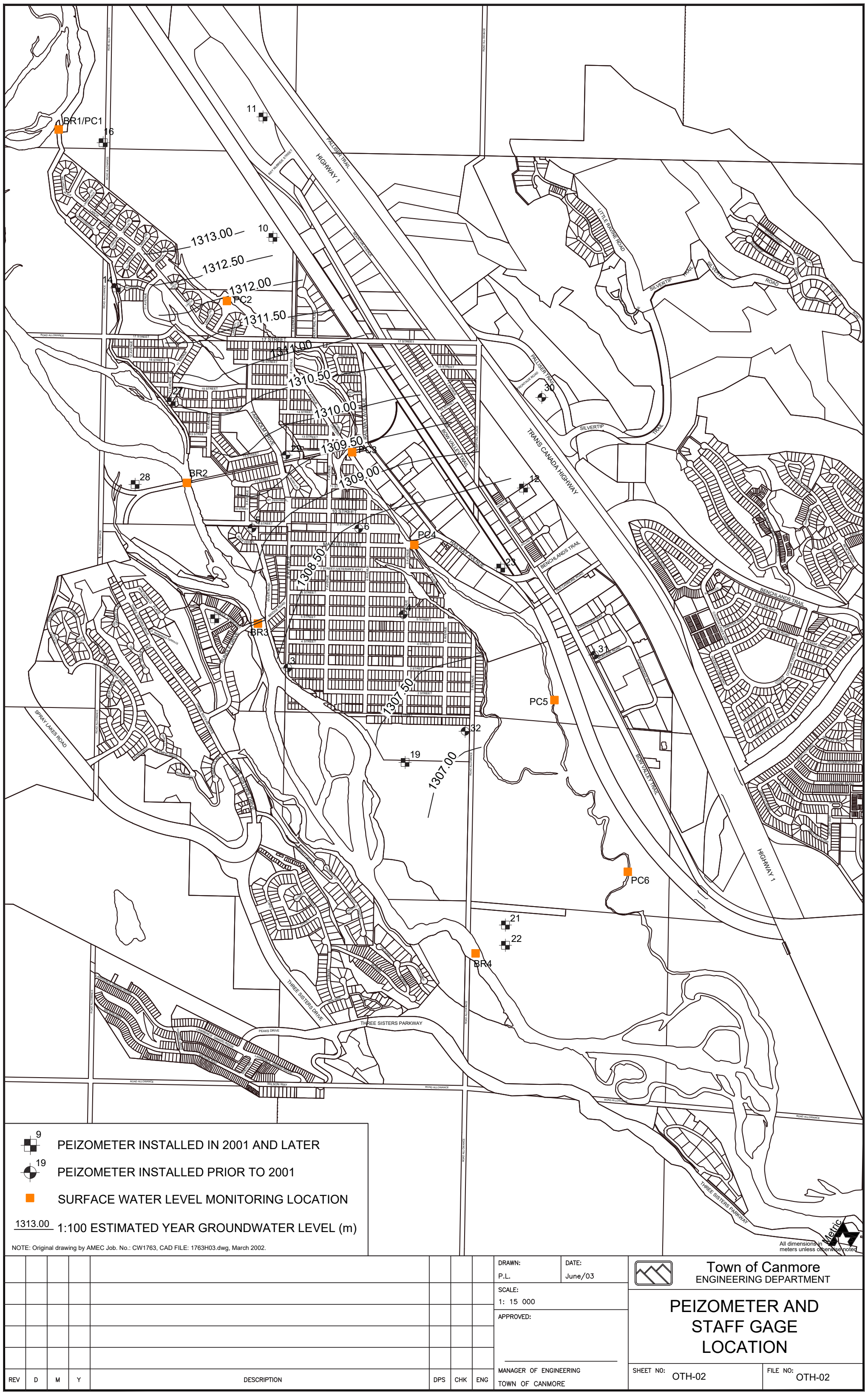
Town of Canmore Engineering 1:100 Year Estimated Groundwater Level (m)



Source: Town of Canmore Engineering Design and Construction Guidelines

4.7 Indirect Damage Estimates

Indirect damage estimates were calculated as outlined in Sections 3.6 and 3.7. Because these damages are associated with direct damage to buildings, they are presented in categories described above.

4.7.1 Commercial Indirect Damages – Business Interruption

As indicated, commercial direct damages up to an including the 1:100-year event are small in relation to residential damages. As a result, so are the corresponding indirect damages indicated in **Exhibit 4.13**. For the 1:2, 1:5, and 1:10-year events, the groundwater damage amounts have been adjusted as described in Section 4.6.2.

Exhibit 4.13: Indirect Damages – Business Interruption

Damage Category		Return Frequency, in Years					
		2	5	10	20	50	100
Non-Residential	Indirect Zone 1	$39,000	$65,000	$90,000	$103,000	$107,000	$119,000
	Indirect Zone 2	$0	$0	$0	$0	$0	$0
	Indirect Zone 3	$0	$0	$0	$0	$0	$0
	Indirect Zone 4	$0	$0	$0	$0	$2,000	$17,000
	Indirect Sewer/Groundwater	$1,000	$10,000	$41,000	$201,000	$419,000	$441,000
	Total	$40,000	$75,000	$131,000	$304,000	$528,000	$577,000

Although many businesses were not directly affected by flooding, additional interruptions may occur due to evacuations or road closures. Conversely, unaffected businesses may later experience increased demand during the recovery period.

4.7.2 Residential Indirect Damages

The residential displacement and intangible damages are illustrated in **Exhibit 4.14**. For the 1:2, 1:5, and 1:10-year events, the groundwater damage amounts have been adjusted as described in Section 4.6.2.

Exhibit 4.14: Residential Indirect Damages

Damage Category		Return Frequency, in Years					
		2	5	10	20	50	100
Residential	Displacement Zone 1	$0	$0	$0	$0	$0	$0
	Displacement Zone 2	$37,000	$47,000	$60,000	$69,000	$192,000	$235,000
	Displacement Zone 3	$0	$15,000	$71,000	$134,000	$603,000	$722,000
	Displacement Zone 4	$37,000	$138,000	$307,000	$484,000	$1,066,000	$1,319,000
	Displacement Sewer/Groundwat	$122,000	$373,000	$830,000	$1,666,000	$1,440,000	$1,364,000
	Intangible Zone 1	$0	$0	$0	$0	$0	$0
	Intangible Zone 2	$221,000	$319,000	$662,000	$735,000	$1,985,000	$2,156,000
	Intangible Zone 3	$0	$98,000	$417,000	$711,000	$3,044,000	$4,244,000
	Intangible Zone 4	$221,000	$784,000	$1,715,000	$2,598,000	$5,293,000	$6,249,000
	Intangible Sewer/Groundwater	$928,000	$2,688,000	$5,583,000	$11,139,000	$9,725,000	$9,112,000
	Total	$1,566,000	$4,462,000	$9,645,000	$17,536,000	$23,348,000	$25,401,000

It should be noted that mitigation of residential indirect damages can include community resiliency efforts in addition to flood protection.

4.8 Infrastructure, Flood Fighting, and Emergency Response

In the absence of specific cost estimates for Bow River flooding in Canmore, the costs for these categories were determined by benchmark data from past events in various communities. The costs have been associated with direct overland flood damage values. For infrastructure, this amount is 15%. For flood fighting and emergency response values between 6% and 4% were used, decreasing with flood magnitude. At the 1:100-year event, this amounts to $9 million for infrastructure and $2 million for flood fighting and emergency response.

4.9 Total Damages

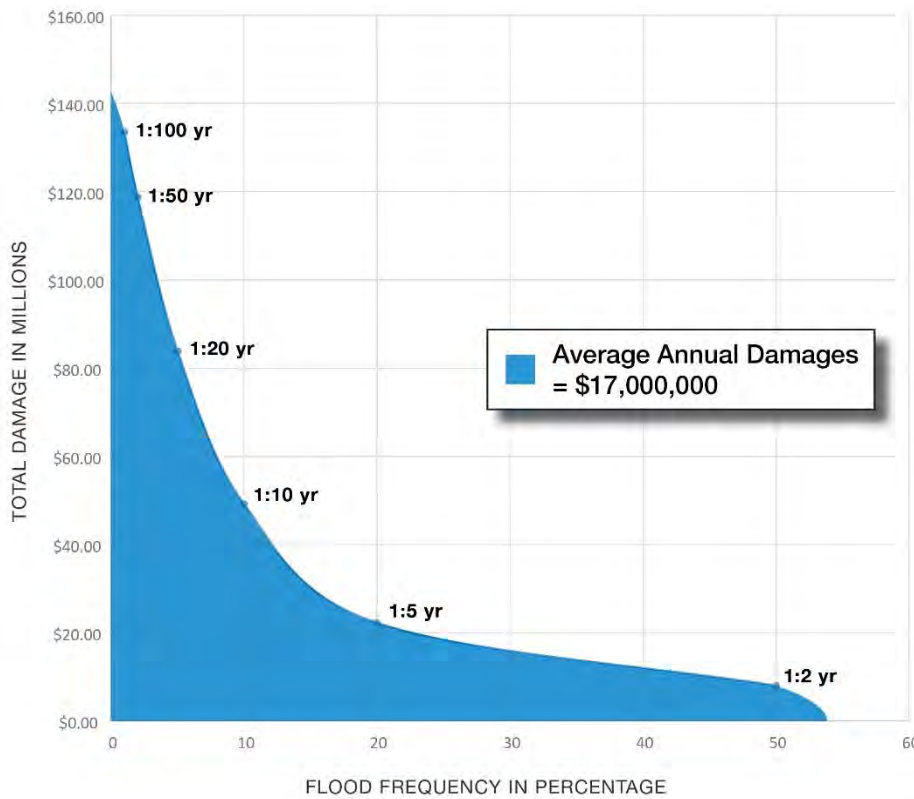
Total damages for each return period are summarized in **Exhibit 4.15**. For the 1:2, 1:5, and 1:10-year events, the groundwater damage amounts have been adjusted as described in Section 4.6.2.

Exhibit 4.15: Total Damages – With Groundwater Adjustment

Damage Category		Return Frequency, in Years					
		2	5	10	20	50	100
Zone 1	Direct Overland	$110,000	$136,000	$167,000	$189,000	$196,000	$215,000
	Indirect Overland	$39,000	$65,000	$90,000	$103,000	$107,000	$119,000
	Direct Sewer/Groundwater	$24,000	$63,000	$174,000	$352,000	$516,000	$603,000
	Indirect Sewer/Groundwater	$6,000	$15,000	$45,000	$89,000	$114,000	$114,000
	Subtotal	$179,000	$279,000	$476,000	$733,000	$933,000	$1,051,000
Zone 2	Direct Overland	$896,000	$1,475,000	$2,349,000	$2,622,000	$7,217,000	$8,067,000
	Indirect Overland	$258,000	$365,000	$721,000	$804,000	$2,177,000	$2,391,000
	Direct Sewer/Groundwater	$85,000	$175,000	$370,000	$820,000	$154,000	$72,000
	Indirect Sewer/Groundwater	$28,000	$77,000	$133,000	$318,000	$56,000	$28,000
	Subtotal	$1,267,000	$2,092,000	$3,573,000	$4,564,000	$9,604,000	$10,558,000
Zone 3	Direct Overland	$0	$466,000	$2,021,000	$3,081,000	$11,493,000	$15,444,000
	Indirect Overland	$0	$113,000	$487,000	$845,000	$3,646,000	$4,966,000
	Direct Sewer/Groundwater	$1,111,000	$3,904,000	$7,786,000	$16,277,000	$14,412,000	$12,910,000
	Indirect Sewer/Groundwater	$373,000	$1,333,000	$2,696,000	$5,661,000	$4,628,000	$4,115,000
	Subtotal	$1,484,000	$5,816,000	$12,990,000	$25,864,000	$34,179,000	$37,435,000
Zone 4	Direct Overland	$1,287,000	$3,955,000	$8,445,000	$12,209,000	$23,808,000	$29,491,000
	Indirect Overland	$257,000	$923,000	$2,023,000	$3,081,000	$6,362,000	$7,584,000
	Direct Sewer/Groundwater	$2,396,000	$6,223,000	$13,733,000	$26,880,000	$29,011,000	$30,615,000
	Indirect Sewer/Groundwater	$656,000	$1,675,000	$3,623,000	$6,937,000	$6,786,000	$6,660,000
	Subtotal	$4,596,000	$12,776,000	$27,824,000	$49,107,000	$65,967,000	$74,350,000
Infrastructure		$395,000	$1,041,000	$2,239,000	$3,122,000	$7,368,000	$9,180,000
Flood Fighting and Emergency Response		$138,000	$362,000	$649,000	$905,000	$1,709,000	$2,129,000
Total	Direct Overland	$2,293,000	$6,032,000	$12,982,000	$18,101,000	$42,714,000	$53,217,000
	Indirect Overland	$554,000	$1,466,000	$3,321,000	$4,833,000	$12,292,000	$15,060,000
	Direct Sewer/Groundwater	$3,616,000	$10,365,000	$22,063,000	$44,329,000	$44,093,000	$44,200,000
	Indirect Sewer/Groundwater	$1,063,000	$3,100,000	$6,497,000	$13,005,000	$11,584,000	$10,917,000
	Total	$8,059,000	$22,366,000	$47,751,000	$84,295,000	$119,760,000	$134,703,000

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 a damage-probability curve which depicts total damage versus probability of occurrence, as illustrated in **Exhibit 4.16**. For the 1:2, 1:5, and 1:10-year events, the groundwater damage amounts have been adjusted as described in Section 4.6.2.

Exhibit 4.16: Flood Damages Probability Distribution – With Groundwater Adjustment



As illustrated, the unmitigated total potential flood damages amount to $17 million in average annual damages. Of this, approximately $200,000 occurs within Zone 1, $1.6 million occurs within Zone 2, $4.85 million occurs within Zone 3, and $10.45 million occurs within Zone 4. Overall, sewer backup or groundwater infiltration risk accounts for $9.8 million of the total AAD.

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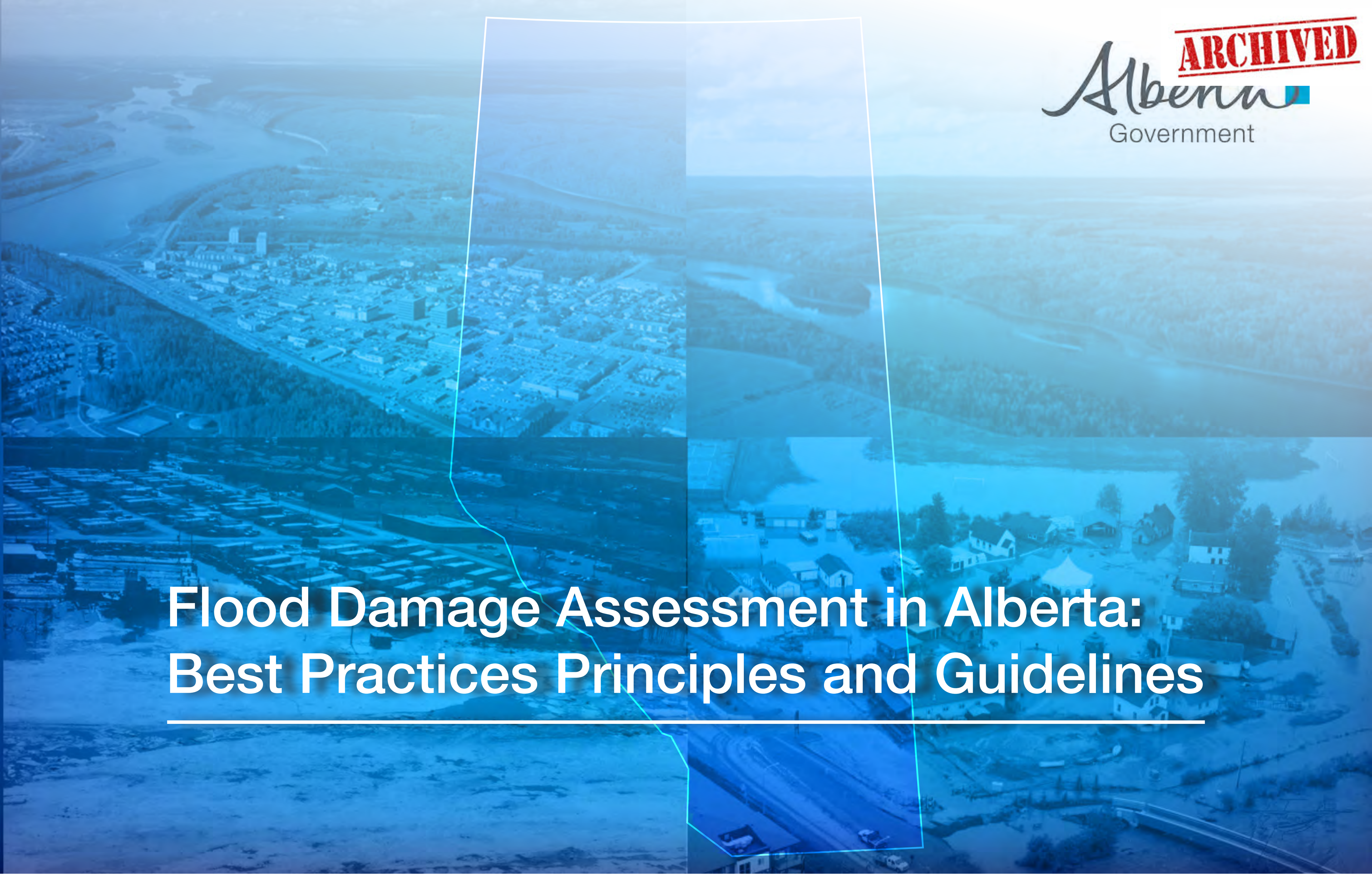
Appendix A – Alberta Government Bulletin: Best Practices Principles and Guidelines



Flood Damage Assessment in Alberta: Best Practices Principles and Guidelines

Prepared for Government of Alberta
by IBI Group

AUTHORS:
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1 Introduction

1.1 Purpose

The following bulletin has been generated by the Government of Alberta to describe how flood damages are estimated within the Province, and how they are subsequently employed to evaluate the economic viability of flood mitigation projects.

