Report

Development and Application of Flood Depth-Damage Curves for the Muskoka River Watershed

H367619-0000-200-230-0001

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Appendix B **GIS Process – Structure Classification and Valuations**

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1. Introduction

1.1 Background

The District Municipality of Muskoka (DMM) seeks to reduce flood risk and address watershed health in the Muskoka River Watershed (MRW) and engaged the Province of Ontario for support to do so. In turn, DMM scoped 12 projects designed to describe the existing conditions within the watershed, and to inform a future integrated watershed management (IWM) approach to flood risk reduction. This IWM approach seeks to balance conservation and development while managing human activities and natural resources at a watershed scale. As part of this initiative, Hatch was retained by DMM to execute two projects:

- Operational Adjustments and Scoping Study for the Muskoka River Water Management Plan
- Structural and Watershed-scale Flood Mitigation.

These projects derived flood risk mitigation options for areas within the MRW with a focus on changes to the operational aspects of the water management plan, and structural changes to the flow conveyance network (e.g., channel enlargement). The ranking (or relative merit) of the conceived options in terms of net benefit was relatively uncertain because flood risk reduction could only be quantified by changes to water level and the number of buildings impacted between pre-implementation and post-implementation. The number of *impacted buildings* simply represented the number of buildings within the inundation zone and, consequently, provided only a granular indication of impact. This metric of impact assessment did not quantify damage (in any form) and, in turn, could not be used to definitively assist flood risk mitigation decision making. As such, DMM commissioned this supplemental study to define flood stage- (or depth-) damage curves for the MRW, develop a tool for assessing flood impact more decisively, and apply the tool to estimate damages for the regulatory flood event.

1.2 Objective and Approach

The Federal Guidelines[1] define flood depth-damage curves as *a one-dimensional mathematical relationship between the depth of water above or below the first floor of a building and the amount of damage that can be attributed due to that level of water. They typically represent the average damage of a group of buildings with similar properties due to flooding in a given community.* The basis of such curves can be either empirical (derived from historically recorded damage) or synthetic (generated from expert knowledge, hypotheses, and assumptions about potential damage), or a combination. Damages are categorized into two types:

[1] Natural Resources Canada. *Federal Flood Damage Estimation Guidelines for Buildings and Infrastructure*. Version 1.0. 2021.

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- Tangible – damages to which a dollar value may be assigned.
- Intangible – damages not easily quantified monetarily such as emotional stress, illness, or loss-of-life.

Both types can be further subdivided into direct and indirect damages. Direct damages are those that occur immediately and can be directly attributable to flood inundation, while indirect damages are incidental consequences that are difficult to quantify. The Federal Guidelines illustrate these damage categories, which are repeated in Figure 1-1.

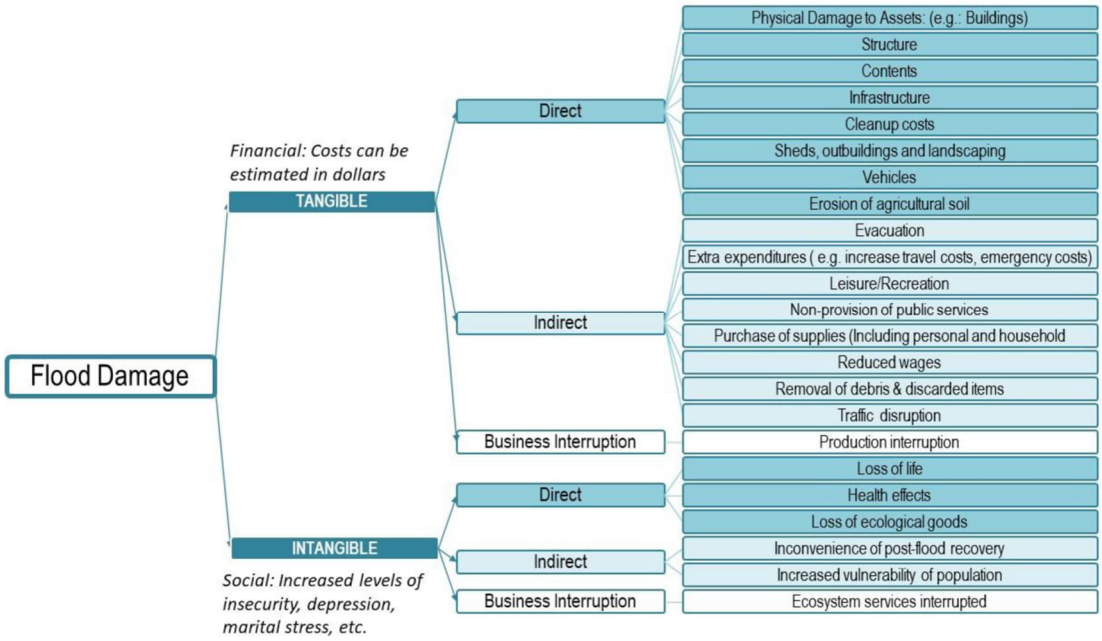

Figure 1-1: Types of Flood Damage (not exhaustive)[2]

The focus of this assessment was on potential tangible, direct damages. That is, physical damage to buildings (including structures and contents) and infrastructure (specifically roads, bridges, culverts, and water and wastewater facilities). Previous studies commissioned by the Government of Alberta and the Toronto and Region Conservation Authority (as executed by IBI Group) derived synthetic depth-damage curves that were leveraged for this study and augmented to derive synthetic Muskoka-specific curves based on data readily available from DMM and supplemental resources (e.g., Statistics Canada). The objective of this assessment was to derive representative depth-damage curves and then use these curves to estimate the total tangible, direct damages associated with the Regulatory Flood Event as determined by

[2] Natural Resources Canada. *Federal Flood Damage Estimation Guidelines for Buildings and Infrastructure*. Version 1.0. 2021. Figure 8, p22.

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the flood plain mapping studies completed by DMM and Hatch in 2020[3] and 2023[4]. The breakdown of the categories that comprise the total direct tangible damage estimate are shown in Figure 1-2.

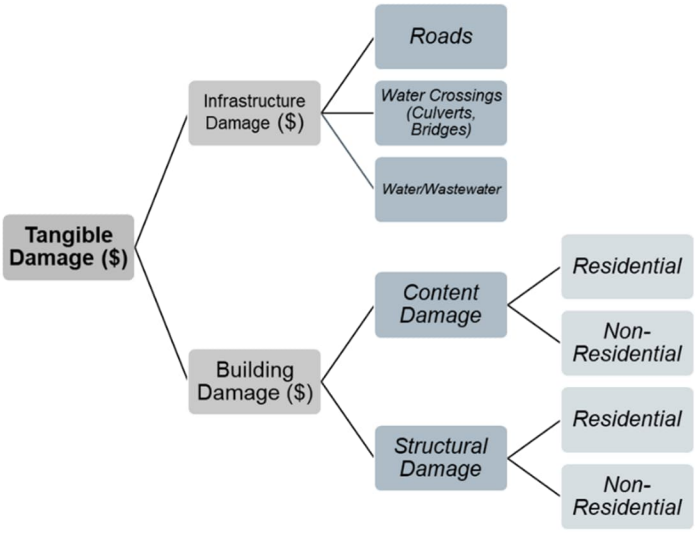

Figure 1-2: Direct Tangible Damage Categories for MRW

The focus areas within the MRW included:

- Big East River starting near Williamsport Road, to Lake Vernon, Fairy Lake, Peninsula Lake, Mary Lake, and the North Branch of the Muskoka River to its confluence with the South Branch of the Muskoka River in Bracebridge
- Lake of Bays and the South Branch of the Muskoka River to its confluence with the North Branch of the Muskoka River in Bracebridge
- Lake Muskoka to Bala and downstream to Moon Chutes (not including Lakes Rosseau and Joseph).

The work was divided into two phases where Phase 1 focused on the development of efficient procedures for manipulating and processing the datasets necessary for estimating the depth versus damage relationships. These procedures were developed using a portion of the targeted areas noted in the bulleted list above. Phase 2 applied those procedures to process depth-damage estimates for the remaining targeted areas. This report serves to summarize the work completed and offers recommendations for future study.

[3] Hatch. Technical Report for Muskoka River Flood Plain Mapping Study. Document No. H356689-00000-200-230-0002, Rev. 0. February 12, 2020.

[4] Hatch. Floodplain Mapping Technical Report for Floodplain Mapping Study. Document No. H366496-0000-200-230-0002, Rev. 0. March 16, 2023.

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2. Methodology

2.1 Data Collection and Review

Material collected for this study included data deemed to be relevant and useful to the derivation of depth-damage curves for the variety of buildings that populate the MRW and reside within flood lines presented in the floodplain maps produced between 2020 and 2023[5,6]. The geospatial data utilized to support this study is shown in Table 2-1.

Table 2-1: Project Data Sources

Source	Dataset	Data Type
DMM	Building Inventory[7]	Polygon
	Administrative Boundaries	Polygon
	Road Network	Line
	Bridge Replacement Costs	Table
	Culvert Replacement Costs	Table
	Water/Wastewater Buildings with Replacement Costs	Point
Hatch (extracted from numerical hydraulic models (HEC-RAS) described in floodplain mapping reports[5,6])	Flood Polygons	Polygon
	Flood Depth Water Surface Elevation	Raster
Town of Huntsville	Infrastructure Asset Replacement Costs	Table
	Road Asset Management Data	Table
Town of Bracebridge	Bridge Replacement Costs	Point
	Culvert Replacement Costs	Point
Esri	Basemap Imagery (used for background and data checking)	Online Service
DMM Towns	Zonal Boundaries (Muskoka, Gravenhurst, Georgian Bay, Bracebridge, Lake of Bays, and Huntsville)	Polygon
Hatch (data described in floodplain mapping reports[5,6])	LiDAR data (Digital Terrain Model/Digital Surface Model)	Raster
Municipal Property Assessment Corporation (MPAC)	MPAC Code	Online Reference
	Assessed Value	Value
Statistics Canada	Survey of Household Spending[8]	Value

[5] Hatch. Technical Report for Muskoka River Flood Plain Mapping Study. Document No. H356689-00000-200-230-0002, Rev. 0. February 12, 2020.

[6] Hatch. Floodplain Mapping Technical Report for Floodplain Mapping Study. Document No. H366496-0000-200-230-0002, Rev. 0. March 16, 2023.

[7] Procedure developed by DMM (Structure Classification and Valuation - GIS Process (2021-11-24, Revised 2023-05-30) to create Building Inventory provided to Hatch (GIS Process - Structure Classification and Valuation.docx)

[8] Statistics Canada. Table 11-10-0222-01 Household spending, Canada, regions and provinces

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Source	Dataset	Data Type
	Consumer Price Index [9]	Value
	Building Construction Price Index[10]	Value
Altus Group	Construction Cost Guide[11]	Value

The base depth-damage curves adapted for this project were sourced from the following reports.

2.1.1 Provincial Flood Damage Assessment Study (IBI Group, 2015)

This Alberta-based report is the original source of the depth-damage curves adapted for this study. This 2015 report serves as an update to curves initially derived in 1981 by IBI Group and Ecos Engineering for municipalities throughout Alberta. The scope of this report included development of updated depth-damage curves for residential, commercial, and industrial buildings vulnerable to flooding. These updates leveraged scaling indices to account for effects of inflation and economic growth on total damage estimates.

2.1.2 Toronto Flood Risk Ranking (IBI Group, 2019)

This Ontario-based report documents a study completed in 2019 by IBI Group to scale the depth-damage curves from Alberta for application within the jurisdiction of the Toronto and Region Conservation Authority (TRCA). Curve scaling included both spatial (i.e., interprovincial) and temporal factors to adjust 2015 Alberta-based curves. This report serves as a case study that, in turn, served as a basis for the current study in the MRW.

The spatial and temporal indexing was based on the following data sources.