1.2 Preamble

Flooding is natural and essential to a healthy environment, but when severe events occur can cause human hardship and economic loss. In Canada, governments discourage flood-vulnerable development on the floodplain, and are involved in the mapping and designation of flood risk areas. From the mid-1970s until 1998, there was a national program of flood damage reduction involving mapping of floodplain areas and encouragement of land use controls within areas subject to risk of flooding. The Government of Alberta participated in this program in the 1980s and undertook studies to estimate flood damages in affected communities and propose mitigation alternatives where appropriate.

The Province of Alberta has mapped many of the communities that may be affected by flooding. The Government of Alberta =has posted the flood hazard mapping prepared for Alberta communities under the Flood Hazard Identification Program.

The website link is: http://maps.srd.alberta.ca/FloodHazard/viewer.ashx?viewer=Mapping.

In terms of assessing flood damages within flood affected communities, in 1982 the Government of Alberta commissioned a study of best practices and adopted a first principles approach employing Alberta-specific building practices and contents data. The resultant methodology and related tools were considered to be the leading edge of the field at the time.

Considerable time has passed since the original research was undertaken and the information was developed. In the interim, the type and value of household contents have changed dramatically, along with the use and level of improvement in typical basements. Given these substantial changes, it was considered prudent to update the flood damage estimation techniques to accurately reflect potential damages and hence provide a more reliable base for benefit/cost analyses and the ultimate selection of potential flood mitigation alternatives. Accordingly, in 2014 the Government retained the consultants who had undertaken the original work to update Provincial flood damage assessment techniques which are the subject of this bulletin.

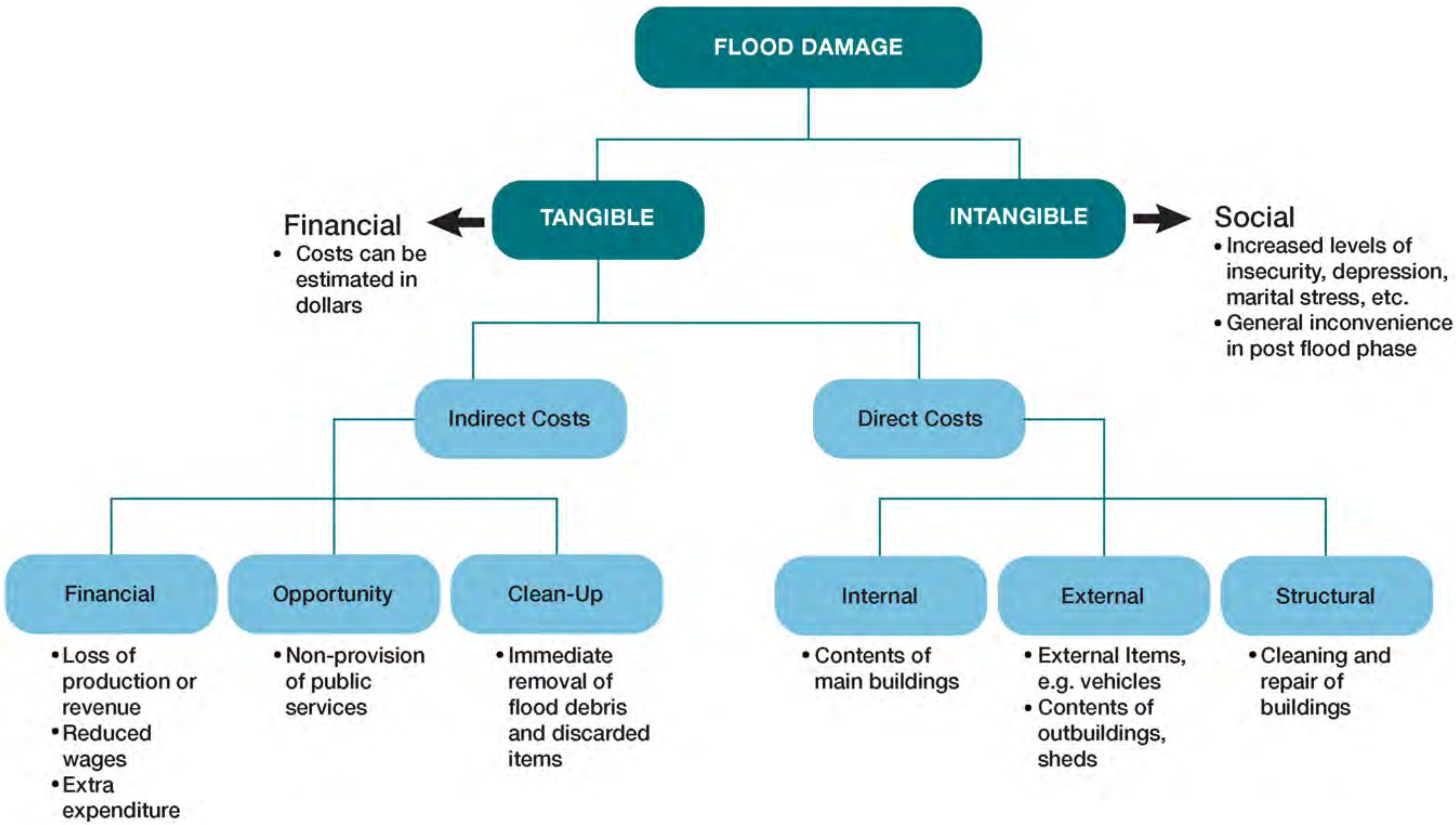
1.3 Types of Flood Damage

Damages resulting from major flood events can be broadly categorized as:

- Tangible damages – flood damages that one can attribute a dollar value to.
- Intangible damages – those that cannot be assessed in dollar terms, for example emotional stress or loss of life.

This bulletin will focus on tangible damages, which can be further categorized as direct damages and indirect damages. See **Exhibit 1** for a list of items covered.

EXHIBIT 1 - FLOOD DAMAGE



Tangible damages are those that can be readily measured in monetary terms. Damages to building structures and contents are considered tangible because they can be measured in terms of replacement or restoration costs.

Direct damages are those that occur immediately and can be directly attributed to the flood inundation. They include damage to both public infrastructure and private property.

Indirect damages also occur as a result of direct flood impacts but they are also more difficult to quantify. They include reduced economic activity and individual financial hardship, as well as adverse impacts on the social well-being of a community, and encompass disruptive impacts, including lost trading time and loss of market demand for products. Consequently indirect damages are often estimated as a percentage of direct damage.

1.4 Actual Versus Potential Damages

In many flooding situations the actual damages incurred are less than the potential damages because sufficient warning has been provided to the community such that mitigative measures, such as the removal of valuables, or the relocation of valuable contents to a higher level in the structure results in a reduction of the potential damages. Contingency measures including warning, flood fighting and individual adjustments within commercial and residential structures can result in reductions of up to 30% of damages.

It should also be noted that the communities suffering frequent flooding will have significantly reduced potential damages versus communities that have not been impacted by a severe flood in recent memory. Consequently, communities in flood prone areas with a high risk potential need to be reminded about the potential for flooding in their community from time to time.

1.5 Approaches to Flood Damage Assessment

There are a number of different approaches that can be taken to estimate tangible damages:

1. the first entails an examination of the floodplain immediately after the water recedes. If such estimates were available for every flood over a period of many years, a damage-frequency curve could be created;
2. an alternative method is to determine the damage caused by three or four recent floods whose hydrologic frequency can be determined and a smooth damage frequency curve plotted through these points; however, for most floodplains, changes in land use with calendar time prevent direct usage of a damage-frequency relationship from historical damages; and
3. the third method entails hydrologically determining various flood elevations for specific flood frequencies and deducing synthetically the damages that would occur given these flood events. This analysis provides a synthetic damage-frequency curve from which one can estimate average annual damages for a given study area.

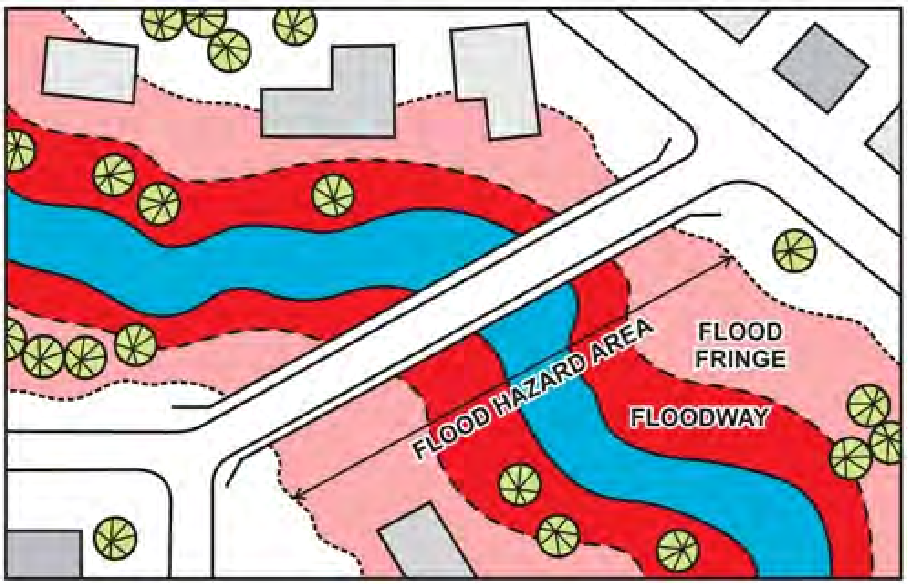
The third method is the one most frequently employed primarily due to a number of limitations inherent in the first two techniques. To reiterate, land use changes over time prevent the direct usage of damage-frequency relationships based on historical damages; this is particularly problematic for jurisdictions experiencing rapid growth. In addition, flood damage payments do not necessarily reflect real damages; however, they can serve as a useful check. Moreover, there are generally insufficient events to extrapolate from, and large voids in the data render the techniques susceptible to error.

In light of the above, the third methodology is considered the best approach for obtaining accurate and representative estimates of damages based on current economic factors and has been adopted for use in Alberta.

1.6 Terminology and Definitions

The following **Exhibits 2 and 3** provide an illustration of the terms and definitions below as it relates to flood hazard mapping and flood inundation mapping.

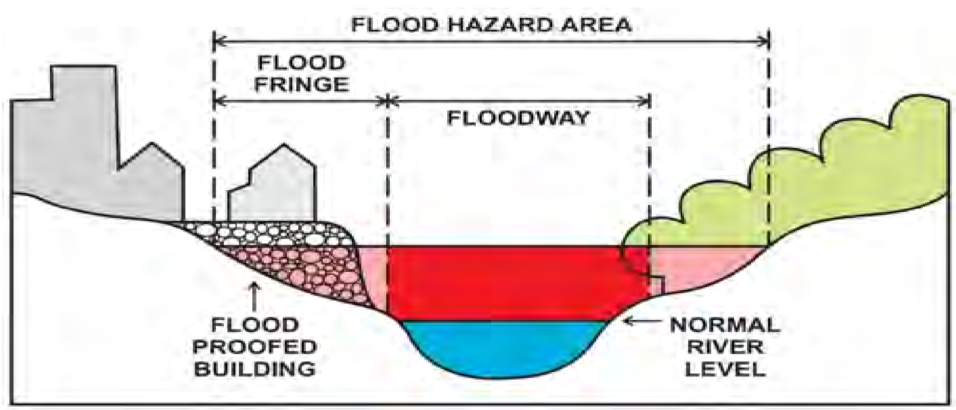
EXHIBIT 2 - FLOOD HAZARD AREA



Flood Hazard Mapping - Delineates the flood hazard area, showing the extent of a design flood event under encroachment conditions. Depending on the particular design flood scenario, the mapping may have associated design flood levels or be divided into multiple zones. Flood hazard mapping is typically used for long-term flood hazard area management and land-use planning.

Flood Hazard Area – The area affected by the design flood under encroachment conditions. The flood hazard area is typically divided into floodway and flood fringe zones, and may also include areas of overland flow.

EXHIBIT 3 - CROSS-SECTION OF FLOOD HAZARD AREA



Floodway – The portion of the flood hazard area where flows are deepest, fastest and most destructive. The floodway typically includes the main channel of a stream and a portion of the adjacent overbank area. The floodway is required to convey the design flood. New development is discouraged in the floodway and may not be permitted in some communities.

Flood Fringe – The portion of the flood hazard area outside of the floodway. Water in the flood fringe is generally shallower and flows more slowly than in the floodway. New development in the flood fringe may be permitted in some communities and should be floodproofed.

Overland Flow – Areas of overland flow are part of the flood hazard area outside of the floodway, and typically considered special areas of the flood fringe.

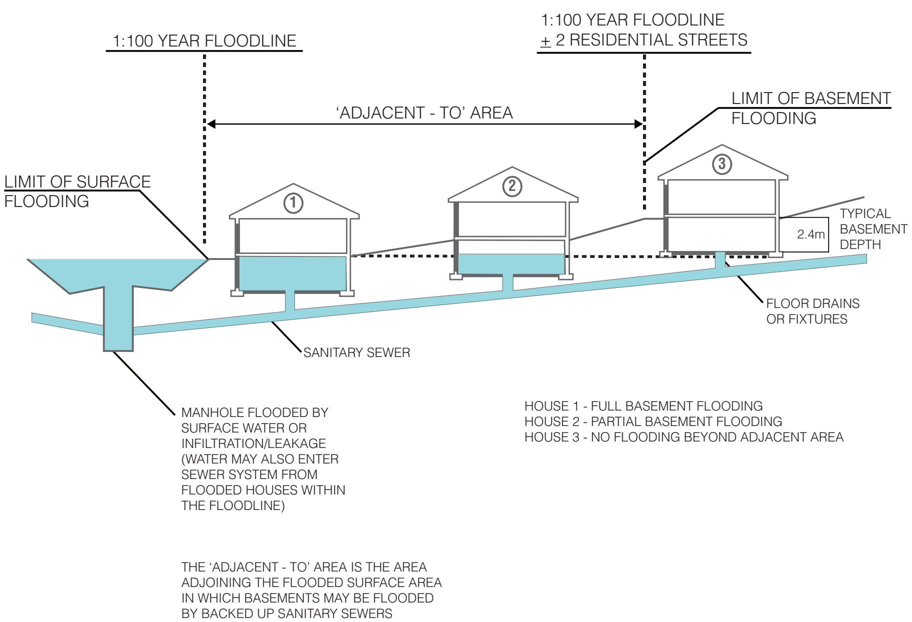
Design Flood – The current design standard in Alberta is the 100 year flood, determined when a flood hazard study is undertaken. A 100 year flood is defined as a flood whose magnitude has a one percent chance of being equaled or exceeded in any year. The design flood can also reflect a computed 100 year water level resulting from an ice jam or be based on a historical flood event.

Design Flood Levels – Flood hazard area water elevations computed to result from a design flood under encroachment conditions. Design flood levels do not change as a result of development or obstruction of flows within the flood fringe.

Encroachment Conditions – The flood hazard design case that assumes a scenario where the flood fringe is fully developed and flood flows are conveyed entirely within the floodway.

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 is delineated based on a distance of two dwelling units or ±75 m from the 1:100 year flood line. Essentially, with the sewer backup condition, basements which are lower than the floodwaters will automatically suffer damages. **Exhibit 4** depicts this relationship.

EXHIBIT 4 - 'ADJACENT-TO' AREA



Flood Inundation Mapping - Delineates flood inundation areas, showing the extent of one or more flood scenarios under existing, non-encroachment conditions. Depending on the particular flood scenario, the mapping may have associated inundation flood levels or be divided into multiple zones. Flood inundation mapping is typically used for near real-time emergency response planning and operations.

Flood Inundation Area - The area inundated during a particular flood scenario under existing, non-encroachment conditions. The flood inundation area may be divided into multiple zones, including areas inundated due to dedicated flood protection structure failure and isolated areas of inundation due to groundwater seepage.

Flood Scenario - Flow conditions that describe a particular flood event. Flood scenarios typically represent a range of flows, based either on flood frequency analysis or set flow intervals. Typical flood frequency flows in Alberta include the 2-year, 10-year, 20-year, 50-year, 100-year, 200-year, 500-year and 1000-year flood events.

Inundation Flood Levels - Flood inundation area water elevations computed to result from a particular flood scenario under existing, non-encroachment conditions. Inundation flood levels may change as a result of development or obstruction of flows within the flood inundation area.

For more information about flood hazard mapping, contact The Government of Alberta via email at: aenv-flood.risk-maps@gov.ab.ca.

2 Estimating Damages to Residential and Commercial Properties

The amount of flood damage a community suffers is directly proportional to the number of residential and commercial properties in the floodplain, and the depth of flooding these properties suffer as a result of the inundation. In addition to the depth of inundation, the velocity of the floodwaters will have an additional affect on the potential structural damage to a building.

2.1 Depth-Damage Relationships

The damage to residential and commercial properties and contents can be assessed using depth-damage curves. These curves describe the relationship between the depth of inundation and the amount of damage incurred as a result. These curves can be created by surveying damaged properties of a similar grouping over a range of flood depths, or by undertaking a detailed loss assessment with a representative sample of residential properties to create synthetic depth-damage curves.

To reiterate, in 1982 the Government of Alberta commissioned the development of synthetic depth-damage curves based on loss assessment of residential and commercial buildings in the City of Fort McMurray. Additional depth-damage curves were developed as a part of the Elbow River Flood Study in the City of Calgary in 1986. The stage-damage curves were subsequently indexed for use throughout other flood prone centres in Alberta. In 2014 updated residential depth-damage curves were developed based on a representative sampling of properties within the City of Calgary.

The original curves were developed and used in a computerized Flood Damage Database Management System application which was developed specifically for Alberta. This computer model has been replaced by the R-FDA (Rapid Flood Damage Assessment) model, which includes the new synthetic depth-damage curves. The depth-damage curves for the R-FDA model were developed for a range of building types and sizes and include those that represent:

- residential buildings for a range of single-family, multi-family, mobile home and apartment types, for contents and structure expressing damages on a per square metre basis; and
- commercial/retail/industrial and institutional buildings for a number of categories of non-residential use based on damages per square metre for both contents and structure.

2.2 Estimating Levels of Inundation of Affected Properties

It is typically an extreme historical flood event that causes severe inundation and hence damages in a community. However, damage can also be caused by less severe but higher frequency flood events. For benefit/cost purposes it is necessary to determine potential damages from a range of flood events. As a result, hydrologic studies are undertaken to establish the flood flows for different flood frequencies coupled with hydraulic analysis to establish the respective flood elevations in a given location to assist in estimating the levels of inundation on properties in that location. The following for each property is required:

- **Grade** of the property is established using the digital elevation model (DEM) from LiDAR. Alternatively the grade or ground elevation could also be obtained from traditional ground level surveys or detailed topographic maps.
- **Flood elevation** is derived from hydraulic flood modelling (HEC-RAS), or established from historical flood events.
- **Flood depth** at each property can be calculated using floor heights above grade, which can be established from building approval records, traditional field survey, or the use of videos/photography of street views from the location.

2.3 Estimating Flood Damages

The following steps are undertaken to estimate flood damages:

1. Hydrologic and hydraulic studies to establish the floodplain limits under different return flood events (i.e., 1:10 year, 1:25 year, 1:50 year, 1:100 year, 1:500 year, including floods that exceed the design flood).
2. Inventory and classification of all flood affected properties (including the adjacent-to areas) and the depth of inundation by individual property.
3. Selection of appropriate depth-damage curves to determine direct contents and structural damages to individual properties from the flooding.
4. Estimation of indirect damages including such things as costs of evacuation, employment losses, administrative costs, net loss of normal profit and earnings to capital, management and labour, general inconvenience, etc. These are generally calculated as a percentage of direct damages.
5. Calculation of total direct and indirect damages.

Step 1

Flood hazard mapping exercises predict the extent and depth of floodwaters for varying levels of flood severity and frequency. These flood maps provide the information to locate potential properties that may be affected by the flooding. With the use of the 3D DEM surface within the flood area, the grade, main floor elevation and flood depth can be established for each affected property.

Step 2

Flood damages for the affected properties in the floodway, flood fringe and adjacent-to area are estimated for each of the return flood events.

The first stage is to assess if the building property is in the floodway or flood fringe. Typically the floodway is part of the floodplain where the depth of flooding and velocity is greater than one metre and one metre per second respectively. Any properties in the floodway could be subjected to significant structural damage and may need to be relocated.

Basement damages could occur even if the property is outside of the flood hazard area because of sewer backup, or ground seepage. Consequently properties in an adjacent-to area should be included for damage estimates.

Step 3

The depth-damage curves developed for Alberta are divided into residential and commercial categories, and each set includes separate curves for contents and structure. In addition basement damage curves have been developed for the single family residential properties. Twenty-one different content and six structural damage curves have been developed for commercial properties. These are used for flood damage estimation.

Estimate Direct Damages

- Depth-Damage Curve Estimate
- Damage Curve Height = Flood Elevation – (Main Floor Height Above Grade + Grade Elevation)
- Main Floor Damage = Dollar Value On Curve Equal To The Damage Curve Height
- Total Damage = Basement Damage + Main Floor Damage

This process is repeated for all affected properties and a cumulative total for each return flood event is computed. The total potential direct damage resulting from a 1:100 year flood, 1:50 year flood, etc. is established.
Exhibits 6 and 7 illustrate this.

Step 4

Once an assessment of the potential direct damages to the affected properties has been made, the indirect damage can be estimated. It is common practice that the indirect damages for residential and commercial property be estimated as a percentage of the direct damage.
For example, the following percentages have been recommended:

- Residential Indirect Damage - 20% of Direct Residential Damages
- Commercial/Institutional Damage - 41% of Direct Comm./Ind. Damages

In addition a percentage is also attributed to infrastructure, highways and utilities unless these damages can be estimated from first principles by the municipality. It should be noted that the indirect percentages should be re-assessed for each of the flood affected communities and they should be based on the local situation assessment. Indirect damages should be reassessed over time especially if new mitigation measures are proposed.

Step 5

The total damage cost for each return flood is the sum of all direct and indirect damages.

Total damages = direct damages + indirect damages

Exhibit 7 illustrates the input, tasks and output of the flood damage estimation methodology described

EXHIBIT 5 - EXAMPLE OF RESIDENTIAL CONTENT DEPTH DAMAGE CURVE

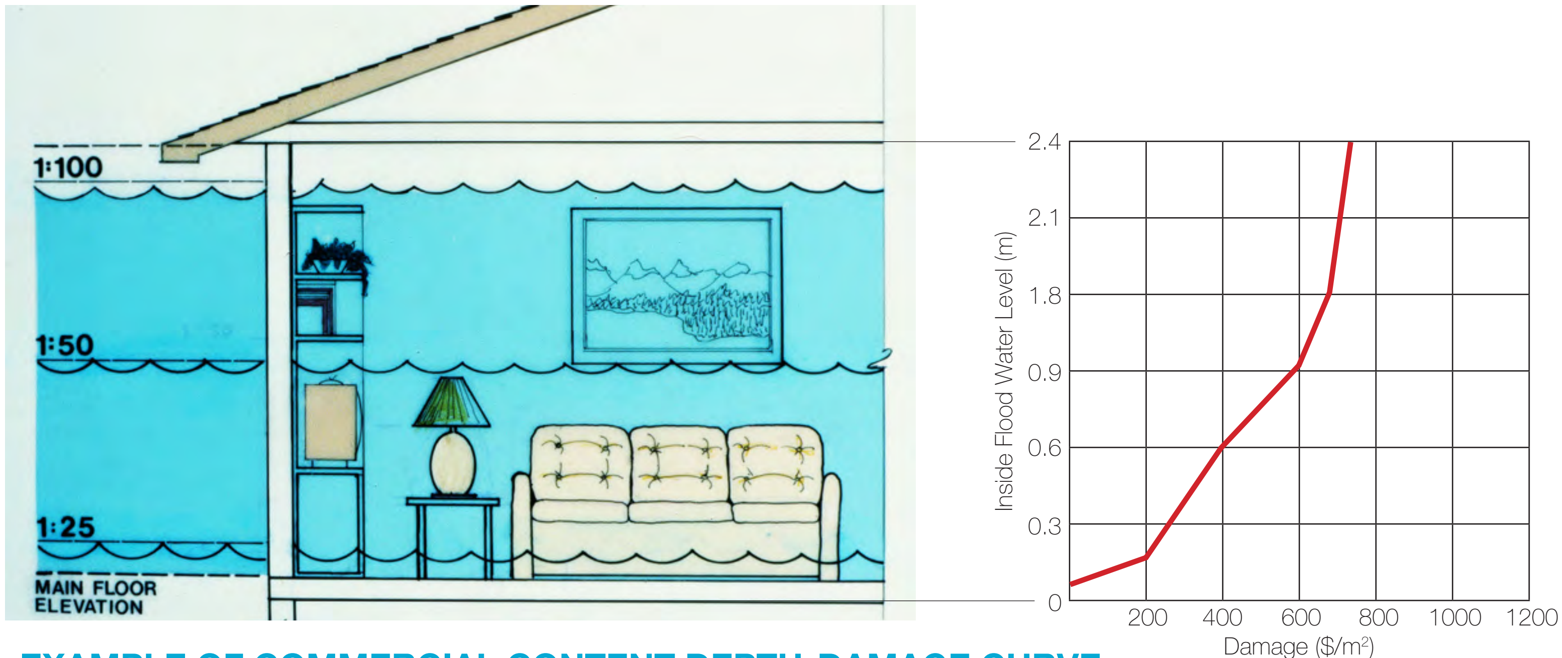


EXHIBIT 6 - EXAMPLE OF COMMERCIAL CONTENT DEPTH-DAMAGE CURVE

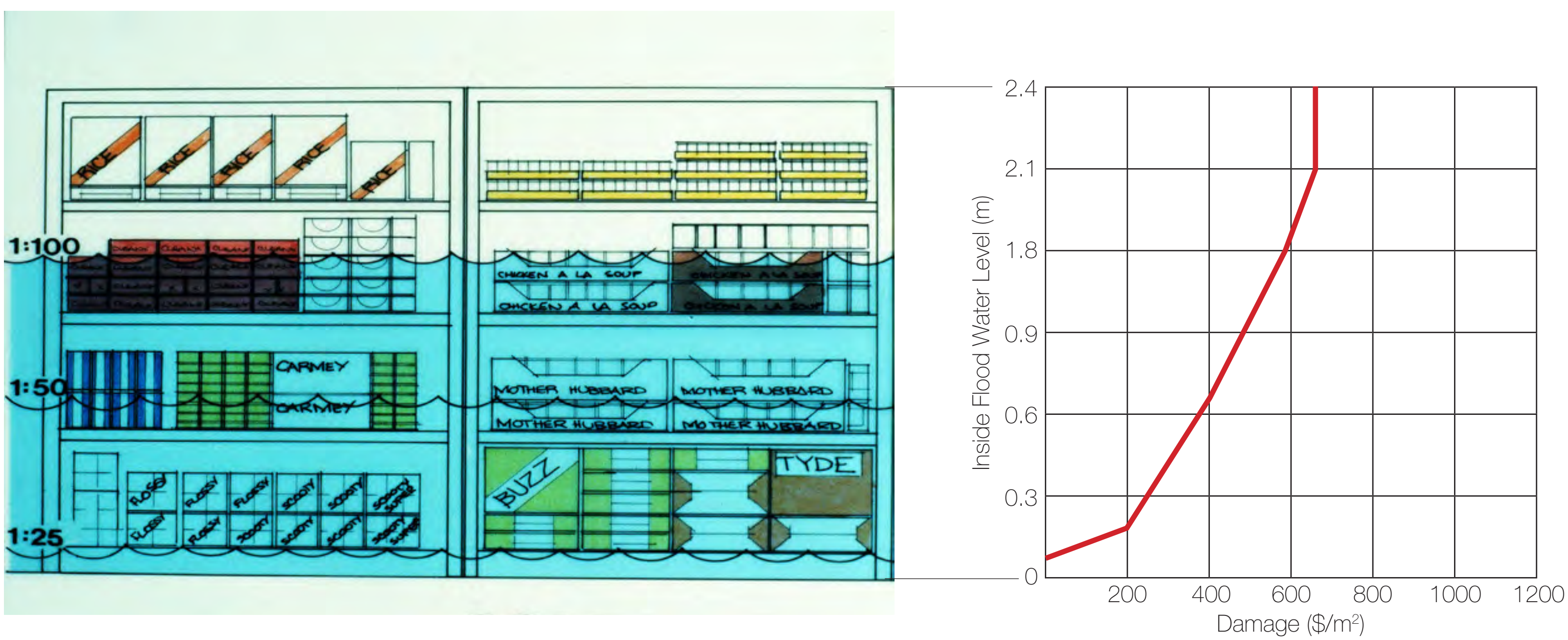
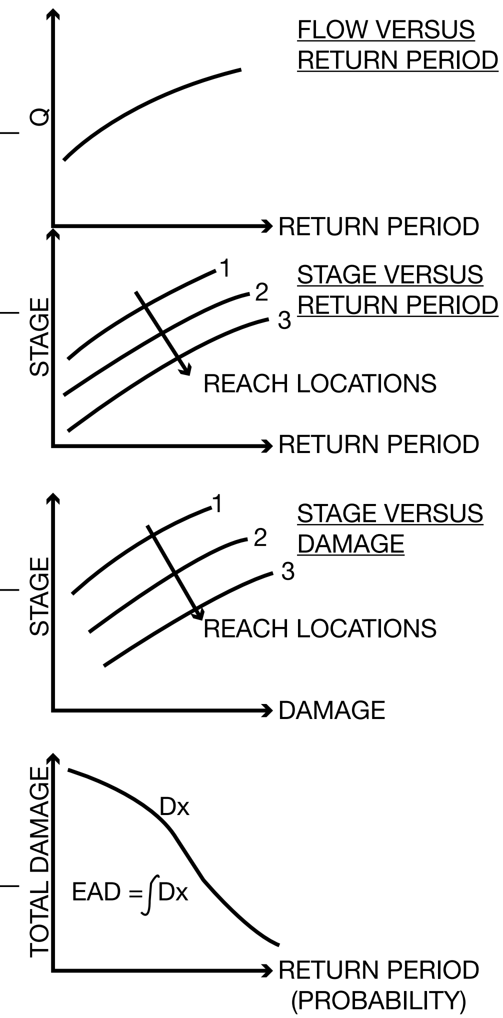


EXHIBIT 7 - GENERAL FLOOD DAMAGE ESTIMATION METHODOLOGY

INPUT	TASK
	IDENTIFICATION OF DAMAGE CENTRE
- DRAINAGE AREA - STEAMFLOW RECORDS - PAST STEAMFLOW ANALYSES	HYDROLOGIC ANALYSIS - SINGLE STATION FREQUENCY ANALYSIS - REGIONAL FREQUENCY ANALYSIS - TESTS FOR SUITABILITY OF LOW RECORD
- CHANNEL AND FLOODPLAIN GEOMETRY - ROUGHNESS COEFFICIENTS - BRIDGE AND CULVERT DETAILS	HYDRAULIC ANALYSIS - BACKWATER PROFILES THROUGH DAMAGE CENTRE FOR ALL RETURN PERIOD FLOODS - SELECT DAMAGE REACHES - ESTIMATE STAGE (DEPTH) FOR EACH REACH RETURN PERIOD
- TOPOGRAPHIC SURVEY OF STRUCTURES - SYNTHETIC/HISTORICAL STAGE DAMAGE CURVES - COMMERCIAL/INDUSTRIAL INVENTORIES - AGRICULTURAL	STAGE DAMAGE CALCULATIONS - SELECT TYPE OF DAMAGE CURVE FOR VARYING LAND USE - MODIFY OR ADD TO CURVES DEPENDING ON PROJECT SPECIFICS - ACCUMULATE DAMAGE ESTIMATES FOR STAGE INCREMENTS
	TOTAL DAMAGE CALCULATIONS - DETERMINE DAMAGE VERSUS RETURN PERIOD (PROBABILITY) AND ACCUMULATE OVER ALL REACHES - INTEGRATE UNDER DAMAGE VERSUS PROBABILITY CURVE TO ESTIMATE EXPECTED ANNUAL DAMAGE (EAD)

OUTPUT



Source: Paragon Engineering "Flood Damages: A Review of Estimation Techniques" - Ministry of Natural Resources (March 1984)

3 Estimating damage to other infrastructure

In addition to private property, there are a number of other assets that may be potentially exposed to flood damage. For example, direct and indirect damages may be caused to:

- **roads and transport infrastructure**
- **parks and recreational facilities**
- **hospitals, schools, and other government buildings**
- **water, sewerage and drainage systems**
- **communication networks**

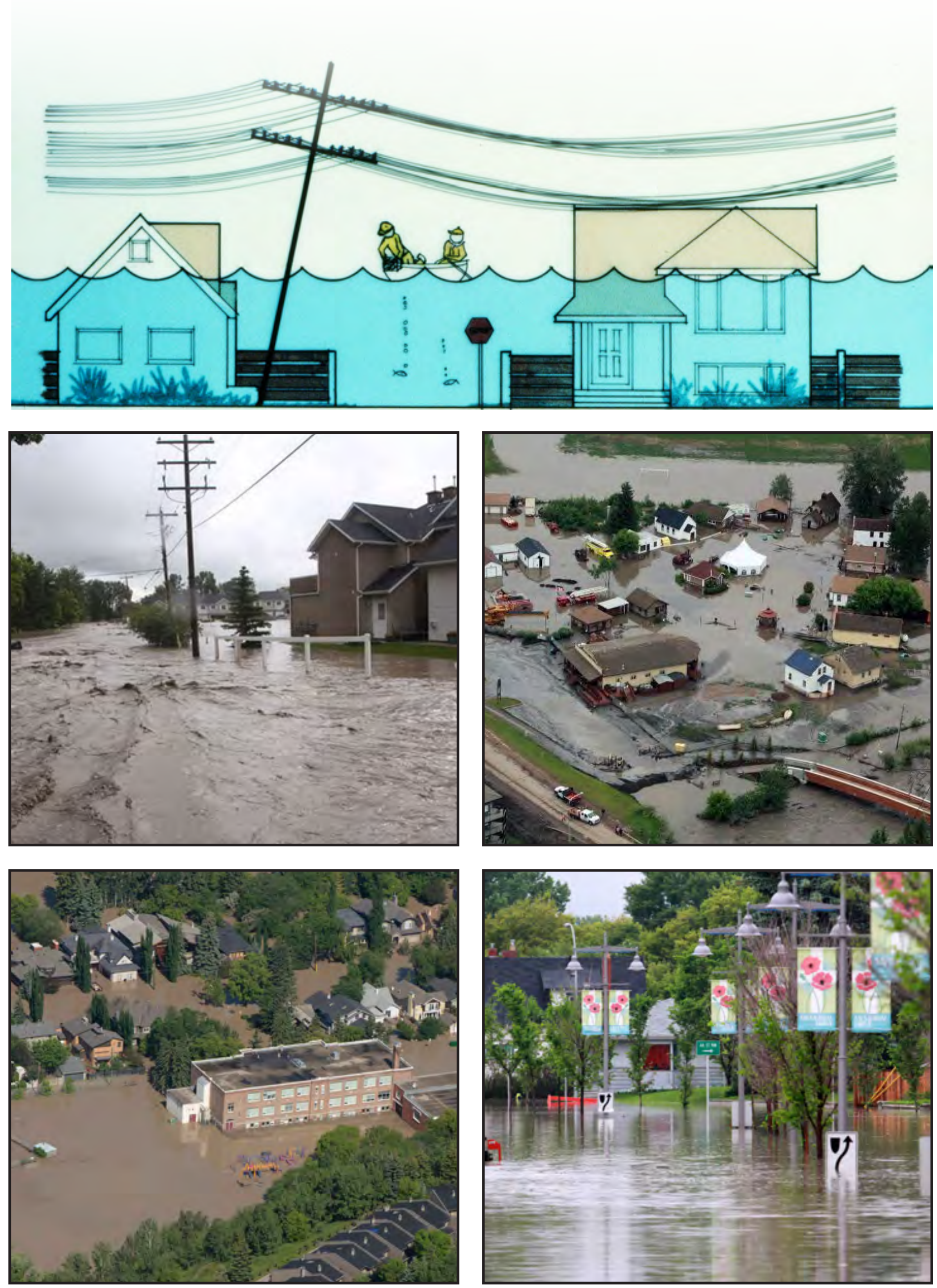
Traditionally, most of these were publicly owned; however, the increasing trend towards privatization of services may have an influence on the costing methodology used to assess damages.