2.1.2.1 Survey of Household Spending (SHS)

Information included in the SHS documents spending habits of Canadian consumers. SHS statistics are available through the Statistics Canada database. Unlike the CPI, the SHS reflects changes in technology and quality of goods. This focus makes the SHS a good basis for an index to scale *Residential Content Damages* (see Section 3.1.1).

2.1.2.2 Consumer Price Index (CPI)

The CPI measures price changes of standardized goods, and excludes changes in factors such as technology, quality, or consumer behaviour. CPI statistics are available through the Statistics Canada database. CPI served as the basis for an index to scale *Non-Residential Content Damages* (see Section 3.1.1).

2.1.2.3 Building Construction Price Index (BCPI)

The BCPI is a quarterly series that accounts for changes over time in real market price for construction work. BCPI statistics are available through the Statistics Canada database, with

[9] Statistics Canada. Table 18-10-0004-01 Consumer Price Index, monthly, not seasonally adjusted
[10] Statistics Canada. Table 18-10-0135-02 Building construction price indexes, percentage change, quarterly, inactive
[11] Altus Group. Construction Cost Guides (2014 and 2023)

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BCPI presented as a value relative to 2017 construction costs. The BCPI served as a basis for an index to scale *Non-Residential Structural Damages* (see Section 3.1.4), while data gaps meant that BCPI could not be used to scale *Residential Structural Damages.*

2.1.2.4 Construction Cost Guides (CC)

Construction Cost (CC) guides produced by Altus Group compare construction costs (organized by building type) in local marks across Canada. CC guides served as the basis for an index to scale *Non-Residential Structural Damages* (see Section 3.1.4).

2.1.3 Hazus Flood Technical Manual (FEMA, 2022)

This report by the Federal Emergency Management Agency (FEMA) focuses on providing guidance on how to estimate losses and risks due to flooding. More specifically for this study, it provided the main methodology to account for direct economic losses to bridges due to flooding (see Section 2.2.3).

2.2 Depth-Damage Curve Derivation

2.2.1 Overview

A depth-damage curve is a tool that relates flood depth to monetary damages resulting from flooding. Depth-damage curves are one of the most accepted and widely applied methods of assessing and quantifying damages related to flood events[12]. For this study, these damages include costs related to the buildings' structure and its contents.

As noted in Section 2.1, depth-damage curves for this study were adapted from two previous studies in Alberta[13] and Ontario[14] by the IBI Group. However, these curves were adjusted (based on judgement) where inconsistencies were found.

The following sections document the approach to estimating flood damages for buildings, roads, and water crossings. For building damage estimates, c*ontent damage* refers to all the potential financial losses resulting from flood-impacts to items that are not permanent parts of the building. Alternatively, *structural damage* refers to potential financial losses related to deterioration of the structural elements of a building caused by flooding that include internal components like electrical and plumbing systems.

2.2.2 Buildings

2.2.2.1 Depth-Damage Curve Assignment

Buildings were assigned depth-damage curves based on categories defined in the IBI Group reports. These categories include classifications of either residential or non-residential, with

[12] McGrath, Heather; Abo El Ezz, Ahmad; Mastev, Miroslav. Probabilistic depth-damage curves for assessment of flood-induced building losses. Natural Hazards. 2019. P1-14.
[13] IBI Group. Provincial Flood Damage Assessment Study. February 2015.
[14] IBI Group. Toronto Flood Risk Ranking. October 2019.

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numerous “Flood Damage Codes” within each classification. Flood Damage Codes are the classification that relates each building to a specific depth-damage curve.

The first step to assigning a depth-damage curve to a specific flood impacted building was to define the building as either residential or non-residential. This definition was based on MPAC classification codes provided in the buildings inventory data supplied by DMM. Assigning a residential/non-residential class to each building was done via a lookup table, which was derived with guidance from Table 5 of Appendix B[15]. An adapted version of IBI Group’s table for this study is provided in Appendix A of this report.

For instances where MPAC codes for flood impacted buildings in the MRW fall outside of the list outlined by IBI Group in their 2019 report, judgement was applied to fill these gaps based on a comparison of the MPAC code description and the flood damage code description. The complete lookup table for the MRW is provided in Appendix A.

The algorithm used to assign Flood Damage Codes to each residential and non-residential Building is illustrated as a flowchart in Figure 2-1.

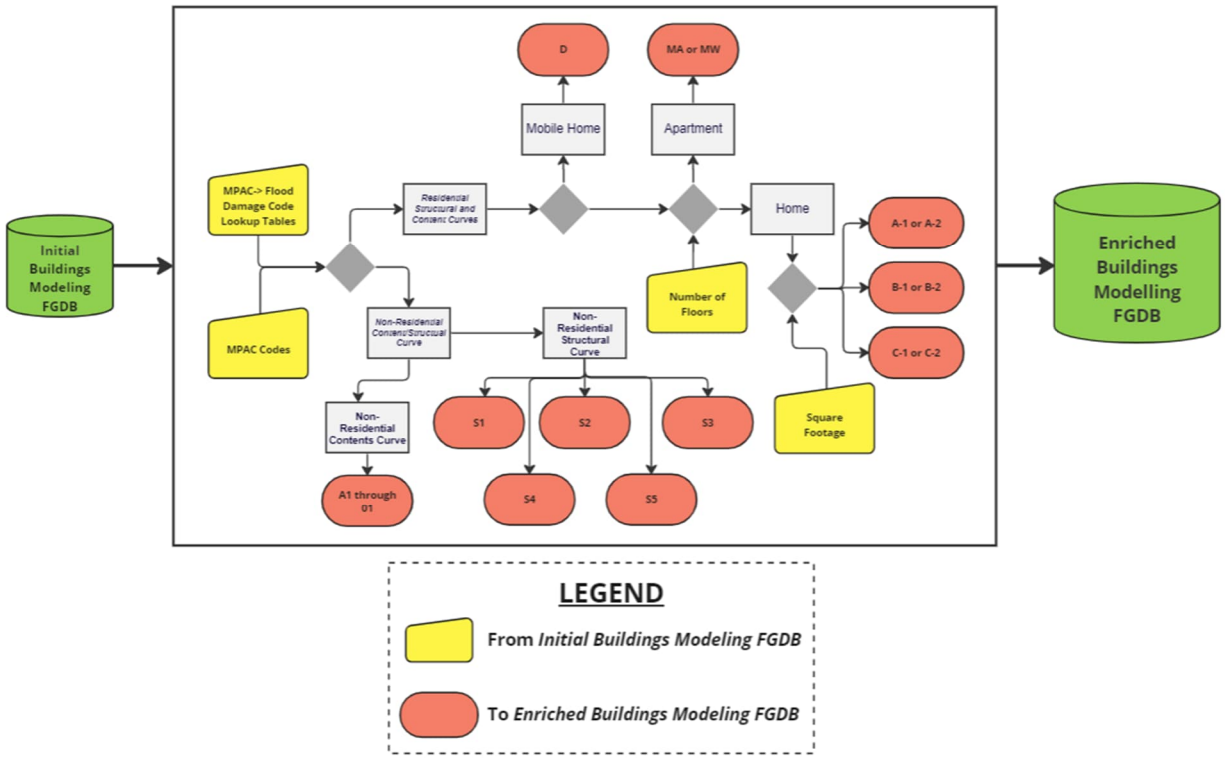

Figure 2-1: Flood Damage Coding Algorithm (Flood Damage Codes shown in Pink Ovals, FGDB refers to File Geodatabase)

[15] IBI Group. Toronto Flood Risk Ranking. October 2019.

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2.2.2.2 *Residential Buildings*

For residential buildings, the Flood Damage Code assigned to each building is the same for both content and structural damages. As shown in Figure 2-1, if a building was identified as a *Mobile Home* through its MPAC code, it was immediately designated a Flood Damage Code of "D". This designation was applied regardless of the floor area or number of stories of the building.

All other residential buildings were identified as either multi-unit buildings (MA/MW) or single dwellings (AA/A/B/C). If the number of floors of a building was five or more, it was classified as an "MA" apartment building. If the number of stories was three or four, it was classified as an "MW" apartment building. Neither MA nor MW classifications considered floor area of the building. If the building had two stories or less, it received a designation of either AA, A, B or C, with a suffix of either "-1" or "-2" appended to represent either one or two stories, respectively. The procedure adopted in this study to estimate the number of floors for each building is described in Section 2.3.

Assignment of flood damage codes AA, A, B, or C was based on the floor area of the building. The implicit assumption in this approach is that under the same flood conditions, there is a positive correlation between structural/content damage and square footage amongst flood-impacted homes. Type AA homes are the largest and most valuable residential buildings, which are also considered to have the highest quality construction materials. As expected, this value drops as the classification goes down in area, with type C homes having the lowest value.

The criteria for classifying Residential Buildings described in this section are summarized in Table 2-2.

Table 2-2: Residential Flood Damage Code Assignment

Code[1,2,3]	General Description	Number of Stories
AA-1 AA-2	Home with living space defined as equal to or more than 372 m^2	1 or 2
A-1 A-2	Home with living space defined as equal to or between 371 m^2 and 223 m^2	1 or 2
B-1 B-2	Home with living space defined as equal to or between 222 m^2 and 112 m^2	1 or 2
C-1 C-2	Home with living space defined as equal to or less than 111 m^2	1 or 2
D	Mobile Home	N/A[4]
MA	5 floors or more Apartment Building	5 or more
MW	4 floors or less Apartment Building	3 or 4

Note 1: The suffix 1 and 2 in the code refers to the number of floors of the building.
Note 2: Flood Damage Codes A-1 and AA-1 were considered equivalent for damage estimate purposes.
Note 3: Flood Damage Codes A-2 and AA-2 were considered equivalent for damage estimate purposes.
Note 4: Mobile Homes are assumed to be single floor buildings.

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2.2.2.3 *Non-Residential Buildings*

As summarized in Figure 2-1, non-residential buildings were assigned Flood Damage Codes based on MPAC code alone (see Appendix A), without consideration of building height or floor area.

Note that non-residential buildings are assigned a distinct Flood Damage Code for both content (A0 through O1) and structural (S1 through S5) damages. Definitions of these codes are provided in Table 2-3 and Table 2-4, respectively.

Table 2-3: Non-Residential Flood Damage Codes (Content)

Code	General Description
A1	General Office
B1	Medical
C1	General Merchandise - Shoes
C2	General Merchandise - Clothing
C3	General Merchandise - Stereo/TV/Electronics
C4	General Merchandise - Paper Products
C5	General Merchandise - Hardware/Carpet
C6	General Merchandise - Miscellaneous Retail
C7	General Merchandise - Generalized Retail
D1	Furniture/Appliances
E1	Groceries
F1	Drugs
G1	Auto
H1	Hotels
I1	Restaurants
J1	Personal Service
K1	Financial
L1	Warehouse/Industrial
M1	Theatres
N1	Institutional/Other
O1	Hospital

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Table 2-4: Non-Residential Flood Damage Codes (Structural)

Code	General Description
S1	Office/Retail
S2	Industrial/Warehouse
S3	Hotel/Motel
S4	High-Rise Residential/Office
S5	Institutional

2.2.2.4 Exceptional Building Cases

As discussed throughout Section 2.2.2.1, translation of MPAC codes to Flood Damage Codes was based on guidance outlined in Table 5 of the Ontario study by IBI Group[16]. Upon applying this guidance to the study area of the MRW, 11 percent (or 704 buildings) of the 6343 flood impacted buildings[17] were assigned a Flood Damage Code of 'NA' (i.e., not applicable). It is not known how, or if, buildings with an 'NA' designation were accounted for in IBI Group's assessments.

A more detailed review of these MPAC codes and their associated buildings was conducted. Based on this review, a re-classification scheme for these MPAC codes was derived and is summarized in Table 2-5.

[16] IBI Group. Toronto Flood Risk Ranking. October 2019.
[17] Impacted under the Regulatory Event.