3.1 Direct Damages to Infrastructure

In general the repair and replacement of roads and bridges is the largest component of damages to public assets. The amount of damage caused is a result of the flood-related factors and the ability of the road to withstand flood conditions. Relevant factors include both the initial repair cost and the possibility of a significant reduction in the overall life of the road surface as a result of the flood.

Generally annual maintenance costs and other documented historical costs can be used to develop locally specific damage costs. Where this information is not available then data from other studies may have to be used.

EXHIBIT 8 - INFRASTRUCTURE DAMAGE



3.2 Indirect Damages to Infrastructure

The indirect damages to services provided by government or community agencies should be based on the lost wages from downtime and disruption to operations. This may be calculated by multiplying lost working hours by wages.

Business or activities not provided by government or community agencies are profit driven. Accordingly, the calculation of their damages needs to be based on different assumptions. These indirect losses should be calculated only as the lost profit component.

4 Economic Assessment of Flood Mitigation Projects

The purpose of this section is to provide guidance on the economic assessment of flood mitigation projects based on their respective cost and benefits.

Depending on its size (or severity), each flood will cause a different amount of flood damage. The average annual damage (AAD) is the average damage in dollars per year that would occur in a designated area from flooding over a very long period of time. In many years there may be no flood damage, in some years there will be minor damage (caused by small, relatively frequent floods) and, in a few years, there will be major flood damage (caused by large, rare flood events). Estimation of the average annual damage provides a basis for comparing the effectiveness of different floodplain management measures (i.e., the reduction in the annual average damage).

4.1 Average Annual Damages

The average annual damage (AAD) cost from flooding is a common performance indicator used to measure the level of potential flood damages. It expresses the costs of flood damage as a uniform annual amount based on the potential damages inflicted by a range of flood magnitudes.

The calculation of an AAD estimate requires potential damage costs for a number of flood events – the more the better (including the events greater than the design flood which is usually the 1:100 year flood).

To calculate AAD:

1. Estimate the potential flood damage costs from a range of flood events, including those greater than the design flood if possible.
2. Plot the graph of flood damages versus annual exceedance probability.
3. Calculate the average annual damages from flooding.
4. Calculate the reduction as a result of the proposed flood mitigation activities.
5. The net benefit is the difference of the two over the design life of the mitigation.

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Step 1

To complete this step, it is necessary to have estimates of potential flood damages for a range of flood sizes.

Following is an example of flood damage costs that is used to illustrate the process used to calculate AAD. If the cumulative total of direct and indirect flood damages including residential, commercial, infrastructure, utilities and highways for the 25, 50 and 100 year annual recurrence interval (ARI) flood events are:

	25 year	50 year	100 year
Annual Recurrence Interval (ARI)	25 year	50 year	100 year
Annual Exceedance Probability (AEP)	0.04	0.02	0.01
Total Damages	$ 35,082,000	$ 118,519,000	$ 220,323,000

Step 2

A graph of potential damage estimates versus annual exceedance probability is plotted. Potential damages in dollars are plotted on the vertical axis and the annual exceedance probability is plotted horizontally.

The annual exceedance probability for a given flood event is the inverse of the average recurrence interval:

- Annual exceedance probability = 1 / Average recurrence interval
- Using the example flood damage costs:
- 10 year ARI = 10%, AEP = 0.1
- 100 year ARI = 1%, AEP = 0.01

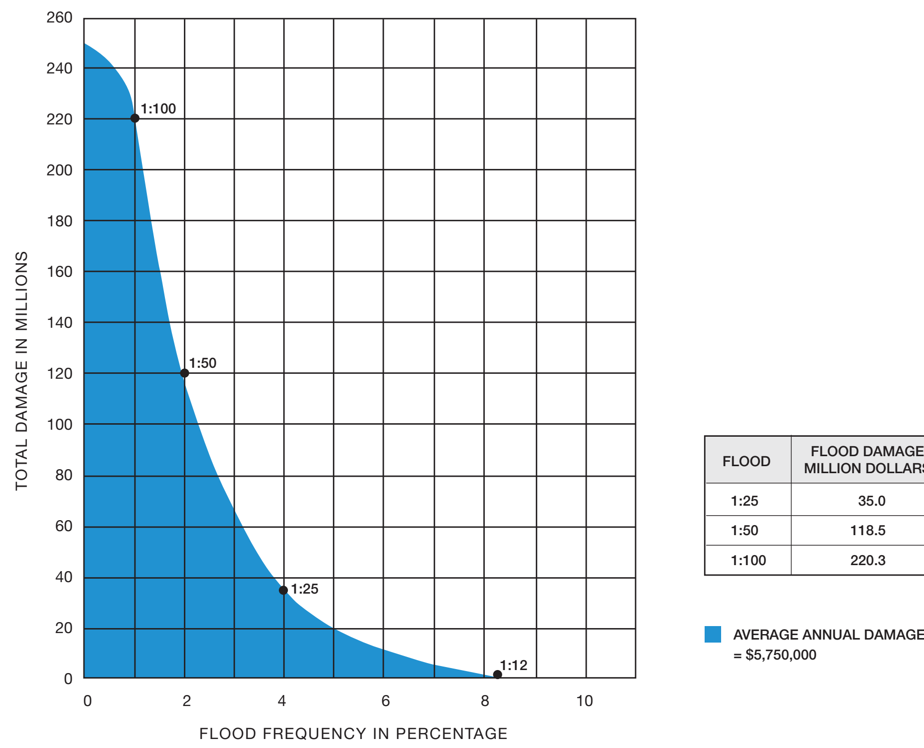
For the rarer flood events like the probable maximum flood, the annual probability of exceedance (AEP) approaches zero. **Exhibit 9** depicts a damage-probablity curve, which is used to calculate Average Annual Damage.

Step 3

The average annual damage cost is the area under the flood damage cost curve plotted in the graph. It is expressed in units of dollars per year.
Using the example:

- Each square unit in the graph = $ 20,000,000 * 0.01 = $ 200,000
- Cumulative area in blue in the graph = 28.75 units
- Therefore, average annual damage = $ 5,750,000

EXHIBIT 9 - DAMAGE - PROBABILITY CURVE



FLOOD	FLOOD DAMAGE MILLION DOLLARS
1:25	35.0
1:50	118.5
1:100	220.3

Step 4

The benefit that will accrue to a flood mitigation project is equal to the reduction in the AAD that can be realized by that project, and is calculated as:

- Reduction in AAD = AAD without project – AAD with project
- A project that protects the properties up to 100 year flood = 16.75 units
- Therefore, AAD with mitigation project = $ 2,400,000
- Reduction in AAD = $ 5,750,000 - $ 2,400,000
- Assuming a project life of 50 years and a discount rate of 4%

The benefit/cost will be positive if the flood mitigation project is less than $71,965,370 in terms of capital and operating costs over the life of the project.

4.2 Evaluation of Flood Mitigation Alternatives

This bulletin has been developed by Alberta Environment Sustainable Resources Development to provide stakeholders with guidance on the economic development of flood mitigation alternatives. It is intended that topics of social and environmental assessment also be covered in future bulletins.

5 Appendix

5.1 Acronyms

AE – Alberta Environment (now ESRD)

AAD – Average Annual Damage

AEP – Annual exceedance probability

ARI – Average recurrence interval

DEM – Digital elevation model

ESRD – Environment Sustainable Resource Development

FDA – Flood Damage Assessment

FDDBMS – Flood Damage Database Management System

FEMA – Federal Emergency Management Agency

HAZUS-MH – FEMA software for multi hazard loss estimation

HEC-FDA – USACE software for flood mitigation

HEC-RAS – USACE software for flood mapping

LiDAR – Light detecting and ranging remote sensing method

R-FDA – Rapid Flood Damage Assessment

USACE – U.S. Army Corps of Engineers

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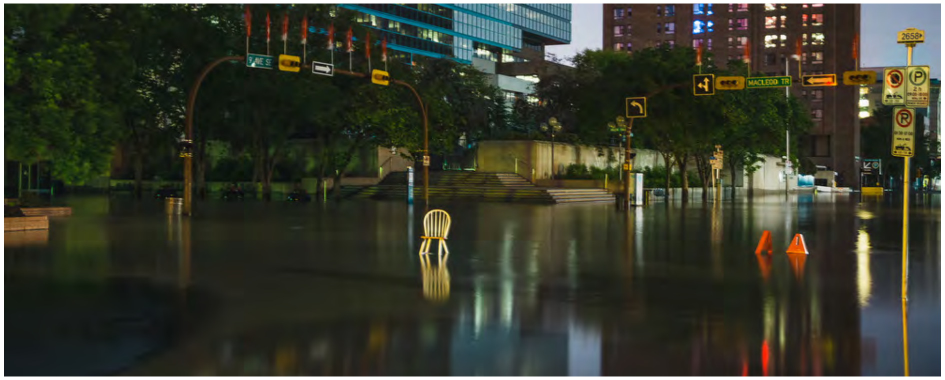

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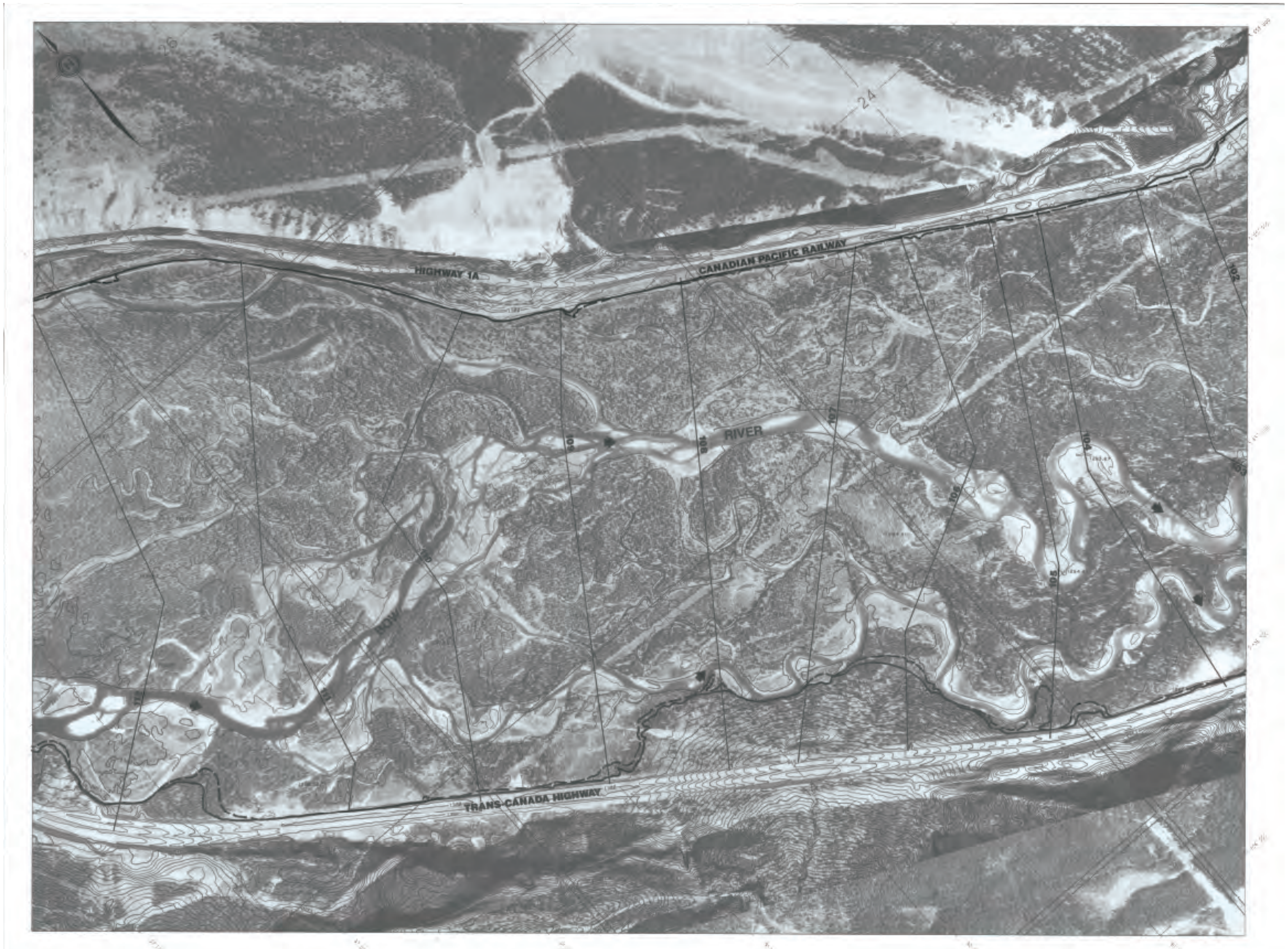
Appendix B – Canmore Flood Hazard Mapping

Source: Alberta Environmental Protection River Engineering Branch - March 1993
W-E-R AGRA Ltd.

Source: Alberta Environmental Protection River Engineering Branch - March 1993
W-E-R AGRA Ltd.

Source: Alberta Environmental Protection River Engineering Branch - March 1993
W-E-R AGRA Ltd.



Source: Alberta Environmental Protection River Engineering Branch - March 1993
W-E-R AGRA Ltd.

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Source: Alberta Environmental Protection River Engineering Branch - March 1993
W-E-R AGRA Ltd.

Appendix C – Residential Classification Scheme

APPENDIX C - Residential Classification Scheme

Class	Floor Area	General Description
AA-1 AA-2	372+ m^2 (4,000+ ft^2) Typical 456 m^2 (4,903 ft^2)	Typically custom construction built during the 2000s, with superior architectural design and premium quality construction materials, finish materials and workmanship. These units typically include numerous large windows, extensive basement finishing, superior millwork, and built-in high-quality appliances. These very large dwelling units are few in number, and account for the highest reaches of the real estate price distribution, with an average value of $3,400,000.*
A-1 A-2	223 – 371 m^2 (2,400 – 3,999 ft^2) Typical 266 m^2 (2,858 ft^2)	The A Class structures are relatively large, high-end homes typically featuring moderately high-quality construction materials and finishes. These units have good quality millwork and large window area ratios, and typically have most of the basement areas finished, and have attached garages. While much more numerous than the AA Class, the A units represent a relatively small share of the total population of single dwelling units, reflective of their upper-middle price positioning, with an average value of $1,400,000.*
B-1 B-2	112 – 223 m^2 (1,200 – 2,399 ft^2) Typical 163 m^2 (1,754 ft^2)	B Class units are generally the most numerous type of single dwelling units in Alberta municipalities. These average quality units were generally built from stock plans as tract or speculative housing for mid-market consumers, from the 1950s onward. These houses are typified by conventional design, and medium quality materials, finishes and workmanship, with some basement finishing and detached garages. They have an average value of $680,000.*
C-1 C-2	<112 m^2 (<1,200 ft^2) Typical 88 m^2 (947 ft^2)	The C Class units tend to be older housing stock in inner-city locations, or tract starter housing in newer suburban locations. These houses are of average to below average quality in terms of design and construction materials, finishes and workmanship. Generally, units of this class located in the municipal core area have a high land to building value ratio as these structures are approaching functional and physical obsolescence. While C Class units represent the lower range of real estate values, many of these units have been upgraded by owners and feature average or better quality finishes in the renovated areas. They have an average value of $450,000.*
D	Typical 128 m^2 (1,377 ft^2)	D Class units are mobile homes, located on temporary foundations, and without basements. These units tend to reflect the lower range of real estate values.
MA	Typical 93 m^2 (1,002 ft^2)	MA units are apartment units located in high-rise (5+ storey) structures. The high-rise apartment towers are typically of concrete and light steel frame construction, and have one or more levels of underground parking.
MW	Typical 65 m^2 (704 ft^2)	MW units are apartments located in low-rise (less than 5 storey) apartment structures. These structures are typically of wood construction and often have single level concrete parking structures underground.

Source: IBI Group, Golder Associates Ltd., *Provincial Flood Damage Assessment Study, Government of Alberta*, ESRD, February 2015.

* Calgary assessed market values 2015.