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Table 2-5: Re-Classification Scheme for "NA" Buildings

MPAC Descriptor	MPAC Code	Number of Flood-Impacted Buildings in the Study Area	Flood Damage Code (Re-Classified)
Campground	486	222	Mobile Home (D) *only include if floor area >34 m^2 (otherwise exclude from damage estimate)
Vacant residential land not on water	100	20	Residential (AA-1, AA-2, A-1, A-2, B-1, B-2, C-1, C-2, MW, or MA)
Vacant residential/recreational land on water	110	257	
Island under single ownership	111	2	
Farm with residence – with or without secondary structures; with farm outbuildings	211	6	
Farm without residence – with secondary structures; with farm outbuildings	210	3	Industrial/Warehouse (L1 and S2)
Marina – located on waterfront – defined as a commercial facility for the maintenance, storage, service and/or sale of watercraft	492	74	
Vacant commercial land	105	1	Institutional/Other (N1 and S5)
Land associated with power dam	155	2	
Golf course	490	8	
Ski resort	491	1	
Marina – not located on waterfront – defined as a commercial facility for the maintenance, storage, service and/or sale of watercraft	493	1	
Amusement Park	725	14	
Museum and/or art gallery	730	1	
Government – wharves and harbours	824	1	
Second tier vacant lot – refers to location not being directly on the water but one row back from the water	101	1	Exclude from damage estimate (remains NA)
Municipal park (excludes Provincial parks, Federal parks, campgrounds)	103	2	
Provincial Park	107	2	
Water lot (entirely under water)	120	65	
Non-buildable land (walkways, buffer/berm, storm water management pond, etc)	130	14	
Managed forest property, vacant land on water	241	6	
Railway right-of-way	597	1	

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The rationale for applying a two-tiered system for buildings designated as 'Campground' acknowledges the likelihood that some of these buildings are recreation vehicles (RVs). The floor area threshold of 34 m^2 represents the upper limit of RV size according to the *Canadian Recreational Vehicle Association*[18]. Excluding 'Campground' buildings of a size less than 34 m^2 accounts for the ability of RVs to relocate from low-lying areas in the event of a flood (provided sufficient warning time is available). In total, 53 'Campground' classified buildings in the study area were excluded from total damage estimates as their areal footprint was identified to be less than 34 m^2.

2.2.2.5 Indexing

This section describes calculation of indices necessary to adjust depth-damage curves derived by IBI Group both temporally (i.e., 2014 to 2023) and spatially (i.e., inter-provincially from Alberta to Ontario).

All indices were applied by multiplying abscissa values (i.e., damage per floor area) of each depth-damage curve. This scaling either serves to 'stretch' or 'shrink' these curves, i.e., to either increase or decrease estimated damages relative to what would be estimated by the original 2014 curves.

2.2.2.5.1 Residential Content (RC) Damage Indexing

RC indices were derived using SHS (defined in Section 2.1). This calculation made use of the most recent SHS data at the time of this study, which was from the year 2019. Nothing more recent was available in terms of household spending metrics. Therefore, this information was used without adjustment. Future enhancements to the damage index may include possible escalation of the 2019 SHS estimates to 2023 values using other indices such as inflation.

SHS values were obtained from Statistics Canada for numerous categories that comprise the CPI basket. Out of these categories, only three were considered for indexing in this study. These three categories (*Household Furnishings & Equipment*, *Clothing and Footwear*, and *Recreation*) represent commodities vulnerable to damage in the event of a flood. Weightings applied to each of these categories were based on IBI Group's methodology (2019), as summarized in Table 2-6.

Table 2-6: Weighting of Flood-Affected Contents

Component	Weight
Household Furnishings & Equipment	59%
Clothing and Footwear	21%
Recreation[1]	20%

Note 1: Does not include 'Recreational Services'

[18] CRVA. 2023. Accessed September 11, 2023, at https://crva.ca/types-of-recreational-vehicles/.

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The SHS amounts from Alberta (2014) and Ontario (2019) were extracted from the Statistics Canada database and weighted as per Table 2-6 (in Equation 1):

$$SHS_{weighted}\ (\$) = \sum_{i=1}^{3} \left(SHS_{component}\right)_i * \ (Weight)_i \qquad \text{Equation 1}$$

where *i* represents the categories in Table 2-6. Once $SHS_{weighted}$ was calculated for Alberta and Ontario (for both 2014 and 2019), the RC index was calculated and applied as shown in Equations 2 and 3:

$$I_{RC} = \frac{SHS_{weighted_{Ontario(2014)}}}{SHS_{weighted_{Alberta(2014)}}} * \frac{SHS_{weighted_{Ontario(2019)}}}{SHS_{weighted_{Ontario(2014)}}} = \frac{SHS_{weighted_{Ontario(2019)}}}{SHS_{weighted_{Alberta(2014)}}} \qquad \text{Equation 2}$$

$$RC_{Ontario(2019)} = RC_{Alberta(2014)} * I_{RC} \qquad \text{Equation 3}$$

2.2.2.5.2 Non-Residential Content Damage Indexing (NRC)

For the reasons described in Section 2.1, the metric used for the calculation of the NRC index was the CPI. This calculation made use of CPI data from January 2014 and January 2023.

As part of the CPI, Statistics Canada provides a category called “Goods” that excludes services, shelter, and energy. This categorization is convenient, as these exclusions are items not included in tangible damage estimates. As such, the “Goods” category of CPI (CPI_{goods}) provided the basis for NRC indexing, as reflected in Equations 4 and 5.

$$I_{NRC} = \frac{CPI_{goods_{Ontario(2014)}}}{CPI_{goods_{Alberta(2014)}}} * \frac{CPI_{goods_{Ontario(2023)}}}{CPI_{goods_{Ontario(2014)}}} = \frac{CPI_{goods_{Ontario(2023)}}}{CPI_{goods_{Alberta(2014)}}} \qquad \text{Equation 4}$$

$$NRC_{Ontario(2023)} = NRC_{Alberta(2014)} * I_{NRC} \qquad \text{Equation 5}$$

2.2.2.5.3 Residential Structural Damage Indexing (RS)

While Statistic Canada’s Residential Construction Price Index (RCPI) provides a more straightforward approach to indexing, RCPI data was not available for the period of interest. As such, the Canadian Construction Cost Guide (CCCG) by Altus Group[19] was instead leveraged for indexing. In both 2014 and the 2023 editions of the CCCG, and the values from Calgary and the Greater Toronto Area were used as surrogates for Alberta and the MRW, respectively.

Considering that 2014 and 2023 CCCG editions present construction costs in different styles, Hatch applied judgement to classify CCCG data into categories of ‘Apartment’ and ‘House’.

[19] https://www.altusgroup.com/insights/canadian-cost-guide/

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Moreover, the CCCG displays costs as an average value (with upper and lower limits), which was applied during calculations.

Using CCCG data, two different RS indices were calculated for each of the categories previously described. Indexing for both time and space was completely in a similar fashion to RC and NRC indexing, as presented in Equations 6 and 7:

$$I_{RS} = \frac{CCCG_{GTA(2014)}}{CCCG_{Calgary(2014)}} * \frac{CCCG_{GTA(2023)}}{CCCG_{GTA(2014)}} = \frac{CCCG_{GTA(2023)}}{CCCG_{Calgary(2014)}} \quad \text{Equation 6}$$

$$RSC_{Ontario(2023)} = RSC_{Alberta(2014)} * I_{RS} \quad \text{Equation 7}$$

Note that both Equation 6 and 7 were applied separately to MW/MW and AA/A/B/C/D buildings, using either *Apartment* or *House* data from the CCCG, respectively.

2.2.2.5.4 Non-Residential Structural Damage Indexing (NRS)

Unlike for RS calculations (see Section 2.2.2.5.3), Construction Price Index data was available from Statistics Canada for Non-Residential buildings for Quarter 1 in 2014 and Quarter 3 in 2022, meaning this data could be applied for temporal indexing of NRS depth-damage curves. This data is referred to as the Non-Residential Construction Price Index (NRCPI).

For the spatial indexing, the Altus Group's CCCG was used, following the same procedure described in Section 2.2.2.5.3. CCCG categories were grouped to reflect Non-Residential Flood Damage Code categories, with groups of: *Office Buildings, Shopping Centres/Retail, Schools & Colleges, Hospitals, Hotels*, and *Light Industrial*.

Using Non-Residential Construction Price Index (NRCPI) and CCCG data, NRS depth-damage curves were indexed using Equations 8 and 9

$$I_{NRS} = \frac{CC_{GTA(2014)}}{CC_{Calgary(2014)}} * \frac{NRBCPI_{Ontario(2023)}}{NRBCPI_{Ontario(2014)}} \quad \text{Equation 8}$$

$$NRSC_{Ontario(2023)} = NRSC_{Alberta(2014)} * I_{NRS} \quad \text{Equation 9}$$

2.2.2.6 Total Damage Estimate

Once depth-damage curves were assigned to each building (Section 2.2.2.1), and these curves were indexed both spatially and temporally, a total damage estimate was derived (for the Regulatory Flood Event). The algorithm applied to compute this damage estimate is summarized in Figure 2-2.

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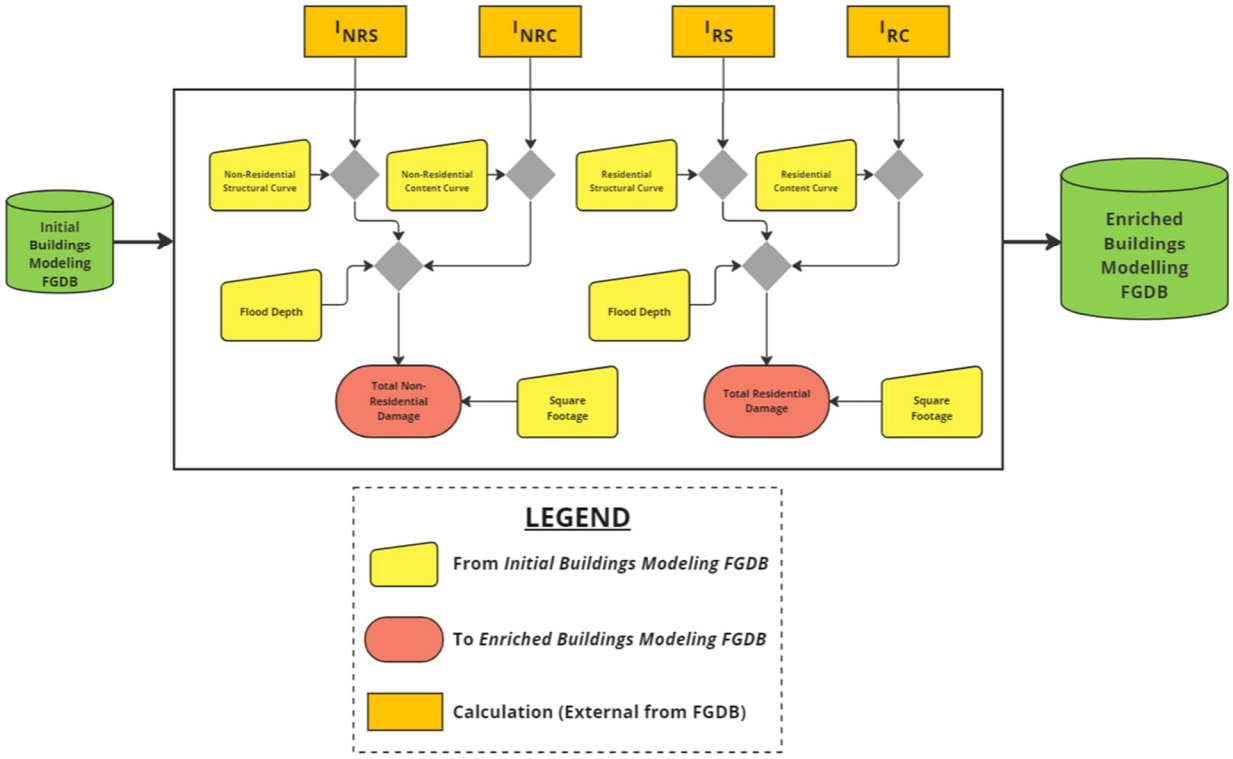

Figure 2-2: Algorithm to Index and Apply Each Depth-Damage Curve at Residential and Non-Residential Structures

The general steps of the procedure shown in Figure 2-2 were as follows:

- Apply indices (I_{RC}, I_{NRC}, I_{RS}, I_{NRS}) to residential and non-residential depth-damage curves.
- Identify the flood depth at each building (procedure described in Section 2.3).
- Using indexed depth-damage curves and flood depth, determine the damage per floor area. Linear interpolation was applied, where needed, as depth-damage estimates were only available on depth intervals of 0.3 m.
- Using the size of building footprint, calculate the total damage estimate (summation of content and structural damage).
- A robust Microsoft® Excel® spreadsheet tool was developed to facilitate the procedures and calculations described in Sections 2.2.2.1 to 2.2.2.5. This tool served as a quality control check to validate independently damage estimates derived using Python coding (described further in Section 2.3).

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2.2.3 *Roads, Bridges, and Culverts*

Estimation of the flood damages to roads, bridges and culverts, was facilitated with the following data:

- Roads
  - DMM's Road Network
  - Town of Huntsville's Road Asset Management Data
- Bridges and Culverts
  - DMM's Bridge Replacement Costs
  - DMM's Culvert Replacement Costs
  - Town of Huntsville's Infrastructure Asset Replacement Costs
  - Town of Bracebridge Ontario Structure Inspection Manual (OSIM) Replacement Costs.

2.2.4 *Roadways*

All data were clipped to the flood inundation extent of the study area to identify the length of roadway that would be impacted by the flood event. Road segments over bridges were removed to avoid double counting of damage costs, since bridge damage costs already account for damages to the overlying road. Inundation damages calculated for these roads assumed that the flooded section of road would require complete replacement. It is recognized that for a lake environment, this may result in a conservative estimate of damage, since it is less likely that the road topping and foundation fill would be removed through erosion. Should historical data on road restoration costs in the area become available, this approach can be refined to incorporate a scaling factor to reflect partial replacement of the road infrastructure rather than complete replacement.

To estimate the replacement cost, road network data provided by both the Town of Huntsville and DMM were used. Data from the Town of Huntsville was used wherever possible since it included a direct estimate of replacement cost for each roadway segment. The replacement costs accounted for the replacement of a full segment of road, yet in many instances only a portion of the road was considered inundated. As a result, the replacement costs were scaled by the percentage of the road segment that was flooded to arrive at a more appropriate replacement cost. Moreover, for the rest of the study area DMM's road network data was used.

DDM's road network data did not include replacement costs. Roads classified as Island or Shore, for the Road Type Category, were excluded since these features represented emergency access paths instead of roads. To calculate the replacement costs for these road segments, the length of road within the inundated area was first estimated. This estimate

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involved calculating the sum of the length of all road segments with a flood depth greater than or equal to 1 cm. A flood depth of 1 cm was chosen as the threshold to classify and segment a section of road as affected by flooding. The length of flooded roads was then multiplied by a road replacement cost per lane kilometer, as summarized in Table 2-7. It was assumed that all roads contained two lanes, resulting in multiplying the costs per lane kilometer by two. The costs in this table differentiate between road types and represent fixed cost per lane kilometer as provided by DMM.

Table 2-7: Road Replacement Costs

Road Class	Road Replacement Cost ($ per Lane km)
High Class Bitumen (Urbanized / Sub-Urban / Rural, High-Volume Roads – Paved)	1.013M
Intermediate Class Bitumen (Urban / Sub-Urban / Rural, Medium – Low Volume Roads – Paved)	900K
Low Class Bitumen (Rural, Low Volume Roads – Bitumen Surface Treatment)	750K

The road network provided by DMM was not classified by road material type. Therefore, a replacement cost range was calculated using the “Low Class Bitumen” replacement costs as the lower boundary, and the “High Class Bitumen” replacement costs as the upper boundary.

2.2.5 Water and Wastewater Facilities

As indicated in Table 2-1, DMM provided replacement cost information for water and wastewater facilities. This information was summarized as point data, with each point associated with one or more footprint polygons that represent one or more buildings or other infrastructure components. However, not all buildings/components evident in aerial imagery (e.g., ponds, pumps, and piping), and perceived to be a part of the water/wastewater facility, were catalogued in the database as footprints. As such, damage estimates associated with this infrastructure required manual intervention.

The full water and wastewater facility replacement cost was applied to the total damage estimate for any point that intersected the flood inundation area. An examination of the results revealed that some points fell outside of the flood inundation area, and consequently were assigned no damage. However, a review of aerial imagery indicated that a portion of these facilities intersected the flood inundation area. Points that fall outside of the flood inundation were not identified for inclusion in the total damage estimate.

The limitations of using point data to represent the footprint of water and wastewater facilities is discussed further in Section 2.2.8.

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Note that if any water/wastewater points intersected a building footprint, only the replacement cost for the point would be applied to the damage estimate (i.e., the depth-damage curve estimate for the building footprint would be excluded).

2.2.6 *Bridges*

Flood damages to bridges located within the inundation zone were estimated using the methodology outlined in FEMA's Hazus Flood Technical Manual. This method relates the expected bridge repair cost to the probability that the bridge may fail during the passage of large events. Damages were estimated using the following equation:

$$Repair\ and\ Replacement\ Cost = Probability\ of\ Failure \times Inventory\ (\$) Value\ (Costs)$$

Equation 10

In this equation, the probability of failure was based on guidance provided in Figure 9-2 of the FEMA manual (reproduced in Table 2-8), and is a function of the scour potential at the site, the type of bridge (e.g., Single-Span Bridges versus Continuous-Span bridges), and the size of the flood event. The *Inventory ($) Value (Costs)* was set as the replacement cost for the bridge, as obtained from DMM, Town of Bracebridge, and Town of Huntsville Bridge data.

Table 2-8: Probability of Bridge Failure Relative to Scour Damage and Span Type Figure 9-2 in FEMA (2022)

Flood Return Period	Probability of Bridge Failure[1]		
	1	2	3
Single-Span Bridges			
100-year	5%	2%	1%
500-year (2 x 100-year probability)	10%	4%	2%
1,000-year (1.5 x 500-year probability)	15%	6%	3%
Continuous-Span Bridges			
100-year	1.25%	0.5%	0.25%
500-year (2 x 100-year probability)	2.5%	1%	0.5%
1,000-year (1.5 x 500-year probability)	3.75%	1.5%	0.75%

Note: See the Damage Functions for Transportation System dialog under the Analysis menu for the full array of probabilities of bridge failure relative to scour damage and span type.

1. *The Scour Potential is a field in the Hazus Bridge database and is from the Federal Highway Administration National Bridge Inventory*

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For this study, the failure probability was based on the single-span bridge category using the following assumptions:

- **Class 3 scour potential**: The overall scour potential at these bridge locations may be low given that they are likely located on scour resistant foundations (e.g., bedrock). Confirmation of this assumption requires further reconnaissance of these flood impacted locations.
- **500-yr return period flood**: A 500-year return period was selected since the return period of the Regulatory Event within the Muskoka River was assumed to be between 100 and 500 years.

Based on the information provided in Table 2-8, this combination of parameters results in a two percent probability of failure. Further review of these individual bridge locations would be required to refine this probability of failure beyond a high-level estimation.

2.2.7 Culverts

Estimation of culvert damage assumed that culverts would require full replacement following the Regulatory Flood. The data available for this study was insufficient to verify this assumption. As such, the damage estimate for culverts was considered conservative and high-level. The estimate includes construction costs, demolition costs, road repair because of the replacement, and road safety infrastructure associated with the culvert.

2.2.8 Assumptions and Limitations

Several assumptions and limitations are highlighted throughout Section 2.2. The following is a summary of these items.

- **Lack of Muskoka-Specific Data for Indexing**: As part of this study, spatial and temporal indices were derived to relate depth-damage curves generated in 2014 for Alberta, to the present-day context in the MRW. While basing indices on economic data from the Greater Toronto Area (GTA), there are acknowledged differences between the GTA and the Muskoka region that limit the accuracy of these scaling factors.
- **Limited Field Verification of Flood Damage Codes**: Flood Damage Codes, which were derived based on MPAC codes and a lookup table adapted from IBI Group (2019), could not be field-verified for every flood-impacted building in this study. Without this verification, the suitability of Flood Damage Codes assigned to each building are highly dependent on the accuracy of MPAC descriptors for each building.
- **Data Availability for Temporal Indexing**: While this study utilized the most suitable and up-to-date data available for temporal indexing, not all datasets were available up to 2023. As such, estimates do not fully reflect the current state of inflation, development, and spending habits in the MRW.

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- **Estimation of Building Height:** Building height estimates were based on the best available data. For future consideration Classified Point Cloud (Building class ASPRS Class Code 6[20]) could be a more accurate method and data source potentially minimizing the influence of Vegetation (Tree) cover.
- **Exclusion of Basements:** No structure-specific data was available to confirm the presence of basements in flood-impacted homes evaluated for this study. Thus, basement flooding was excluded from calculations in this study.
- **Single MPAC Code for Each Structure**: Based on data availability, only one MPAC code was defined for each structure. This limits accurate characterization of flood damages in multi-purpose buildings that may be more accurately defined using multiple MPAC codes.
- **Limited Data to Reclassify Campground Data:** Buildings classified by the MPAC as "Campgrounds" and with a building area of less than 34 m^2 were excluded from damage calculations, since they have a smaller area than the standard RV to be classified as a Mobile Home (residential Type "D"). All remaining campground buildings were classified as Mobile Homes; however, the accuracy of this classification was unconfirmed.
- **No Distinct Depth-Damage Curve for Boathouses**: Despite boathouses being a distinct feature in the Muskoka River Watershed, there is no depth-damage curve specific to this type of structure and its contents. This limitation is discussed further in Section 2.2.8.1.
- **Point Data for Water and Wastewater Facilities:** The point data containing the replacement costs for water and wastewater facilities were not associated with a geo-spatial footprint that covers the extent of the facility. Instead, only select components of the facility (select building footprints) were represented in the dataset, and even these footprints could not be directly tied to the point data by the existing attribute data.

  Because the point data did not intersect the flood inundation area, its associated replacement cost was not included in the total damage estimate. Instead, only mapped building footprints that may be associated with these water and wastewater facilities were included in the damage estimate through use of depth-damage curves (provided that they intersected the flood inundation area).

  An example of this is illustrated for the Town of Huntsville in Figure 2-3. To address this issue, geospatial data representing infrastructure besides buildings (e.g., treatment ponds, and pumping equipment) would be necessary to discern which infrastructure will be flooded within the facility. These footprints would also need an attribute to identify the specific facility it belongs to. This facility attribute would then be used to join the water and wastewater replacement point data to the footprint extent.