APPENDIX C - Residential Classification - Typical Examples

AA

AA

A

A

B

B

C

C

APPENDIX C - Residential Classification - Typical Examples

D

D

MA

MA

MW

MW

Appendix D – Depth-Damage Curves and Values*

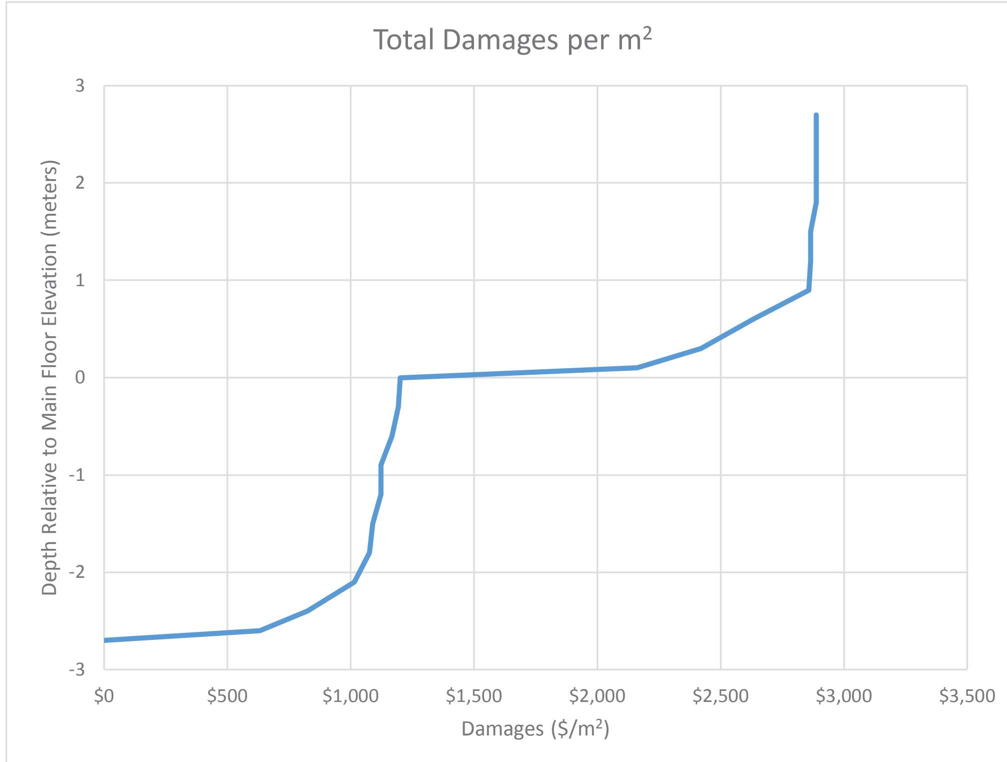
* Calgary 2014 $

APPENDIX D - Damage Curves and Values - Class A - Residential One-Storey

Class A - Residential One-Storey					
Depth relative to main floor[1]	Main Floor Contents	Main Floor Structure	Basement Contents[2]	Basement Structure[2]	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$400	$231	$632
-2.4	$0	$0	$554	$271	$825
-2.1	$0	$0	$715	$299	$1,015
-1.8	$0	$0	$778	$299	$1,077
-1.5	$0	$0	$784	$305	$1,090
-1.2	$0	$0	$786	$335	$1,122
-0.9	$0	$0	$788	$335	$1,123
-0.6	$0	$0	$810	$356	$1,167
-0.3	$0	$0	$836	$357	$1,193
0	$0	$0	$836	$365	$1,201
0.1	$373	$588	$836	$365	$2,162
0.3	$624	$594	$836	$365	$2,420
0.6	$758	$674	$836	$365	$2,633
0.9	$809	$848	$836	$365	$2,858
1.2	$816	$848	$836	$365	$2,865
1.5	$816	$848	$836	$365	$2,865
1.8	$839	$848	$836	$365	$2,888
2.1	$839	$848	$836	$365	$2,888
2.4	$839	$848	$836	$365	$2,888
2.7	$839	$848	$836	$365	$2,888

[1]distance between floors is variable in model, 2.7m illustrated

[2]not all structures have basements and it is a separate calculation in the model

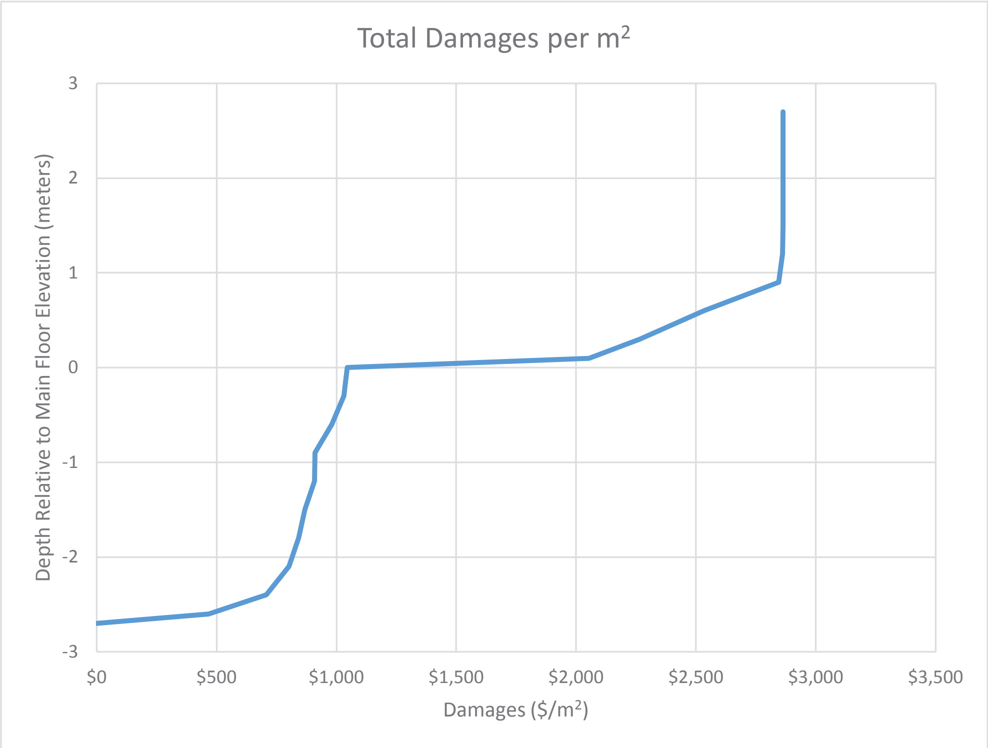


APPENDIX D - Damage Curves and Values - Class A - Residential Two-Storey

Class A -Residential Two-Storey					
Depth relative to main floor[1]	Main Floor Contents	Main Floor Structure	Basement Contents[2]	Basement Structure[2]	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$226	$241	$467
-2.4	$0	$0	$354	$354	$708
-2.1	$0	$0	$395	$406	$802
-1.8	$0	$0	$437	$406	$843
-1.5	$0	$0	$440	$429	$869
-1.2	$0	$0	$442	$466	$908
-0.9	$0	$0	$444	$466	$910
-0.6	$0	$0	$475	$506	$980
-0.3	$0	$0	$523	$507	$1,030
0	$0	$0	$523	$522	$1,045
0.1	$343	$665	$523	$522	$2,053
0.3	$545	$676	$523	$522	$2,266
0.6	$663	$826	$523	$522	$2,534
0.9	$748	$1,051	$523	$522	$2,845
1.2	$766	$1,051	$523	$522	$2,862
1.5	$767	$1,051	$523	$522	$2,863
1.8	$767	$1,051	$523	$522	$2,863
2.1	$767	$1,051	$523	$522	$2,863
2.4	$767	$1,051	$523	$522	$2,863
2.7	$767	$1,051	$523	$522	$2,863

[1]distance between floors is variable in model, 2.7m illustrated

[2]not all structures have basements and it is a separate calculation in the model

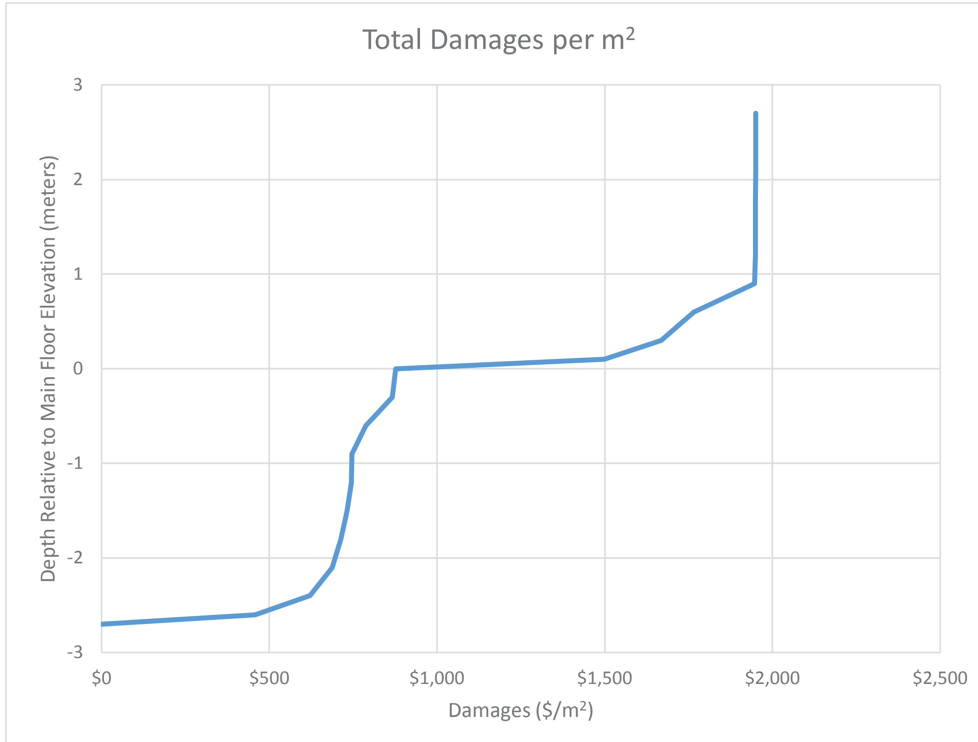


APPENDIX D - Damage Curves and Values - Class B - Residential One-Story

Class B - Residential One-Storey					
Depth relative to main floor[1]	Main Floor Contents	Main Floor Structure	Basement Contents[2]	Basement Structure[2]	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$226	$232	$458
-2.4	$0	$0	$339	$282	$621
-2.1	$0	$0	$375	$312	$687
-1.8	$0	$0	$401	$312	$713
-1.5	$0	$0	$410	$322	$732
-1.2	$0	$0	$411	$334	$745
-0.9	$0	$0	$412	$334	$746
-0.6	$0	$0	$426	$362	$788
-0.3	$0	$0	$504	$363	$867
0	$0	$0	$504	$374	$877
0.1	$221	$400	$504	$374	$1,498
0.3	$384	$407	$504	$374	$1,668
0.6	$431	$457	$504	$374	$1,765
0.9	$492	$578	$504	$374	$1,947
1.2	$494	$578	$504	$374	$1,949
1.5	$494	$578	$504	$374	$1,949
1.8	$495	$578	$504	$374	$1,950
2.1	$495	$578	$504	$374	$1,950
2.4	$495	$578	$504	$374	$1,950
2.7	$495	$578	$504	$374	$1,950

[1] distance between floors is variable in model, 2.7m illustrated

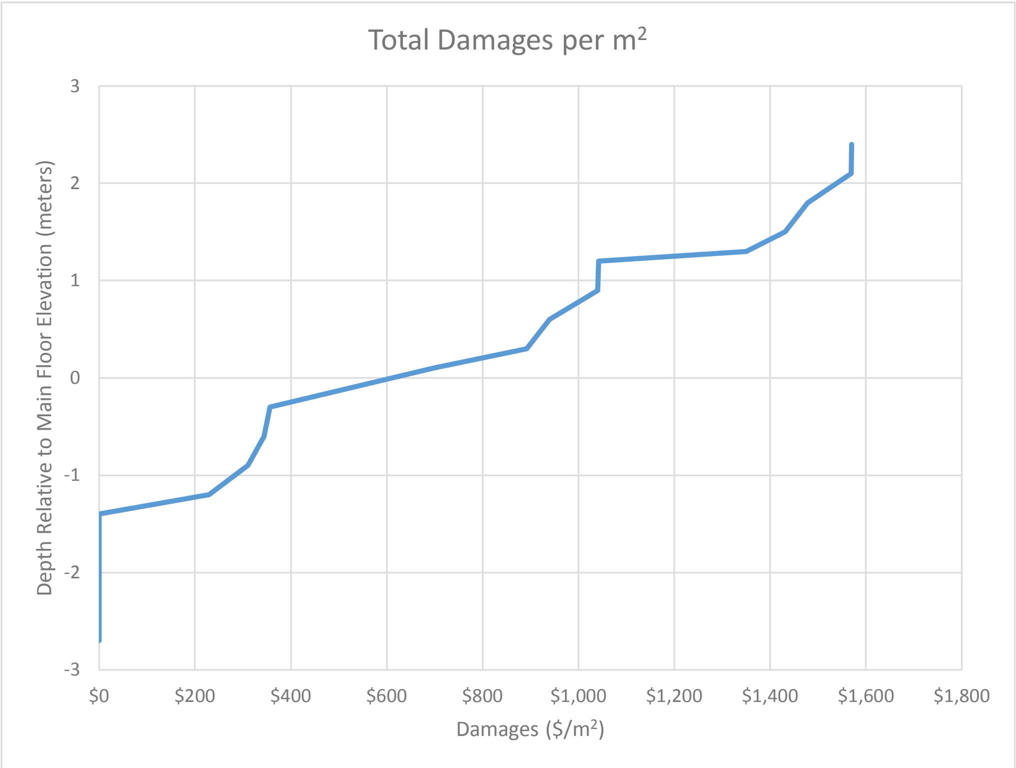
[2] not all structures have basements and it is a separate calculation in the model



Class B - Residential Split Level					
Depth relative to main floor[1]	Main Floor Contents	Main Floor Structure	Basement Contents[2]	Basement Structure[2]	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$0	$0	$0
-2.4	$0	$0	$0	$0	$0
-2.1	$0	$0	$0	$0	$0
-1.8	$0	$0	$0	$0	$0
-1.5	$0	$0	$0	$0	$0
-1.4	$0	$0	$0	$0	$0
-1.2	$0	$0	$113	$116	$229
-0.9	$0	$0	$169	$141	$310
-0.6	$0	$0	$188	$156	$344
-0.3	$0	$0	$200	$156	$356
0.1	$108	$210	$219	$161	$698
0.3	$194	$217	$296	$185	$892
0.6	$217	$242	$296	$185	$940
0.9	$252	$302	$297	$190	$1,040
1.2	$253	$302	$297	$191	$1,043
1.3	$360	$502	$297	$191	$1,350
1.5	$441	$502	$297	$191	$1,431
1.8	$463	$527	$297	$191	$1,478
2.1	$494	$588	$297	$191	$1,569
2.4	$495	$588	$297	$191	$1,570

[1]distance between floors is variable in model, 2.7m illustrated

[2]not all structures have basements and it is a separate calculation in the model

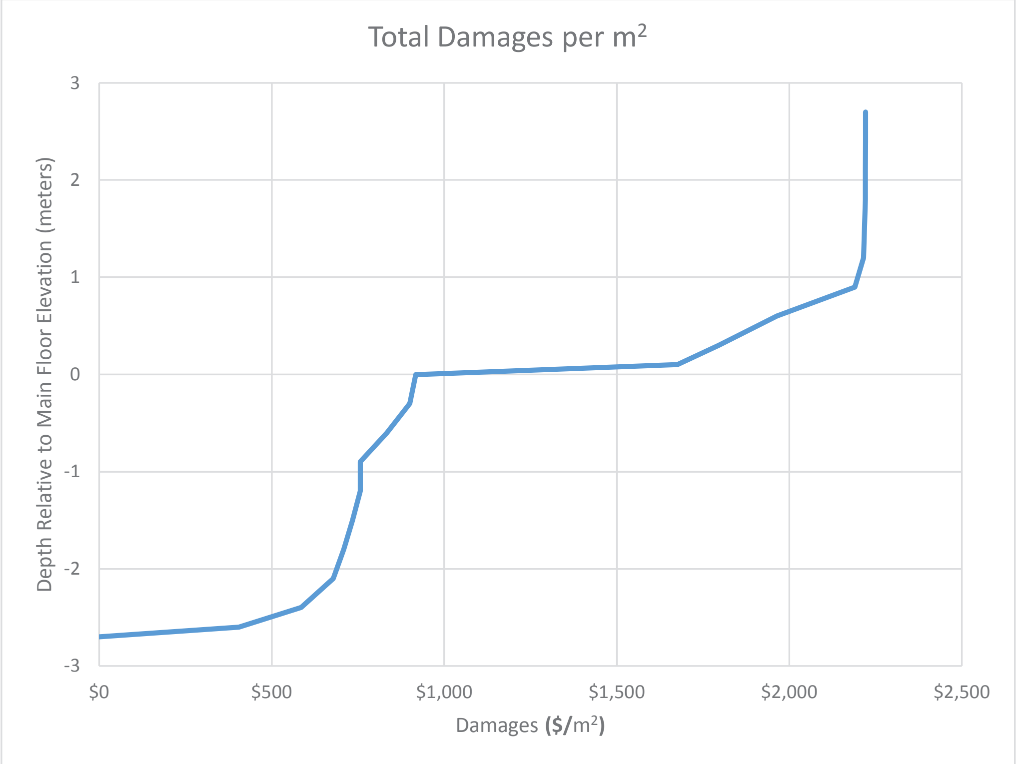


APPENDIX D - Damage Curves and Values - Class B - Residential Two-Storey

Class B - Residential Two-Storey					
Depth relative to main floor[1]	Main Floor Contents	Main Floor Structure	Basement Contents[2]	Basement Structure[2]	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$163	$242	$405
-2.4	$0	$0	$255	$331	$586
-2.1	$0	$0	$294	$385	$678
-1.8	$0	$0	$324	$385	$709
-1.5	$0	$0	$332	$402	$735
-1.2	$0	$0	$336	$420	$756
-0.9	$0	$0	$336	$420	$756
-0.6	$0	$0	$364	$470	$833
-0.3	$0	$0	$427	$473	$900
0	$0	$0	$427	$490	$917
0.1	$235	$524	$427	$490	$1,676
0.3	$342	$536	$427	$490	$1,795
0.6	$422	$625	$427	$490	$1,964
0.9	$481	$792	$427	$490	$2,190
1.2	$507	$792	$427	$490	$2,216
1.5	$508	$792	$427	$490	$2,217
1.8	$511	$792	$427	$490	$2,220
2.1	$511	$792	$427	$490	$2,220
2.4	$512	$792	$427	$490	$2,221
2.7	$512	$792	$427	$490	$2,221