[20] The American Society for Photogrammetry and Remote Sensing (ASRPS). LAS Specification 1.4 - R15. 2019. https://www.asprs.org/wp-content/uploads/2019/07/LAS_1_4_r15.pdf

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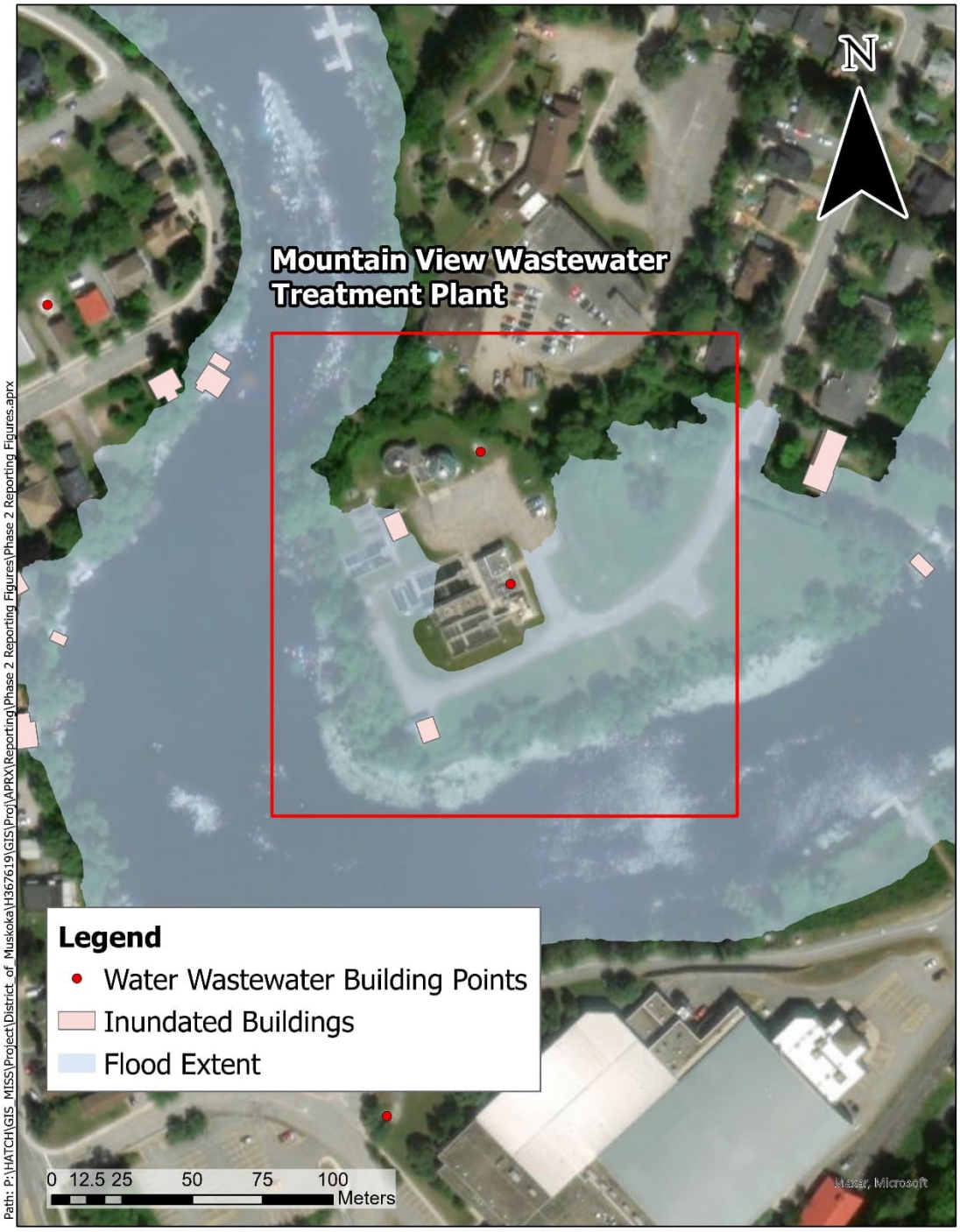

Figure 2-3: Points and Building Footprints Representing the Mountain View Wastewater Treatment Plant

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2.2.8.1 *Boathouses*

One prominent feature of the MRW is the extensive presence of boathouses. These structures range in size, quality, and function, and in some cases can be quite valuable. One key limitation of the study was that depth-damage curves specific to boathouses were not available, meaning that residential structural and content curves were instead assigned to these structure types.

The building inventory was analyzed as a means of quantifying uncertainty associated with applying residential curves to boathouses. Using the building attributes defined as “Est Structural Value”, “Building Class”, and “Area”, box-whisker plots of estimated structure value (normalized by building area) were created for all buildings within each municipality for both residential, and boathouse classes (Figure 2-4). Where “Est Structural Value” is the same as the “Estimated Building Value” attribute described in Section A.3 of Appendix B.

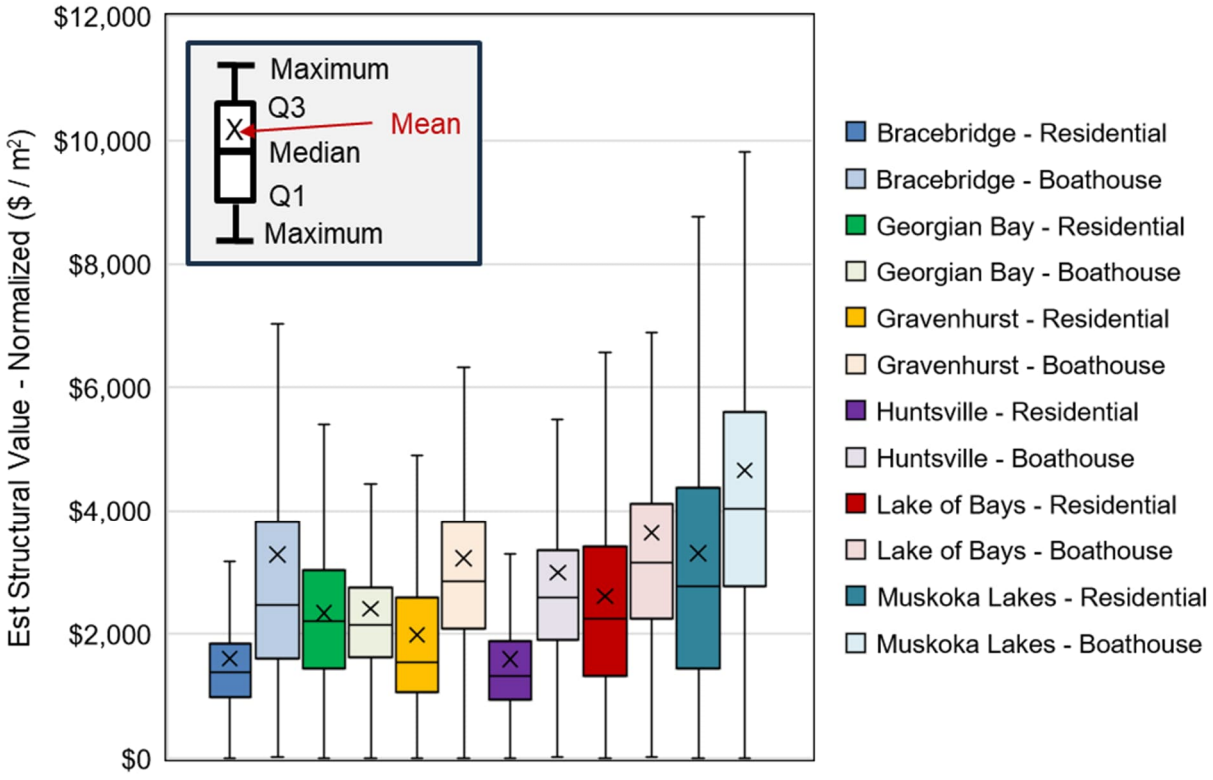

Figure 2-4: Municipality-Based Comparison of Estimated Structure Value (Normalized) for Residences and Boathouses (Note: to Preserve Scale of The Y-Axis, Outliers Are Not Shown on This Figure)

Review of Figure 2-4 shows that for almost all municipalities (except Georgian Bay), boathouses have distinctly higher value per floor area when compared to residences. This observation is primarily the result of the approach followed to derive “Est Structural Value” for buildings, as properties with boathouses generally have a higher value compared to those

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that do not. The existence of boathouses primarily on high valued properties results in a high estimated structural value for boathouses due to the proportionality of "Est Structural Value" to the total value of the property (see Item A.3 in Appendix B). This concept is illustrated by Figure 2-5.

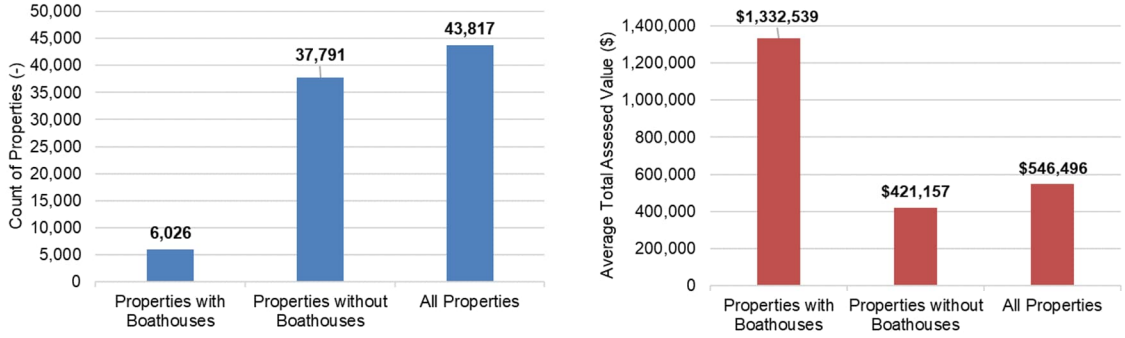

Figure 2-5: Comparison of Count and Total Assessed Value for Properties with and without Boathouses

This treatment results in a relatively high average "Est Structural Value" for boathouses, as compared with the average Est Structural Value for buildings, which includes all properties with or without boathouses.

By comparing median values between Residential and Boathouse box-whisker plots within each municipality, a scaling factor can be derived (as summarized in Table 2-9).

Table 2-9: Depth-Damage Scaling Factors

Municipality	Median Est Structural Value – Normalized ($/m^2) (Figure 2-4)		Boathouse Scaling Factors
	Residences ($)	***Boathouses ($)***	
Bracebridge	1,376	2,477	1.80
Georgian Bay	2,261	2,157	1.00[1]
Gravenhurst	1,544	2,858	1.85
Huntsville	1,323	2,589	1.96
Lake of Bays	2,243	3,153	1.41
Muskoka Lakes	2,770	4,028	1.45

Note 1: Residences and Boathouses values for Georgian Bay are considered equivalent, therefore yielding a scaling factor of 1.00.

A sensitivity analysis was completed by incorporating the scaling factors in Table 2-9, as a means of accounting for this difference in structural value between boathouses and residences. This analysis included multiplying residential structural depth-damage curves by

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these factors prior to applying the curves to quantify structural flood damages of buildings classified as boathouses. The results of this sensitivity analysis are summarized in Section 3.4.

2.3 GIS Processing and Enrichment

Hatch has supported DMM on several flood studies and, in turn, accumulated a large volume of data. At the onset of this project, these GIS datasets were reviewed and subsequently supplied relevant and the most current dataset for this project. The steps taken to confirm and validate GIS data inputs as well as steps taken to add or enrich the required datasets that served as primary inputs into the depth damage curve calculations are outlined below and in Figure 2-6. Enrichment in this case refers to adding additional attributes to the building inventory that are necessary for estimating damages due to flooding.

2.3.1 Project Set-Up

Numerous datasets from past projects for DMM were reviewed and confirmed with DMM to be the most up to date versions before any calculations were performed. Final and confirmed GIS data were migrated from existing project server locations and copied as source data to a new project directory. Copies of current GIS data required to support the project were managed and stored in separate source data folders for future reference and checks as required.

New File Geodatabases (FGDB) were set up for the project. Data was organized in discipline-specific FGDB's to ensure data and information was logically organized to ensure scalability for model scripting and future phase processing support. The migration and setup of project specific FGDB's also eliminated any uncontrolled or documented edits to the source data.

All migrated data was checked spatially with respect to the study area extent coverage. The data extents check ensured that there would be no data abnormalities ("no data" values), or "null" data assigned during the enrichment process. If data gaps existed, additional data was extracted or obtained from previous project databases to ensure complete coverage of all datasets within the defined study area.

Building and Asset data provided by DMM in support of the project was checked against the provided metadata and workflow documentation to ensure completeness, units of measure, as well as the project team's full understanding of the information provided. Based on prior work for DMM, the project team was aware that two horizonal datums were in use within the District of Muskoka's enterprise GIS. These include North American Datum 1983 (NAD83) Original, as well as North American Datum 1983 Canadian Spatial Reference System (CSRS) 1983. While the difference between the two datums is minimal (less than one meter) there are slight horizontal shifts between the two datums that could cause issues or discrepancies with respect to data enrichment. As a result, a custom transformation was defined to support the seamless integration of both datums within the project GIS. The custom transformation used the ON83CSv1 grid shift (GSB) file developed and distributed by

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the Province of Ontario. The custom transformation ensured accurate overlay and alignment of geospatial data during the enrichment process.

It should be noted that all processing and GIS analysis was completed within Esri ArcGIS® Pro Version 3.0.2.

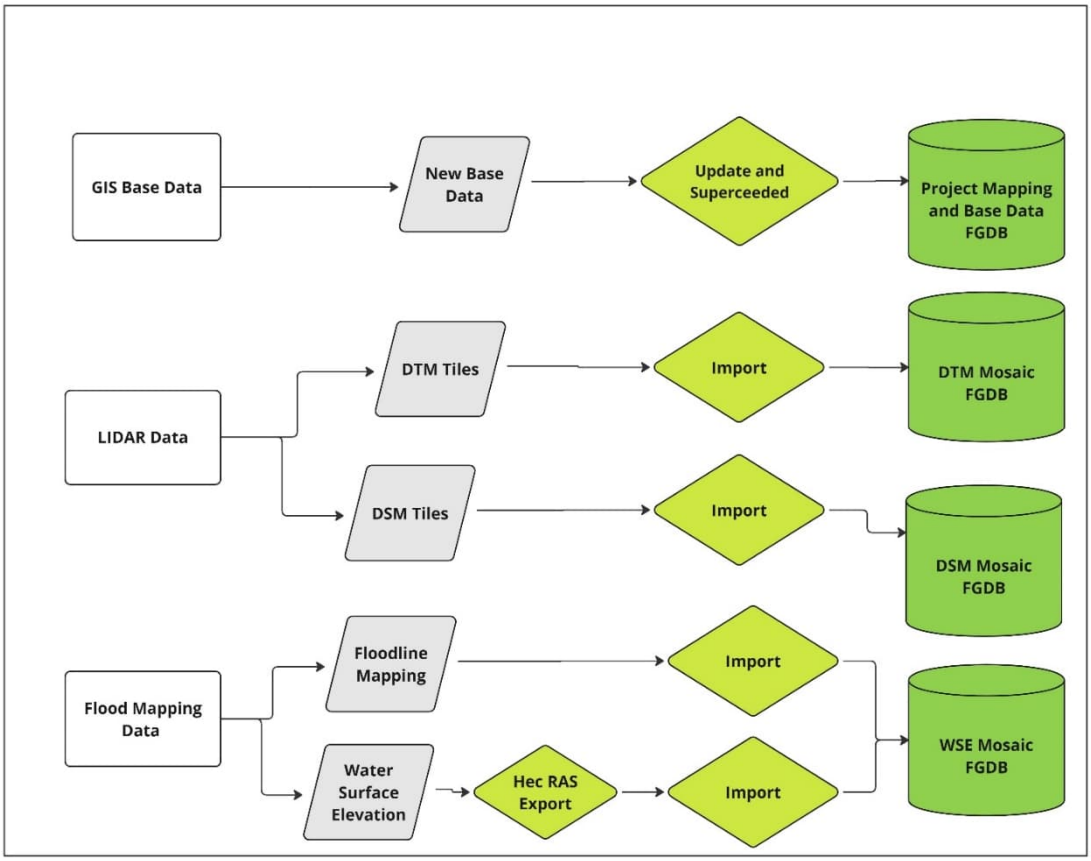

Figure 2-6: Data Assimilation and GIS Preprocessing. Data flows into Figure 2-7Building Data Enrichment

Building footprint polygon data provided by DMM was pre-processed by DMM's GIS team and was provided to Hatch with information extracted from MPAC assessment data (Figure 2-7). For a detailed description of the processing and resulting information provided please refer to document *GIS Process – Structure Classification and Valuation.docx* (included in Appendix B). In keeping with previous Flood Plain Mapping and GIS data set-up, a separate FGDB was created for all building related data and enrichment processing. To support depth-damage curve calculations the following information was calculated using GIS overlays (see Table 2-10).

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Table 2-10: Building Information Calculated by Hatch

Attribute	Input Data Source	GIS Tool	Equation (If Applicable)	Comment
Building Base Elevation	LiDAR Digital Terrain Model (DTM)	DTM Zonal Statistics (Mean)	-	ON83CSv1.GSB Transformation applied
Building Roof Elevation	LiDAR Digital Surface Model (DSM)	DSM Zonal Statistics (Mean)	-	ON83CSv1.GSB Transformation applied.
Building Height	DTM and DSM Zonal Statistics	Attribute Table Calculation	$Building\ height = DTM - DSM$	-
Number of Floors	Building Height	Attribute Table Calculation	$Num\ of Floors = \frac{Building\ Height}{2.3m}$	Average floor height taken from Ontario Building Code (2300 mm)[21]
Zoning Codes	Normalized Zoning data	Overlay	-	-
Flood Water Surface Elevation (WSE)	Water Surface Elevation Raster from HEC-RAS	WSE Zonal Statistics (Mean)	-	-
Flood Depth	WSE Zonal Statistic & DTM Zonal Statistic	Raster Subtraction	$Flood\ Depth = WSE - DTM$	-

[21] King's Printer for Ontario. *Building Code Requirements – Ceiling Heights*. 2022. https://www.ontario.ca/document/build-or-buy-tiny-home/building-code-requirements#section-3

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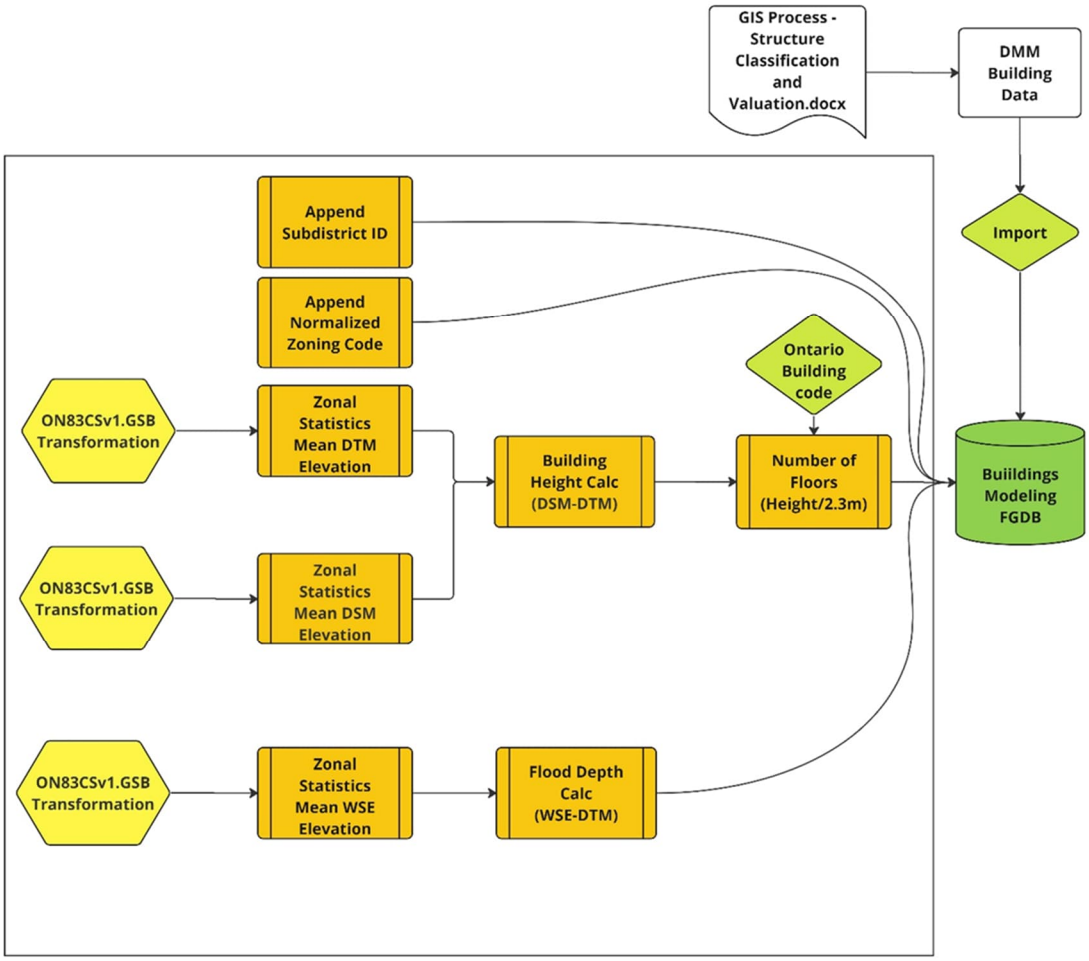

Figure 2-7: GIS Preprocessing of Building Data (Data flowed from Figure 2-6)

2.3.2 Building Polygon Enrichment Assumptions

The following assumptions were made at the time of enriching the building polygon dataset:

- **Data Collection Dates**: MPAC Assessment date and Building polygon data (2018) dates are the same:
- **Building Height** was calculated based on the best available data. For future consideration Classified Point Cloud (Building class ASPRS Class Code 6[22]) could be a more accurate method and data source potentially minimizing the influence of Vegetation (Tree) cover. Alternatively, a building eave elevation dataset is available from the DMM which can also prove useful as a more accurate source of building heights.

[22] The American Society for Photogrammetry and Remote Sensing (ASRPS). LAS Specification 1.4 - R15. 2019. https://www.asprs.org/wp-content/uploads/2019/07/LAS_1_4_r15.pdf

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- **Floor Calculations were based on current Ontario Building Code (2300 mm)[23] guidelines**: It is possible that a more accurate estimate of the number of floors associated with each dwelling could be made if this information exists within the MPAC database.
- **Water Surface Elevation Raster extents versus LiDAR**: The ground floor elevation for each building was set equal to the average terrain elevation associated with each building polygon. The depth of flooding was set equal to the difference between the estimated water surface elevation in the area and the ground floor elevation. In some instances, the flood inundation zone only impacted a portion of the building footprint, and in these cases, the calculation resulted in 'negative' depth values. These instances were limited to tens of structures, and these structures were subsequently edited manually to 0 m.

3. Results

3.1 Depth-Damage Curves

The following is a summary of all indexed depth-damage curves for Residential and Non-Residential buildings.

3.1.1 Residential Content (RC)

Indexed residential content (RC) curves for one and two-story residences are shown in Figure 3-1.