[1]distance between floors is variable in model, 2.7m illustrated

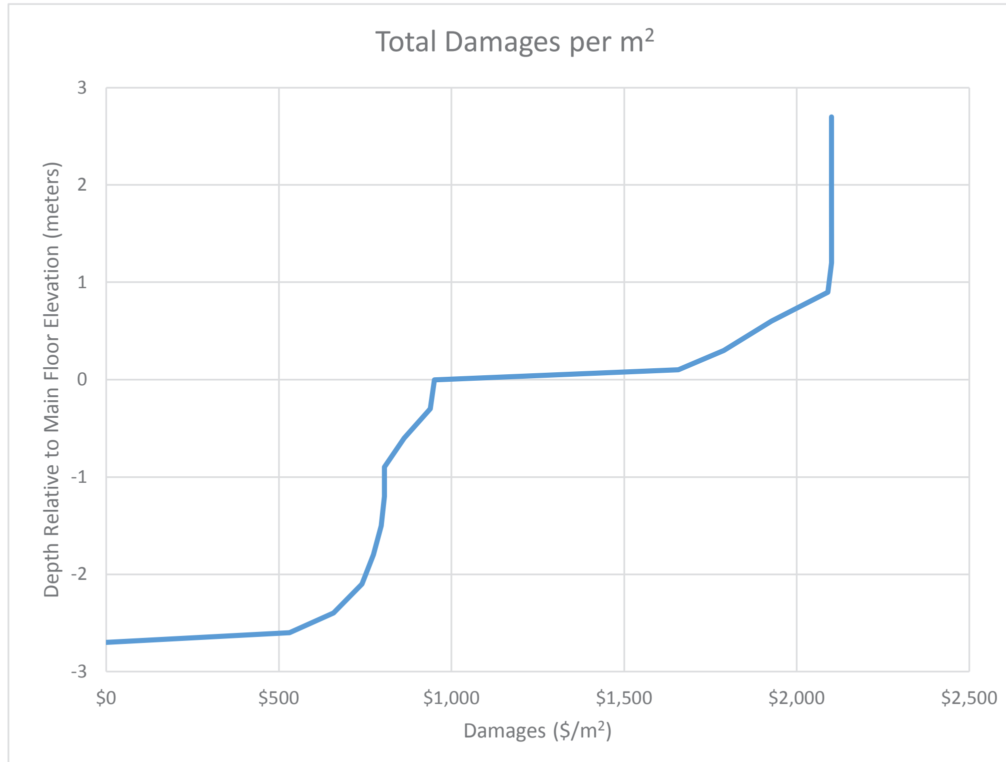
[2]not all structures have basements and it is a separate calculation in the model



Class C - Residential One-Storey					
Depth relative to main floor[1]	Main Floor Contents	Main Floor Structure	Basement Contents[2]	Basement Structure[2]	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$294	$237	$530
-2.4	$0	$0	$350	$309	$659
-2.1	$0	$0	$385	$356	$741
-1.8	$0	$0	$418	$356	$774
-1.5	$0	$0	$422	$374	$796
-1.2	$0	$0	$422	$383	$806
-0.9	$0	$0	$423	$383	$806
-0.6	$0	$0	$439	$424	$863
-0.3	$0	$0	$511	$427	$938
0	$0	$0	$511	$439	$950
0.1	$240	$467	$511	$439	$1,657
0.3	$360	$479	$511	$439	$1,789
0.6	$420	$557	$511	$439	$1,927
0.9	$468	$672	$511	$439	$2,090
1.2	$479	$672	$511	$439	$2,100
1.5	$479	$672	$511	$439	$2,101
1.8	$479	$672	$511	$439	$2,101
2.1	$479	$672	$511	$439	$2,101
2.4	$479	$672	$511	$439	$2,101
2.7	$479	$672	$511	$439	$2,101

[1]distance between floors is variable in model, 2.7m illustrated

[2]not all structures have basements and it is a separate calculation in the model

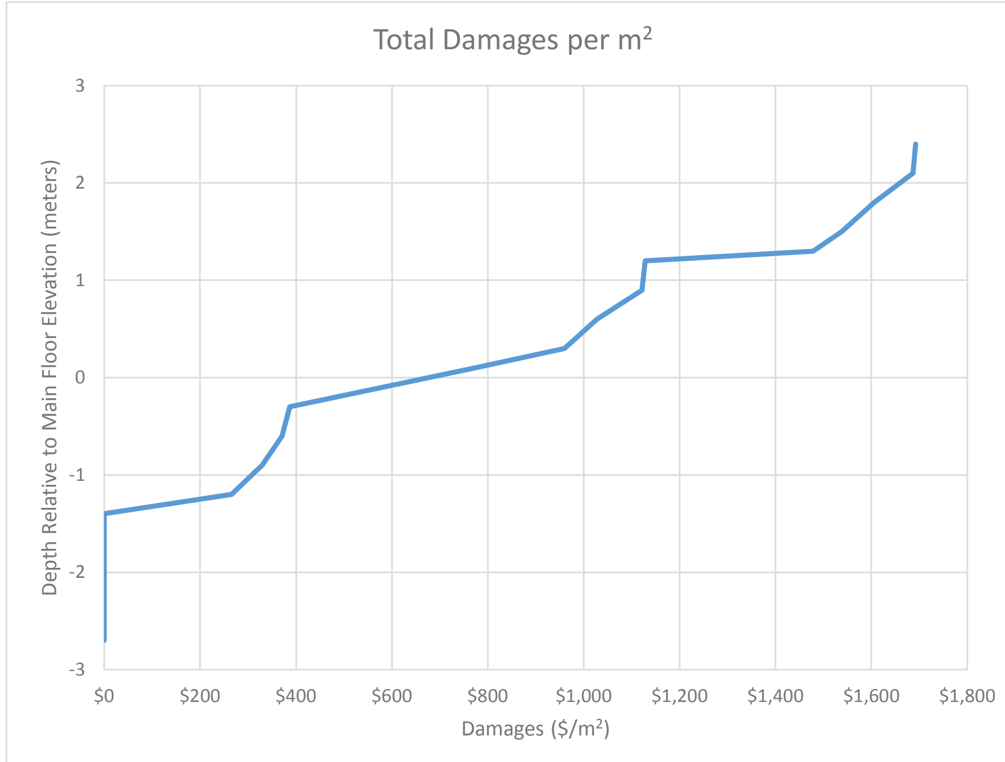


APPENDIX D - Damage Curves and Values - Class C - Residential Split Level

Class C - Residential Split Level					
Depth relative to main floor[1]	Main Floor Contents	Main Floor Structure	Basement Contents[2]	Basement Structure[2]	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$0	$0	$0
-2.4	$0	$0	$0	$0	$0
-2.1	$0	$0	$0	$0	$0
-1.8	$0	$0	$0	$0	$0
-1.5	$0	$0	$0	$0	$0
-1.4	$0	$0	$0	$0	$0
-1.2	$0	$0	$147	$118	$265
-0.9	$0	$0	$175	$154	$329
-0.6	$0	$0	$192	$178	$371
-0.3	$0	$0	$209	$178	$387
0.1	$117	$245	$225	$187	$774
0.3	$183	$257	$302	$218	$960
0.6	$212	$296	$302	$218	$1,028
0.9	$240	$354	$302	$225	$1,121
1.2	$245	$354	$302	$227	$1,128
1.3	$363	$587	$302	$227	$1,478
1.5	$423	$587	$302	$227	$1,539
1.8	$451	$626	$302	$227	$1,606
2.1	$475	$684	$302	$227	$1,687
2.4	$480	$684	$302	$227	$1,692

[1]distance between floors is variable in model, 2.7m illustrated

[2]not all structures have basements and it is a separate calculation in the model

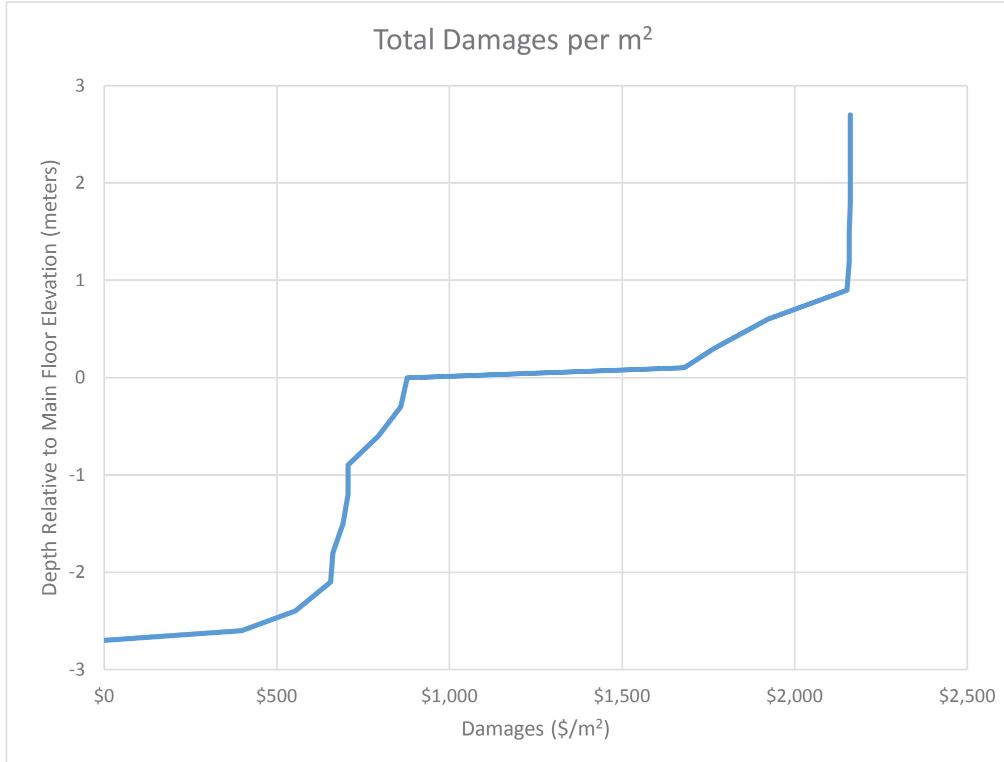


APPENDIX D - Damage Curves and Values - Class C - Residential Two-Storey

Class C - Residential Two-Storey					
Depth relative to main floor[1]	Main Floor Contents	Main Floor Structure	Basement Contents[2]	Basement Structure[2]	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$191	$207	$398
-2.4	$0	$0	$232	$322	$554
-2.1	$0	$0	$257	$399	$656
-1.8	$0	$0	$264	$399	$663
-1.5	$0	$0	$264	$428	$692
-1.2	$0	$0	$264	$442	$706
-0.9	$0	$0	$264	$442	$706
-0.6	$0	$0	$287	$508	$794
-0.3	$0	$0	$346	$512	$858
0	$0	$0	$346	$532	$878
0.1	$204	$599	$346	$532	$1,681
0.3	$271	$619	$346	$532	$1,767
0.6	$301	$744	$346	$532	$1,923
0.9	$376	$897	$346	$532	$2,152
1.2	$383	$897	$346	$532	$2,158
1.5	$384	$897	$346	$532	$2,159
1.8	$386	$897	$346	$532	$2,161
2.1	$386	$897	$346	$532	$2,161
2.4	$386	$897	$346	$532	$2,161
2.7	$386	$897	$346	$532	$2,161

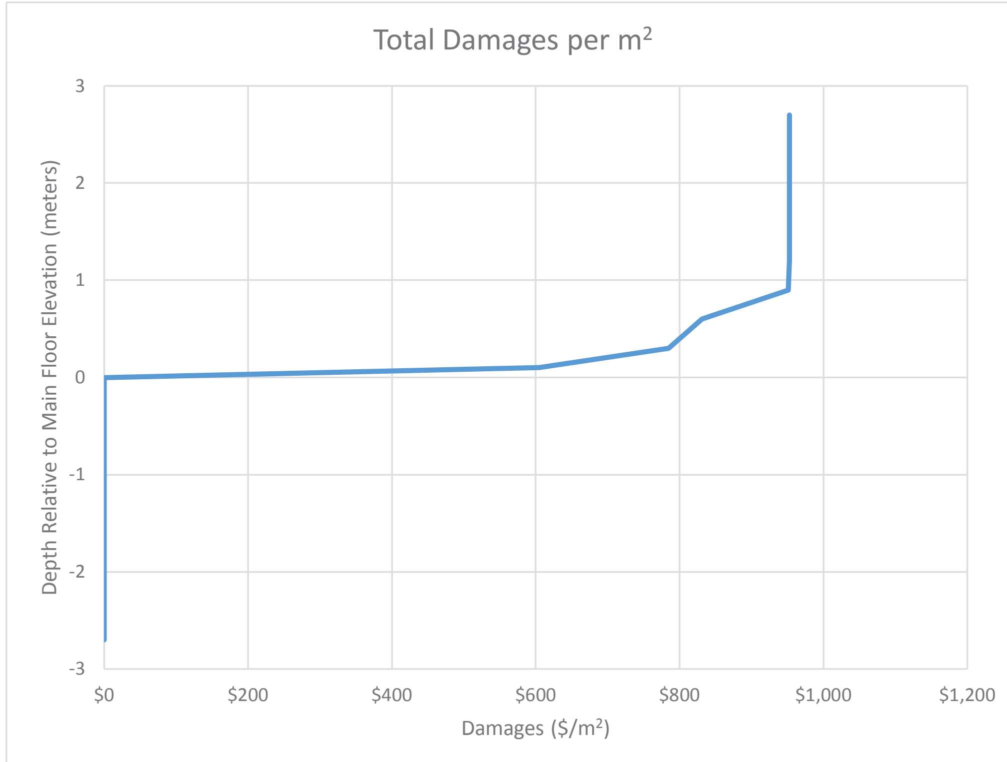
[1]distance between floors is variable in model, 2.7m illustrated

[2]not all structures have basements and it is a separate calculation in the model



APPENDIX D - Damage Curves and Values - One Storey Mobile Home (No Basement)

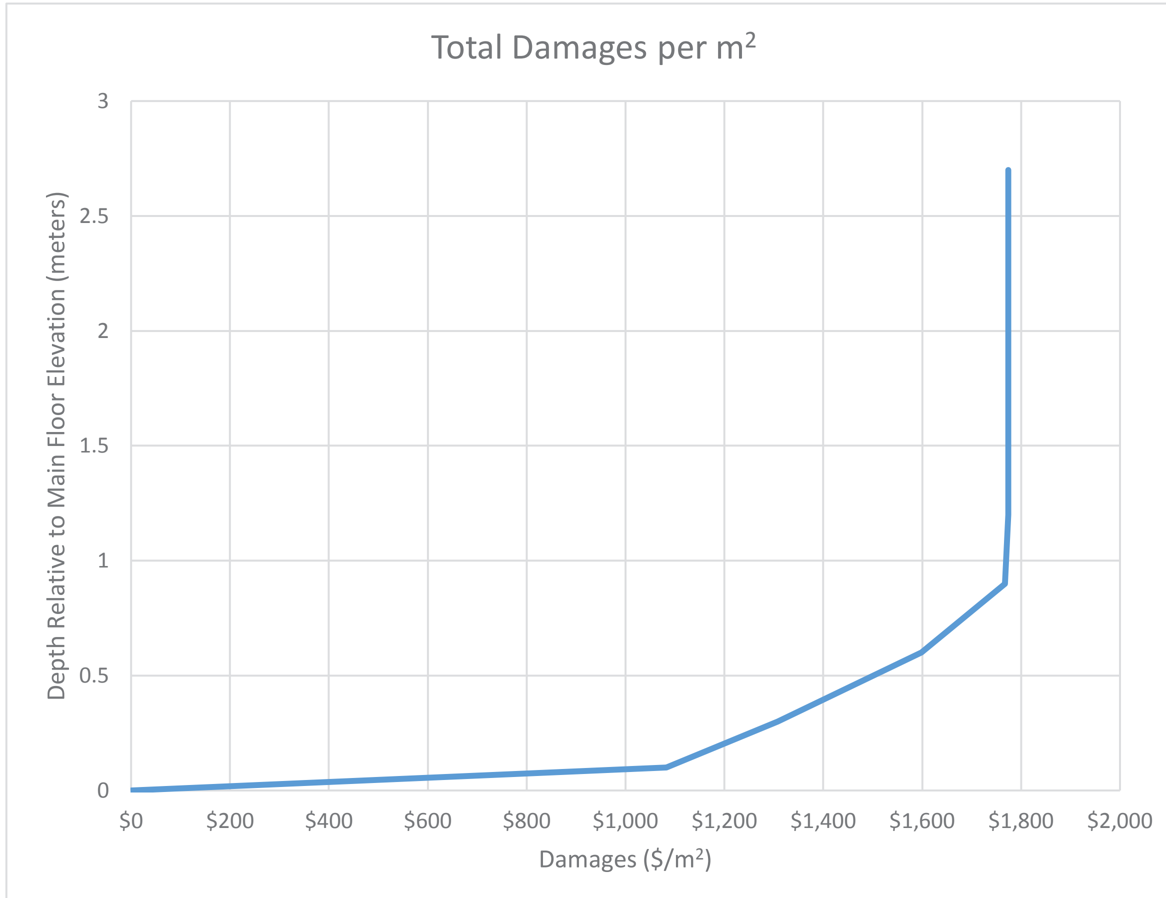
One Storey Mobile Home (No Basement)					
Depth relative to main floor	Main Floor Contents	Main Floor Structure	Basement Contents	Basement Structure	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$0	$0	$0
-2.4	$0	$0	$0	$0	$0
-2.1	$0	$0	$0	$0	$0
-1.8	$0	$0	$0	$0	$0
-1.5	$0	$0	$0	$0	$0
-1.2	$0	$0	$0	$0	$0
-0.9	$0	$0	$0	$0	$0
-0.6	$0	$0	$0	$0	$0
-0.3	$0	$0	$0	$0	$0
0	$0	$0	$0	$0	$0
0.1	$243	$362	$0	$0	$605
0.3	$379	$405	$0	$0	$785
0.6	$426	$405	$0	$0	$831
0.9	$481	$470	$0	$0	$951
1.2	$483	$470	$0	$0	$953
1.5	$483	$470	$0	$0	$953
1.8	$483	$470	$0	$0	$953
2.1	$483	$470	$0	$0	$953
2.4	$483	$470	$0	$0	$953
2.7	$483	$470	$0	$0	$953



APPENDIX D - Damage Curves and Values - Apartment Building with Four Floors or Less