[23] King's Printer for Ontario. *Building Code Requirements – Ceiling Heights*. 2022. https://www.ontario.ca/document/build-or-buy-tiny-home/building-code-requirements#section-3

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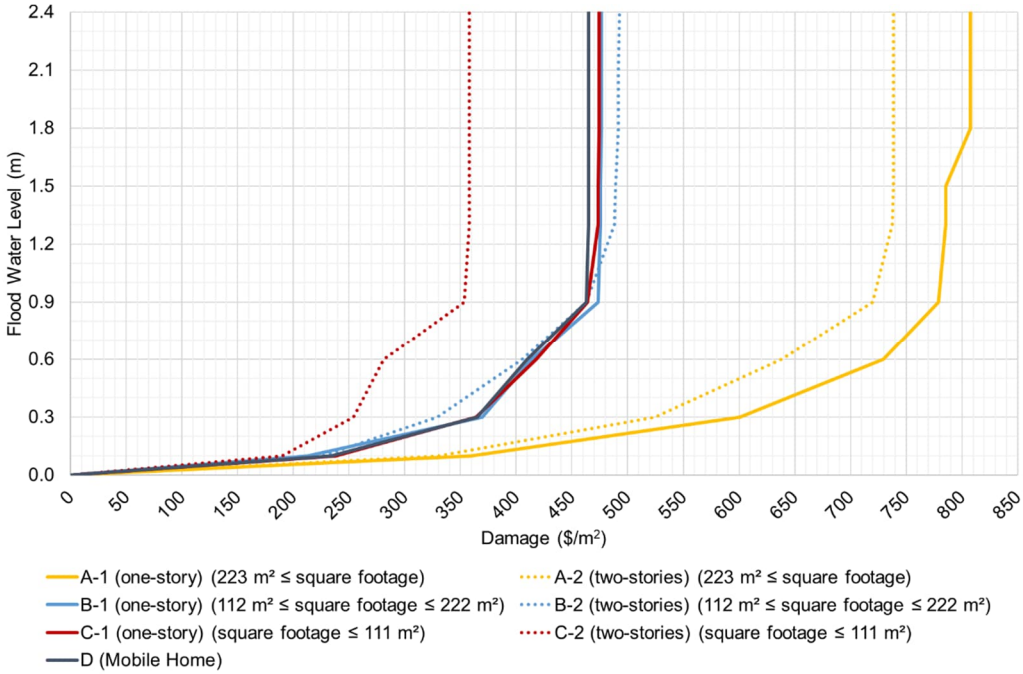

Figure 3-1: Residential Content Depth-Damage Curves (Class A through D)

As expected, the more expensive homes (i.e., A, which also includes AA) have a larger per floor area content damage relative to the least expensive homes. This trend reflects the likelihood that the owners of more expensive homes will furnish their homes with higher value contents.

Single story residences generally reflect more content damage per square foot than two story residences. This trend reflects the likelihood that owners of two-story homes will distribute their belongings between multiple floors, meaning that the overall damage estimate per floor area is reduced.

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Indexed RC curves for apartment buildings are shown in Figure 3-2.

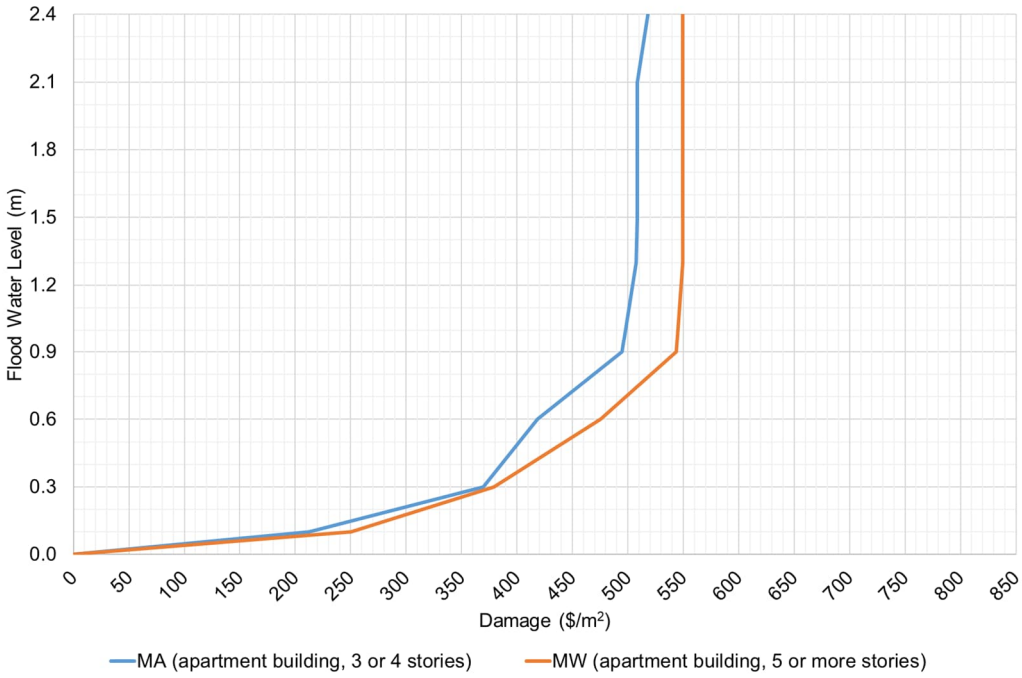

Figure 3-2: Residential Content Depth-Damage Curves (Class MA and MW)

While the difference in content damages between MA (5 or more stories) and MW (3 or 4 stories) is quite small, lower per floor area content damages for MA buildings could reflect the fact that MA buildings are more likely to include multi-story suites, and if so, belongings for those suites may be distributed throughout multiple floors.

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3.1.2 Residential Structural (RS)

Indexed residential structural (RS) curves for one and two-story residences are shown in Figure 3-3.

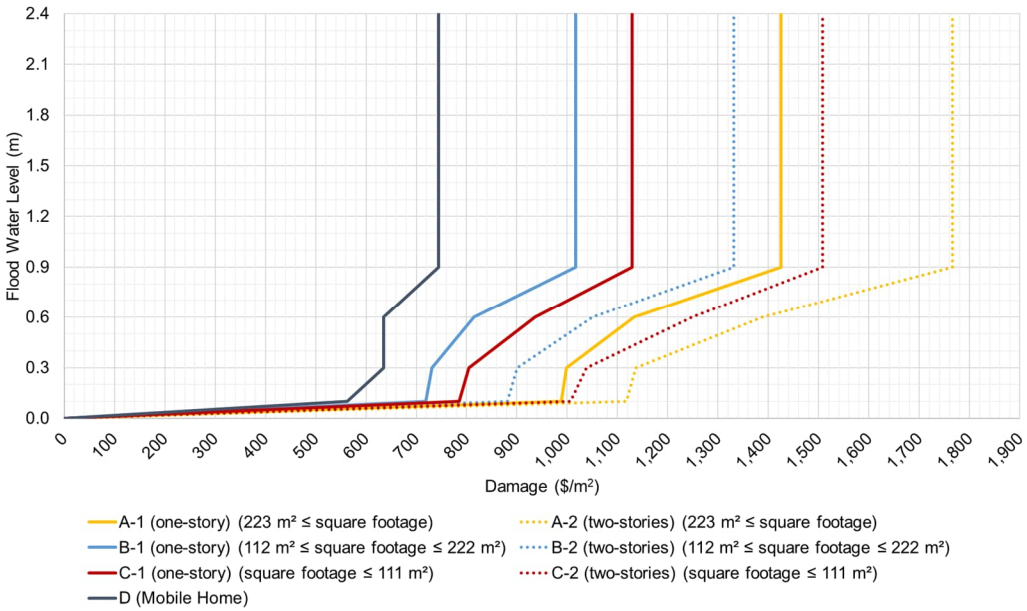

Figure 3-3: Residential Structural Depth-Damage Curves (Class A through D)

Trends in Figure 3-3 are as expected, with more expensive homes (i.e., A, which also includes AA) having higher relative structural damage costs compared to less expensive homes. Relative to one story residences, two story residences are shown to experience more structural damage per floor area.

Some anomalies are noted, like that observed for C class buildings, which show structural damages being less than B class buildings, which have a higher overall value. The reason for this discrepancy is unexplained in the Alberta[24] and Ontario[25] reports.

[24] IBI Group. Provincial Flood Damage Assessment Study. February 2015.
[25] IBI Group. Toronto Flood Risk Ranking. October 2019.

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Indexed residential structural (RS) curves for multi-family apartment buildings are shown in Figure 3-4.

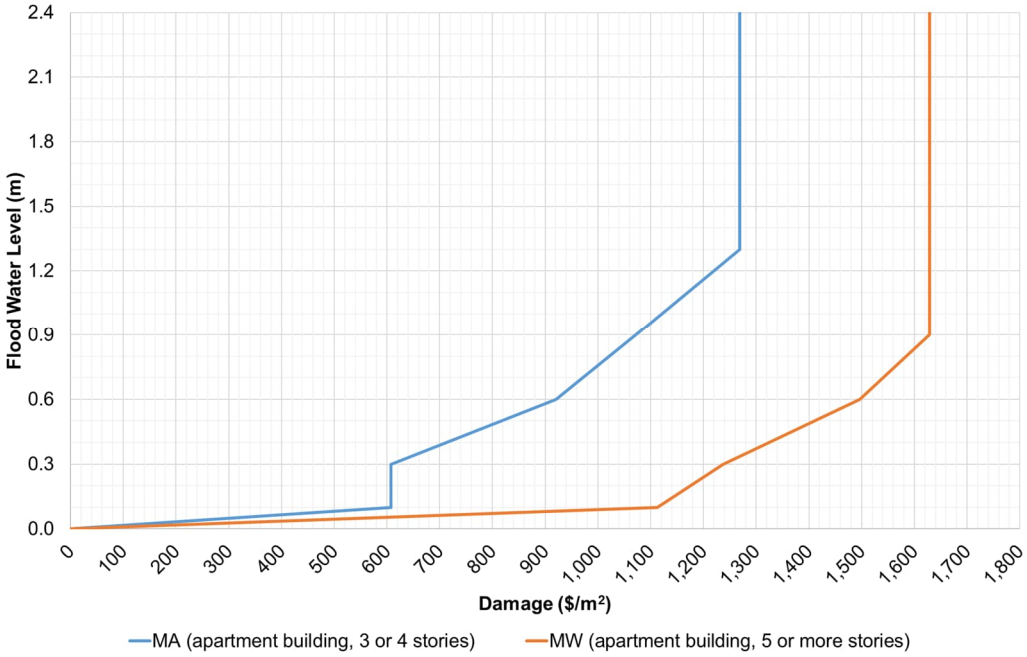

Figure 3-4: Residential Structural Depth-Damage Curves (Class MA and MW)

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3.1.3 *Non-Residential Content (NRC)*

Indexed non-residential content (NRC) curves are shown in Figure 3-5.