Apartment Building with Four Floors or Less			
Depth relative to main floor	Main Floor Contents	Main Floor Structure	Total
0	$0	$0	$0
0.1	$260	$822	$1,082
0.3	$394	$914	$1,307
0.6	$494	$1,105	$1,599
0.9	$565	$1,203	$1,768
1.2	$571	$1,203	$1,774
1.5	$571	$1,203	$1,774
1.8	$571	$1,203	$1,774
2.1	$571	$1,203	$1,774
2.4	$571	$1,203	$1,774
2.7	$571	$1,203	$1,774

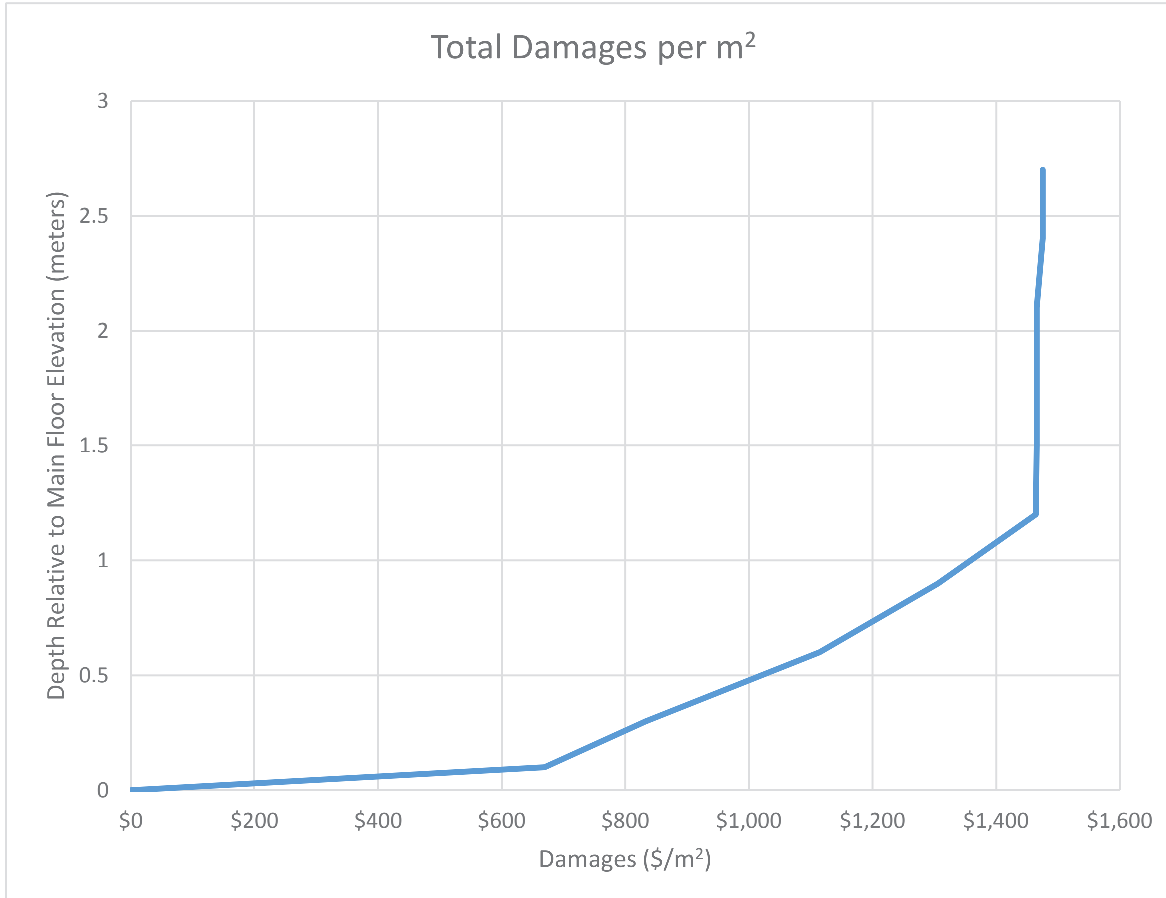
*Underground Parking damages are $215/m^2



APPENDIX D - Damage Curves and Values - Apartment Building with Five Floors or More

Apartment Building with Five Floors or More			
Depth relative to main floor	Main Floor Contents	Main Floor Structure	Total
0	$0	$0	$0
0.1	$221	$449	$670
0.3	$384	$449	$833
0.6	$435	$680	$1,115
0.9	$514	$792	$1,306
1.2	$527	$937	$1,464
1.5	$528	$937	$1,466
1.8	$528	$937	$1,466
2.1	$528	$937	$1,466
2.4	$538	$937	$1,475
2.7	$538	$937	$1,475

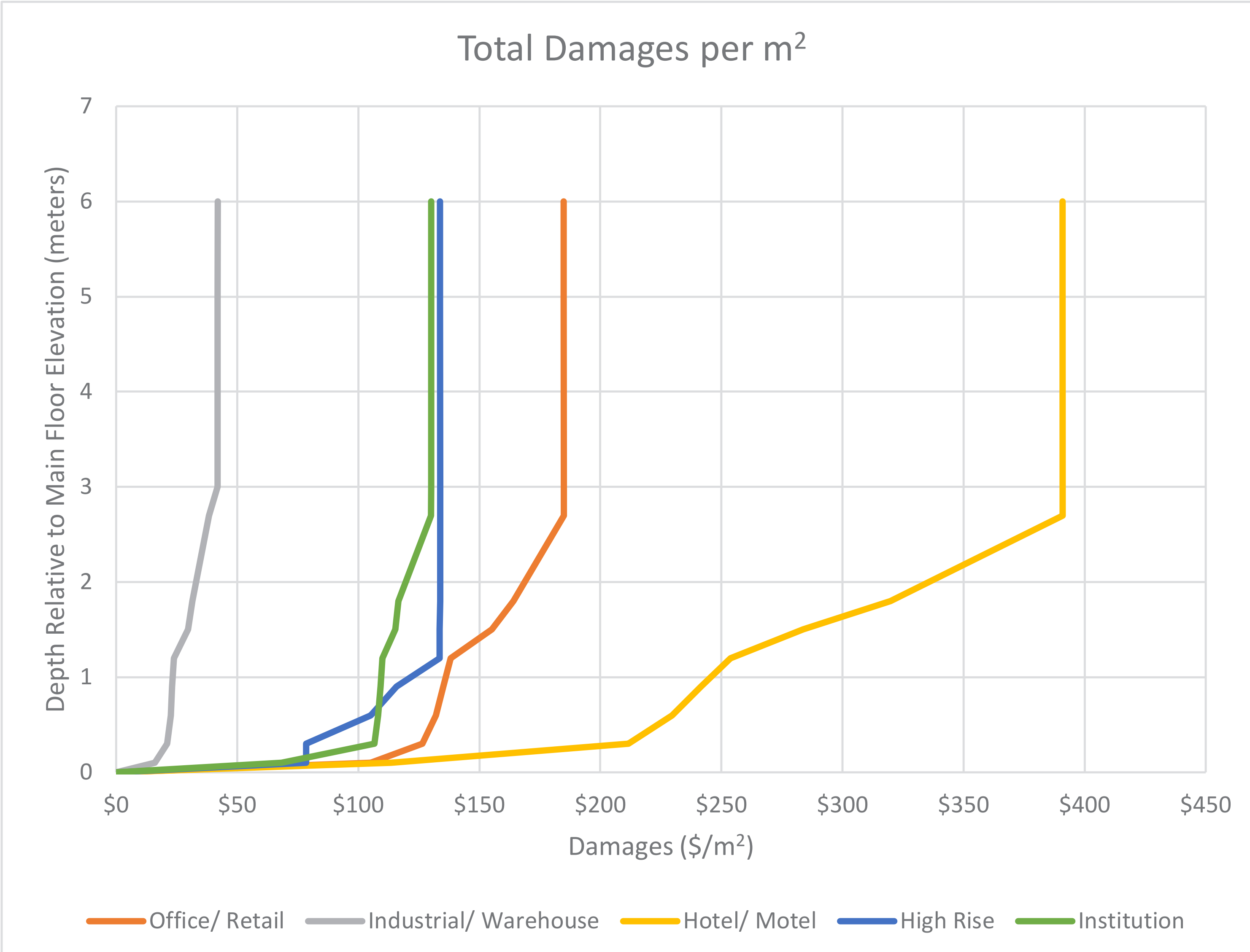
*Underground Parking damages are $215/m^2



APPENDIX D - Damage Curves and Values - Non-Residential Structure

	S1	S2	S3	S4	S5
Relative Depth (m)	Office/ Retail	Industrial/ Warehouse	Hotel/ Motel	High Rise	Institution
0	$0	$0	$0	$0	$0
0.1	$105	$16	$113	$79	$68
0.3	$127	$21	$212	$79	$107
0.6	$132	$23	$230	$105	$108
0.9	$135	$23	$242	$116	$109
1.2	$138	$24	$254	$134	$110
1.5	$155	$30	$284	$134	$115
1.8	$164	$31	$320	$134	$117
2.7	$185	$38	$391	$134	$130
3	$185	$42	$391	$134	$130
5	$185	$42	$391	$134	$130
6	$185	$42	$391	$134	$130

*Underground Parking damages are $215/m^2



Total Damages per m²
Depth Relative to Main Floor Elevation (meters)
0
1
2
3
4
5
6
7
$0
$50
$100
$150
$200
$250
$300
$350
$400
$450
Damages ($/m²)
Office/ Retail
Industrial/ Warehouse
Hotel/ Motel
High Rise
Institution

APPENDIX D - Damage Curves and Values - Non-Residential Contents

	A1	B1	C1	C2	C3	C4	C5	C6
Relative Depth (m)	General Office	Medical	Shoes	Clothing	Stereos/TV	Paper Products	Hardware/ Carpet	Retail
0	$0	$0	$0	$0	$0	$0	$0	$0
0.15	$121	$150	$200	$187	$352	$96	$142	$209
0.3	$127	$450	$600	$385	$504	$183	$265	$408
0.6	$219	$900	$729	$572	$689	$366	$427	$636
0.9	$380	$1,350	$984	$1,314	$852	$557	$880	$844
1.2	$380	$1,380	$1,100	$1,425	$1,139	$740	$943	$1,072
1.5	$380	$1,425	$1,121	$1,705	$1,352	$810	$1,005	$1,252
1.8	$380	$1,500	$1,159	$1,862	$1,467	$906	$1,068	$1,366
2.1	$380	$1,500	$1,189	$1,862	$1,467	$906	$1,130	$1,366
2.4	$380	$1,500	$1,219	$1,862	$1,467	$906	$1,257	$1,366
2.7	$381	$1,500	$1,219	$1,862	$1,467	$906	$1,257	$1,366
3	$381	$1,500	$1,219	$1,862	$1,467	$906	$1,257	$1,366

*Underground Parking damages are $215/m^2

APPENDIX D - Damage Curves and Values - Non-Residential Contents

	C7	D1	E1	F1	G1	H1	I1	J1
Relative Depth (m)	Misc Retail	Furniture / Appliances	Groceries	Drugs	Auto	Hotels	Restaurant	Personal Services
0	$0	$0	$0	$0	$0	$0	$0	$0
0.15	$182	$138	$148	$50	$46	$20	$72	$37
0.3	$349	$198	$270	$350	$254	$39	$257	$74
0.6	$512	$306	$410	$505	$462	$52	$434	$167
0.9	$782	$345	$531	$610	$878	$65	$442	$260
1.2	$919	$376	$616	$715	$982	$104	$452	$278
1.5	$1,026	$408	$616	$820	$1,005	$131	$452	$408
1.8	$1,103	$439	$616	$897	$1,005	$144	$452	$687
2.1	$1,115	$439	$616	$897	$1,005	$144	$452	$696
2.4	$1,134	$439	$616	$897	$1,005	$144	$452	$705
2.7	$1,134	$439	$616	$897	$1,005	$144	$452	$705
3	$1,134	$439	$616	$897	$1,005	$144	$452	$705

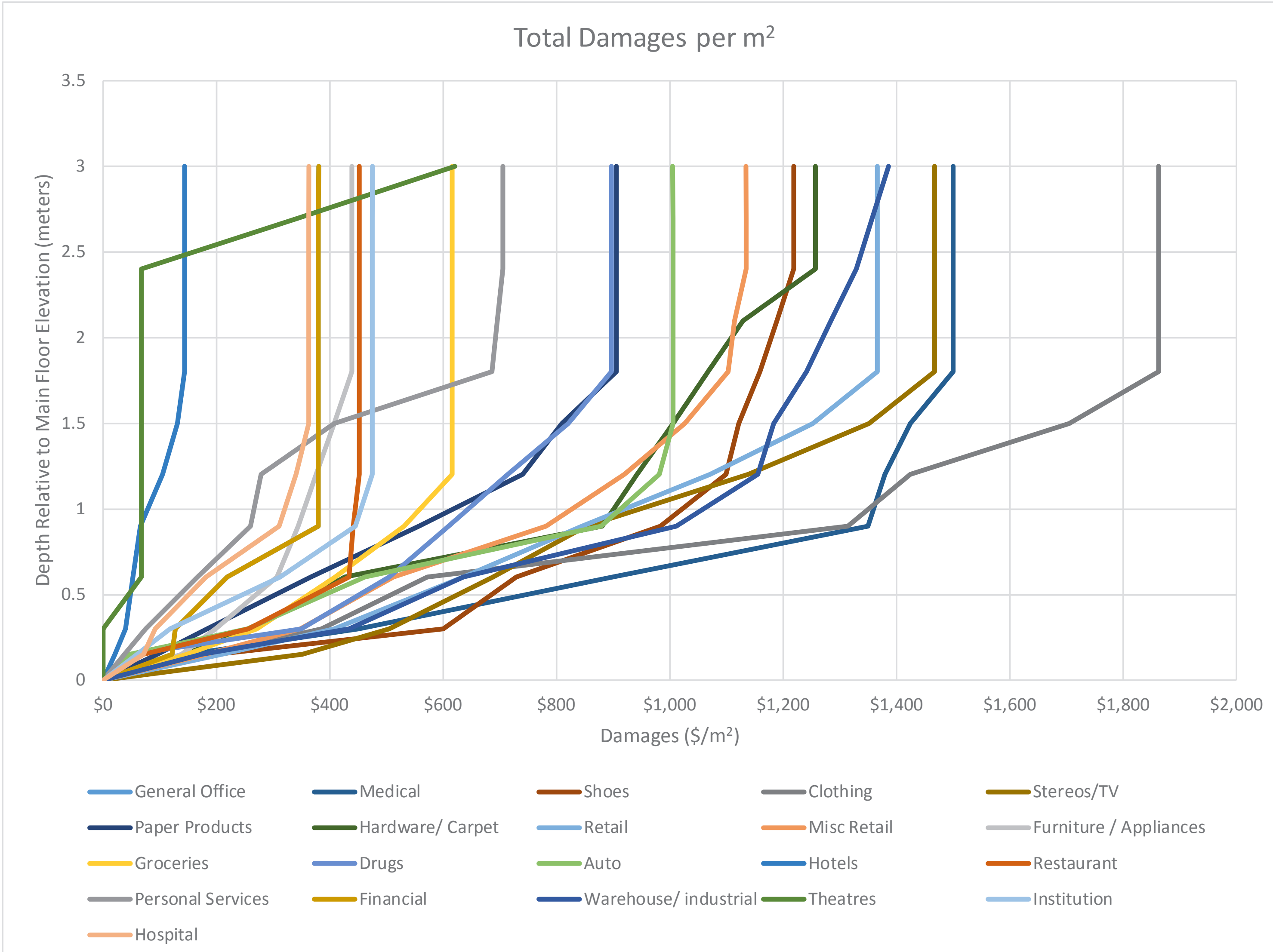
*Underground Parking damages are $215/m^2

APPENDIX D - Damage Curves and Values - Non-Residential Contents

	K1	L1	M1	N1	N2
Relative Depth (m)	Financial	Warehouse/ industrial	Theatres	Institution	Hospital
0	$0	$0	$0	$0	$0
0.15	$121	$173	$0	$59	$72
0.3	$127	$433	$0	$119	$92
0.6	$219	$635	$68	$312	$182
0.9	$380	$1,011	$68	$446	$311
1.2	$380	$1,155	$68	$475	$341
1.5	$380	$1,184	$68	$475	$363
1.8	$380	$1,242	$68	$475	$363
2.1	$380	$1,285	$68	$475	$363
2.4	$380	$1,328	$68	$475	$363
2.7	$380	$1,357	$344	$475	$363
3	$380	$1,386	$621	$475	$363

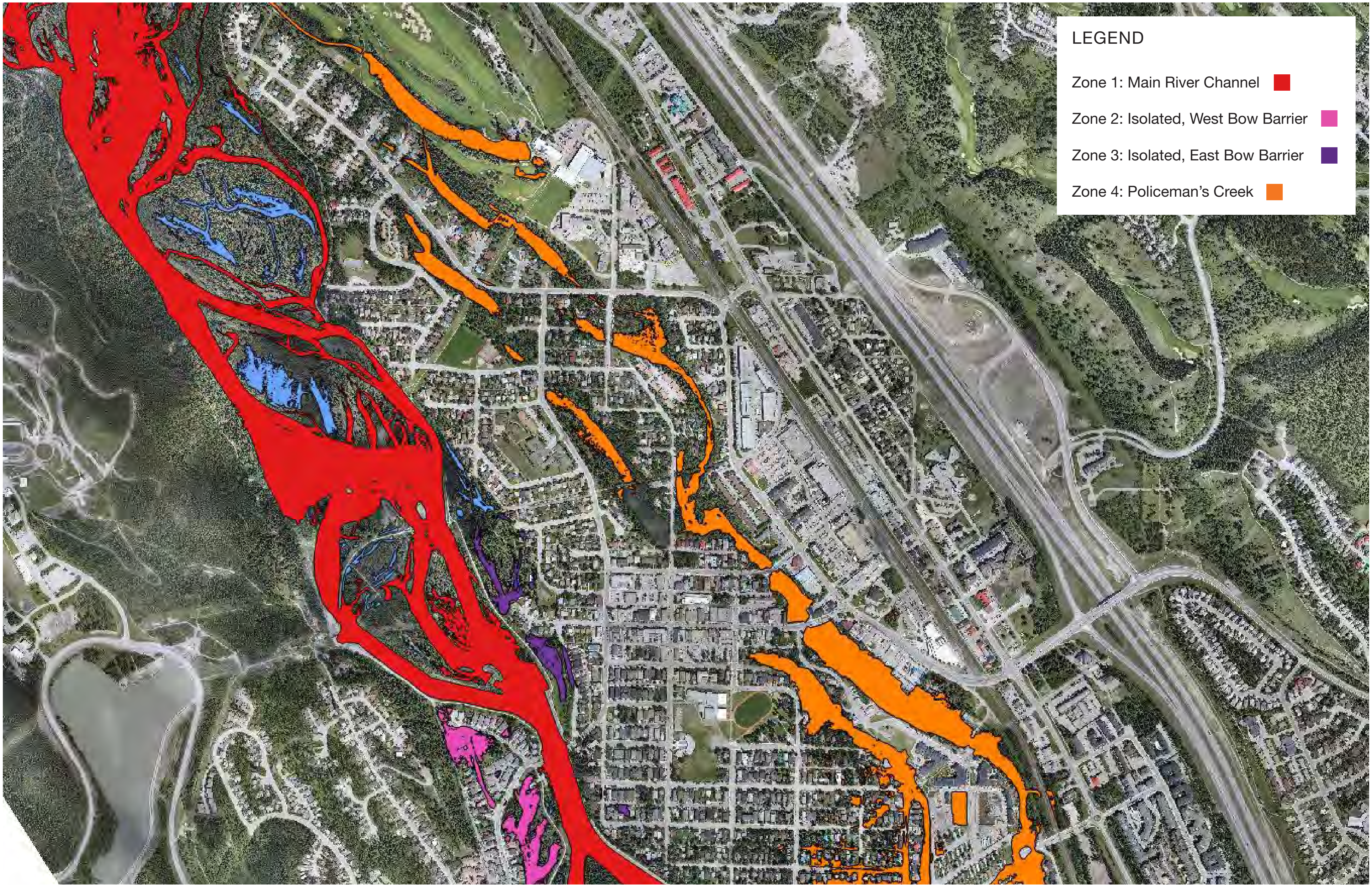
*Underground Parking damages are $215/m^2

APPENDIX D - Damage Curves and Values - Non-Residential Contents

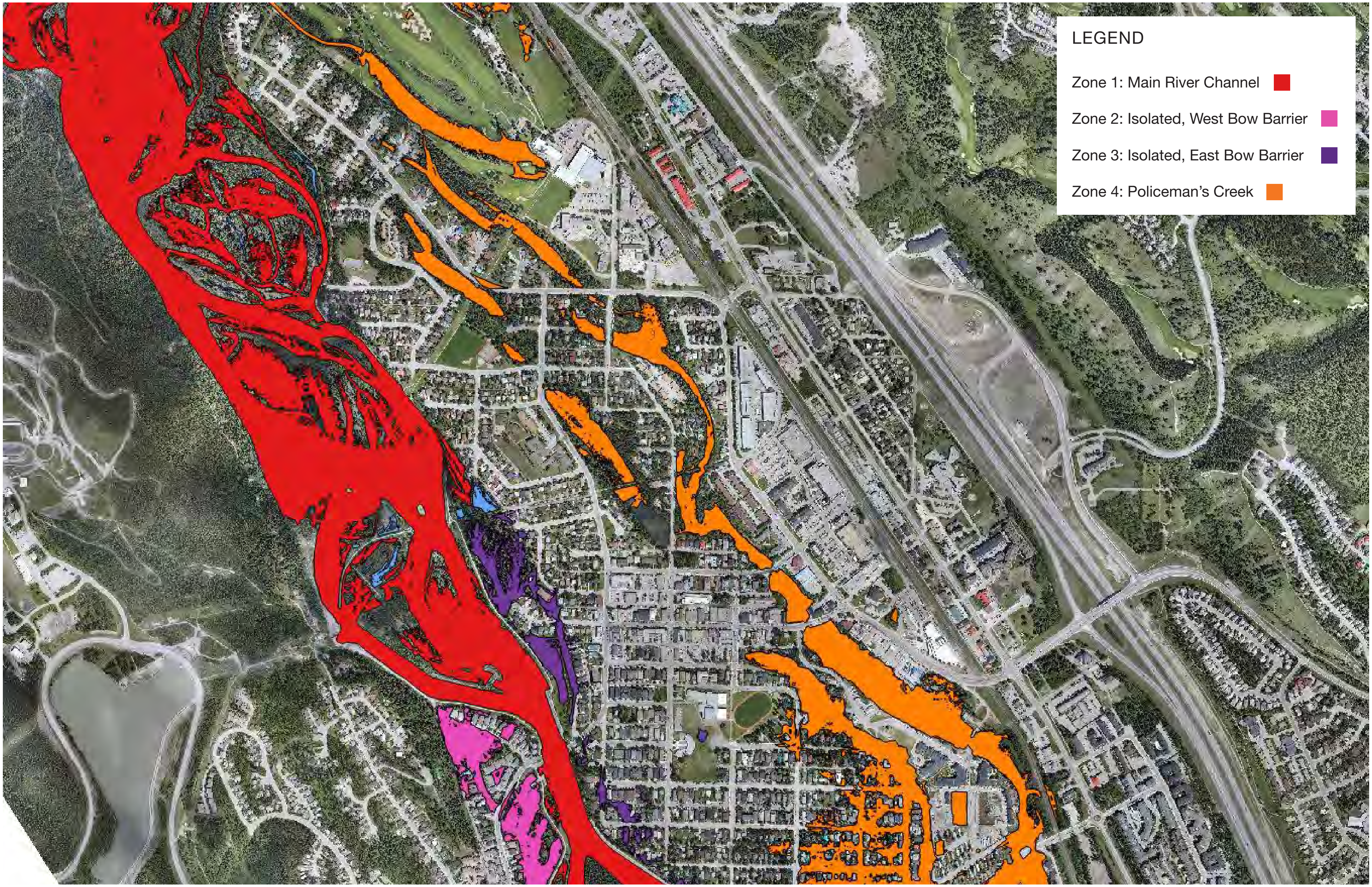


Appendix E – Canmore Flood Elevation Mapping

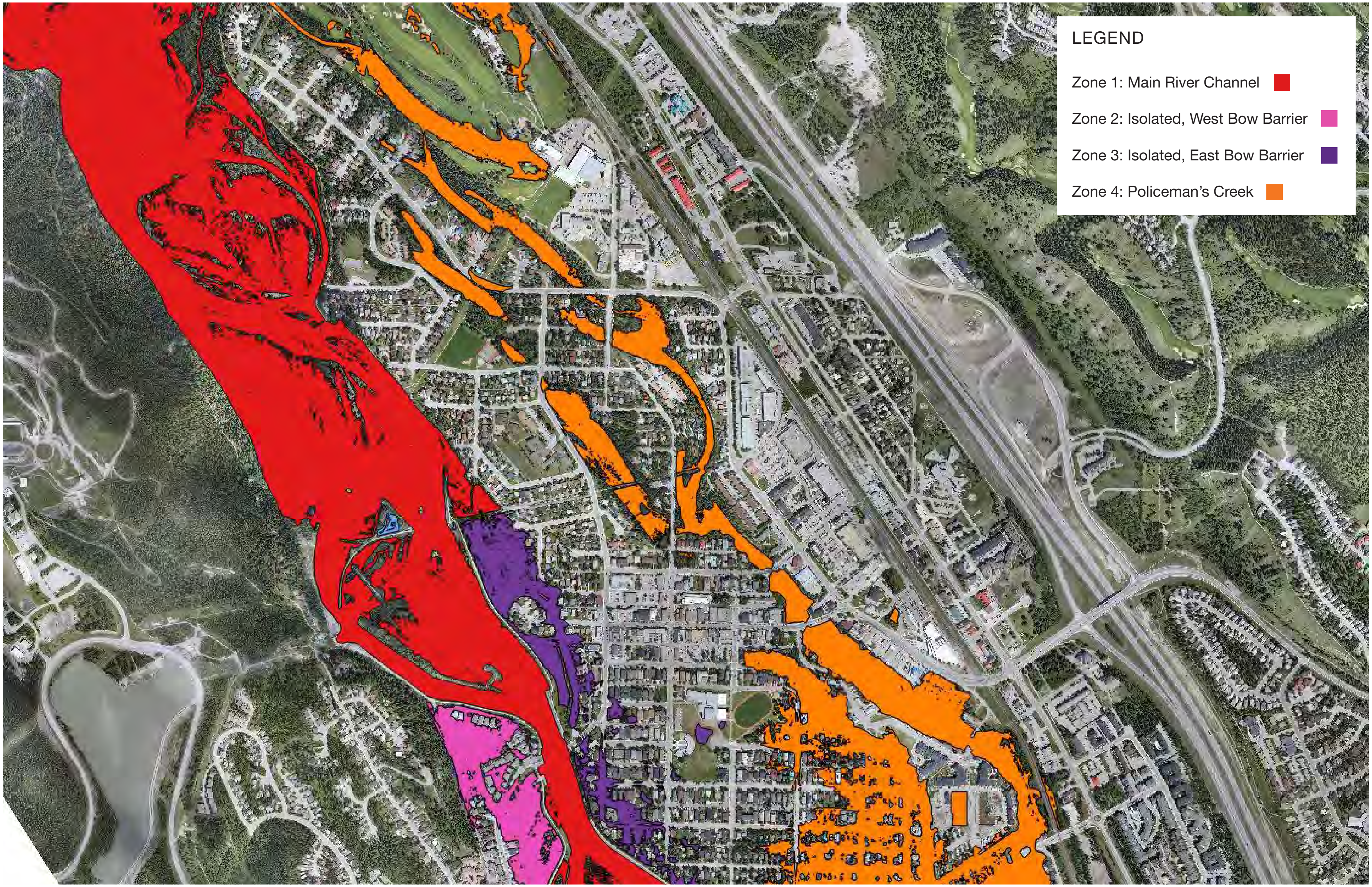
APPENDIX E - Canmore Flood Elevation Mapping - 1:2 Year Flood



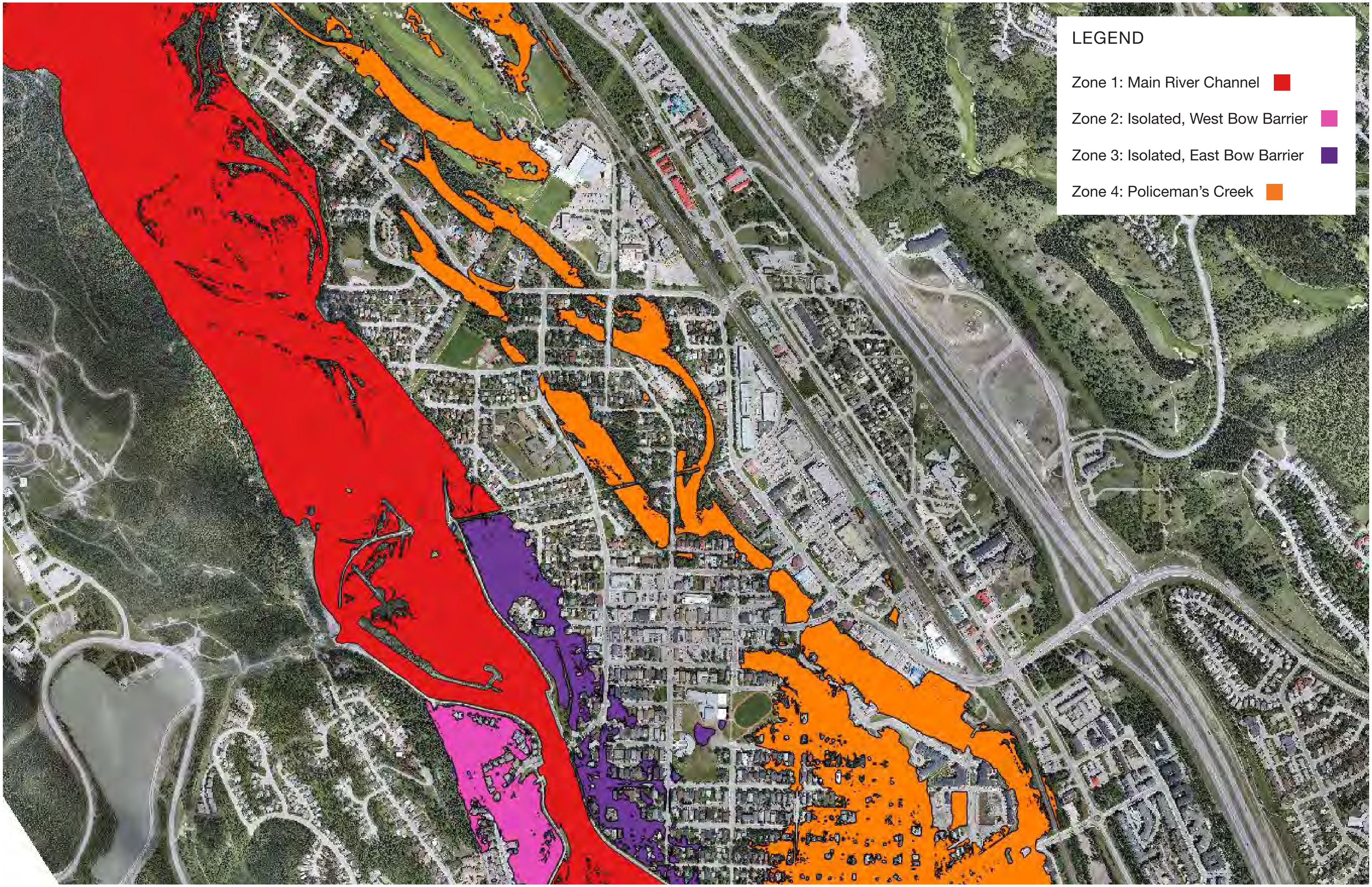
APPENDIX E - Canmore Flood Elevation Mapping - 1:5 Year Flood



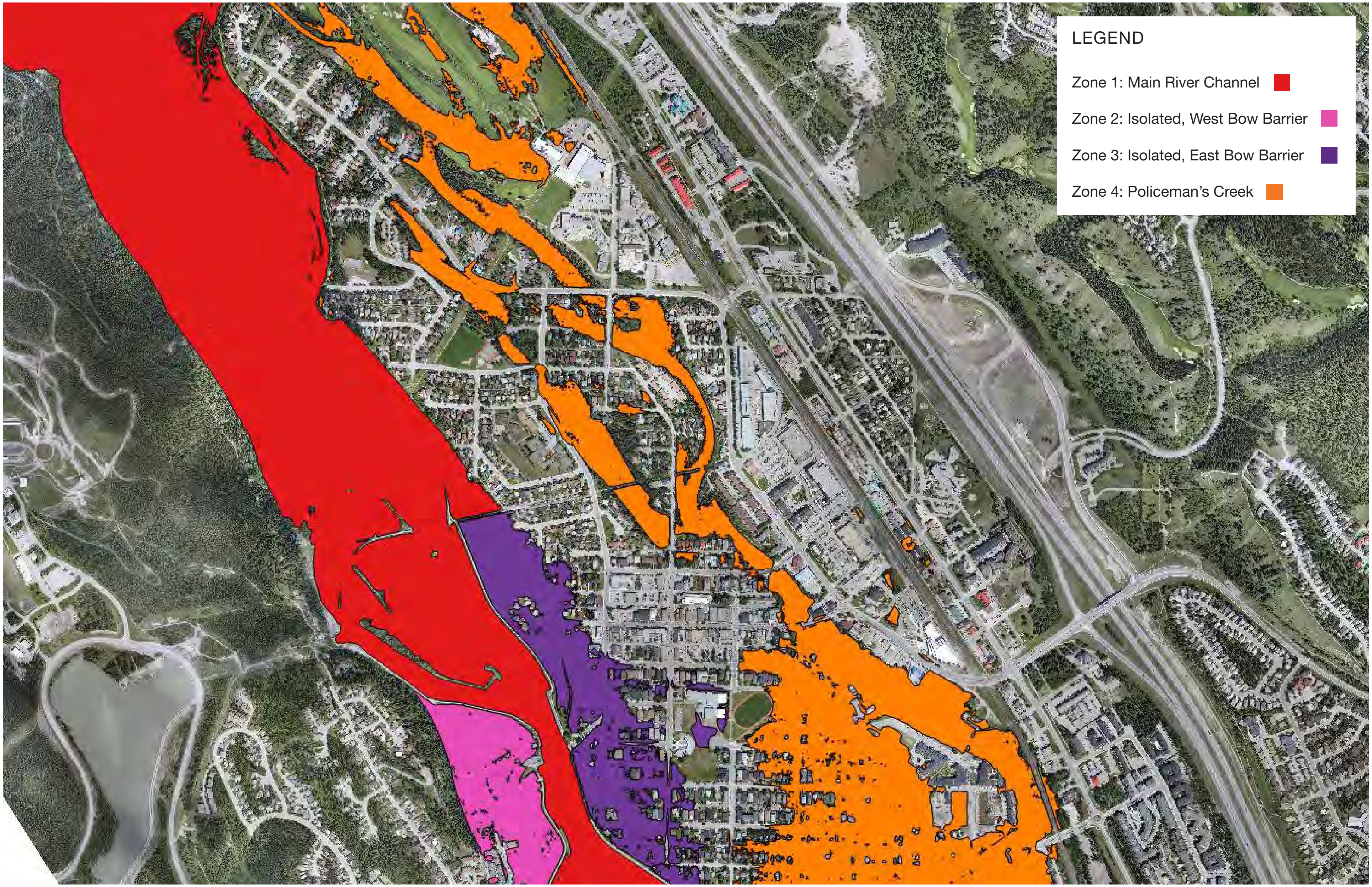
APPENDIX E - Canmore Flood Elevation Mapping - 1:10 Year Flood



APPENDIX E - Canmore Flood Elevation Mapping - 1:20 Year Flood



APPENDIX E - Canmore Flood Elevation Mapping - 1:50 Year Flood



APPENDIX E - Canmore Flood Elevation Mapping - 1:100 Year Flood