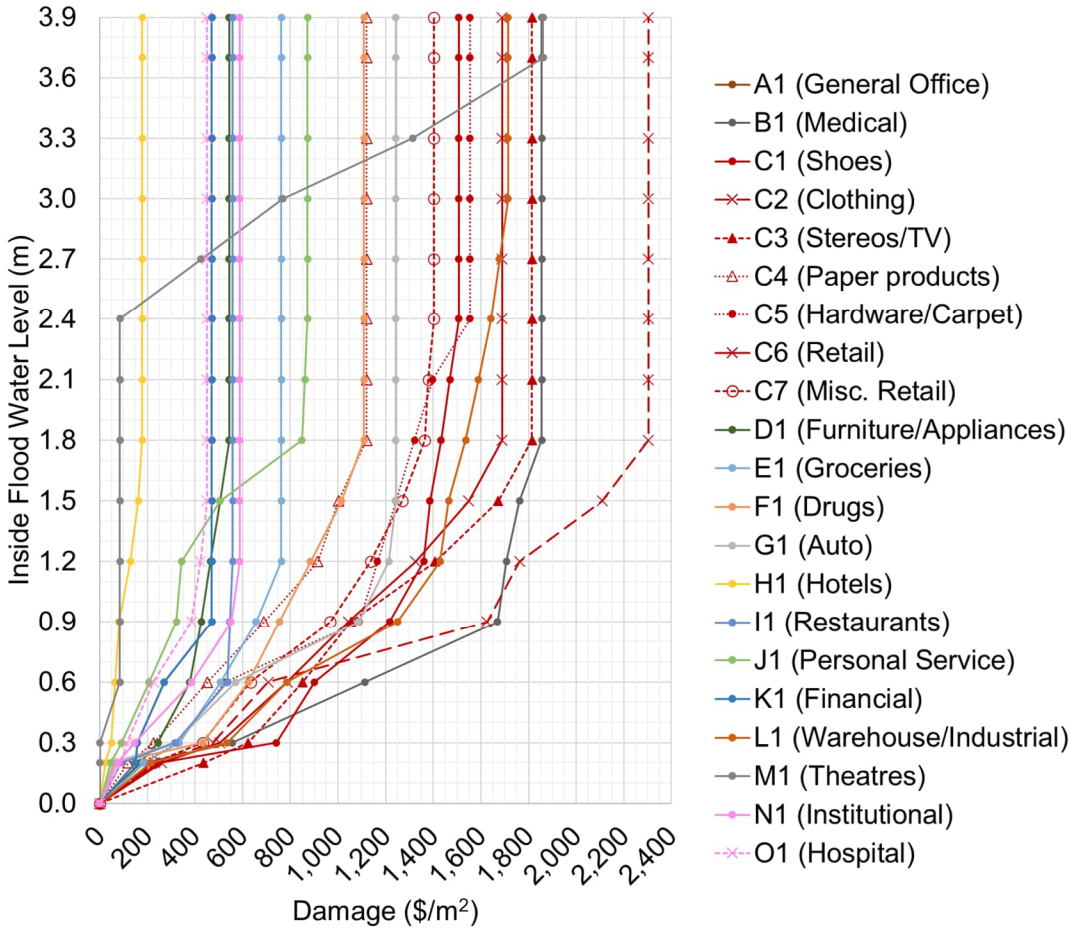

Figure 3-5: Non-Residential Content Depth-Damage Curves

Figure 3-5 shows that the highest non-residential content damages are associated with the C class buildings (i.e., 'General Merchandise' buildings). While most curves follow a consistent shape, others (e.g., M1) do not. In the case of M1 ('Theatres'), per floor area damage does not increase significantly until a flood depth of 2.4 m. This unusual behaviour can be explained by building geometry, as theatres are typically designed with empty space to facilitate acoustic performance.

3.1.4 *Non-Residential Structural (NRS)*

Indexed non-residential structural (NRS) curves are shown in Figure 3-6.

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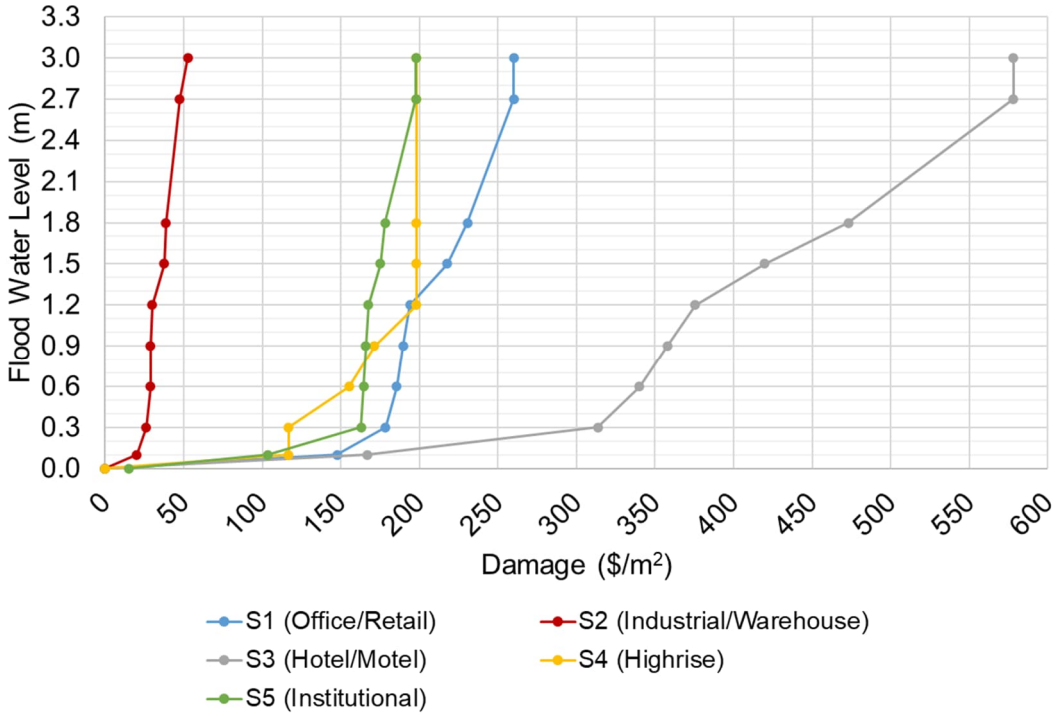

Figure 3-6: Non-Residential Structural Depth-Damage Curves

The higher values shown for the S3 curve are expected, given that hotels function as temporary residences, meaning one would expect the S3 curve to follow the shape and value of the residential curves shown in Figure 3-3 and Figure 3-4.

3.2 Indices

Following the procedure outlined in Section 2.2.2.5, the calculated indices are presented below.

Table 3-1: Residential Content Damage (RC) Index

Category	Weight	2014 Alberta		2019 Ontario[1]	
		Amount ($)	Weighted Amount ($)	Amount ($)	Weighted Amount ($)
Household Furnishings & Equipment	59%	2,359	1,392	2,763	1,630
Clothing and Accessories	21%	4,378	919	3,552	746
Recreation[2]	20%	2,668	534	1,812	362
Weighted Total			**2,845**		**2,738**
				RC Index	***0.96***

Note 1: Most recent data from 2019.
Note 2: Not including Recreational Services

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Table 3-2: Non-Residential Content Damage (NRC) Index

2014 Alberta Goods Index	112.8
2023 Ontario Goods Index	139.5
NRC Index	1.24

Table 3-3: Residential Structural Damage (RS) Index

Type	CC ON 2023 ($)	CC AB 2014 ($)	RS Index
Apartment[1]	353	261	**1.35**
House	365	217	**1.68**

Note 1: Not including “Premium for High Quality”.

Table 3-4: Non-Residential Structural Damage (NRS) Index (using NRBCPI)

Q1 2014 Ontario NRBCPI[1]	91.8
Q3 2022 Ontario NRBCPI[2]	144.5
2022 ON / 2014 ON Index	1.57

Table 3-5: Final Non-Residential Structural Damage (NRS) Indices

Type	CC AB 2014 ($)	CC ON 2014 ($)	2014 ON / 2014 AB	NRS Index
Office Buildings	254	238	0.94	**1.48**
Shopping Centres/Retail	172	145	0.85	**1.33**
Schools & Colleges	269	255	0.95	**1.49**
Hospitals	519	512	0.99	**1.55**
Hotels	261	245	0.94	**1.48**
Light Industrial	89	71	0.79	**1.25**

Note 1: NRBCPI: Non-Residential Building Construction Price Index.
Note 2: Most recent data as of 4th of July 2023 is from Q3 2022.

3.3 Regulatory Event Damage Estimate

The following is a summary of damage estimates associated with the Regulatory Flood in the study area.

3.3.1 Building Damage Estimate

Total building content and structural damage (residential and non-residential) associated with the Regulatory Flood was estimated to be approximately 863 million dollars. This cost is comprised of 616 million dollars in structural damages, and 247 million dollars in content

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damages. There were two water/wastewater buildings not already covered through the depth-damage curve derivation. Replacement costs for these two buildings totaled $1,060,700.

A distributed map visualizing these flood damages throughout the study area is shown in Figure 3-7. Lake Muskoka and Lake of Bays saw the largest total damages out of all the water bodies by a large margin, with damage estimates of $649 million (3220 inundated buildings), and $182 million (1219 inundated buildings), respectively. Total damages for all other waterbodies were less than $70 million (with fewer than 400 inundated buildings).

For most of the waterbodies total damages were made up primarily from flood damages to buildings, followed by road damages. The only exception was Huntsville Narrows, where flooding damages to water/wastewater buildings totaled $9 million (approximately 48% of total damages).

The total damage for each waterbody was divided by the length of the waterbody's shoreline to normalize the data, to allow for a comparison of the damages between the different sized waterbodies (Figure 3-8). After normalizing damage estimates, Huntsville Narrows saw the greatest total damages per meter of shore length, with $1,586/Shore Length (m). This was followed by Lake Muskoka and Lake Vernon with $1,443/Shore Length (m), and $972/Shore length (m), respectively. The lowest total damages per meter of shore length were seen at North Muskoka River Upstream of Mary Lake, with $142/Shore Length (m).

Looking only at building damages, water bodies that ranked high when assessing Average Structural Damage ($) per Building Area ($m^2$) included Port Carling ($1,405/$m^2$), Lake Muskoka ($1,212/m^2), and Lake of Bays ($1,164/$m^2$).

Total damage estimates highlight the potential importance of high valued infrastructure such as water/wastewater facilities (e.g., Mountain View Wastewater Treatment Plant - $9,076,500 replacement cost), in determining the potential flood damages throughout the watershed.

3.3.2 Water and Wastewater Facilities

A total of five water and wastewater facilities were located within the flood inundation area. Estimated damage costs associated with these facilities was $10,960,200 (note that this damage estimate includes the replacement cost of the treatment plant shown in Figure 2-3).

As discussed in Section 2.2.8, these facilities were identified using point data only (not total footprint), and as such the total number of flood-affected facilities may be underestimated. Further site-specific reconnaissance or inclusion or incorporation of additional geospatial data would be required to address this limitation.

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3.3.3 Road, Bridges and Culvert Damage Estimate

3.3.3.1 Roads

Road damages were estimated using the method described in Section 2.2.3 and ranged from $38M for Low Class Bitumen, $45M for Intermediate Class Bitumen, and $50M for High Class Bitumen.

3.3.3.2 Bridges and Culverts

A total of twenty-six bridges were identified within the flood inundation area, with damage costs totaling $2,586,119. Two major culverts were located within the flood inundation area, with estimated damage costs of $571,950.

3.3.4 Total Damages

Table 3-6: Total Damages by Structure and Grand Total

Category	Damage Estimate ($)
Buildings	863,035,723
Water Structure Buildings	10,960,200
Roadways[1]	49,992,061
Bridges	2,586,119
Culverts	571,950
Grand Total	921,858,263

Note 1: Damage reflects the high roadway damage estimate.

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Lake Vernon
B. Contents: $11,951,042
B. Structural: $30,160,812
Roads: $7,875,946
Bridges: NA (0)
Culvert: $428,842
Water/W. Water: NA

Big East River
B. Contents: $13,185,733
B. Structural: $14,010,575
Roads: $6,615,546
Bridges: $111,538 (2)
Culvert: NA
Water/W. Water: NA

Fairy Lake
B. Contents: $4,616,395
B. Structural: $9,923,093
Roads: $472,858
Bridges: $107,886 (1)
Culvert: NA
Water/W. Water: $823,000

Peninsula Lake
B. Contents: $4,320,127
B. Structural: $13,593,286
Roads: $810,500
Bridges: $170,888 (1)
Culvert: NA
Water/W. Water: $158,500

Huntsville Narrows
B. Contents: $5,140,291
B. Structural: $3,508,223
Roads: $684,797
Bridges: $310,646 (2)
Culvert: NA
Water/W. Water: $9,076,500

N. Muskoka Upstream of Mary Lake
B. Contents: $513,159
B. Structural: $1,542,815
Roads: $227,068
Bridges: NA (0)
Culvert: NA
Water/W. Water: NA

Lake of Bays
B. Contents: $39,605,425
B. Structural: $113,449,456
Roads: $7,152,952
Bridges: $246,176 (2)
Culvert: NA
Water/W. Water: NA

Mary Lake
B. Contents: $2,018,951
B. Structural: $5,994,781
Roads: $84,543
Bridges: NA (0)
Culvert: NA
Water/W. Water: NA

Port Carling
B. Contents: $1,844,563
B. Structural: $6,161,183
Roads: $2701
Bridges: NA (0)
Culvert: NA
Water/W. Water: NA

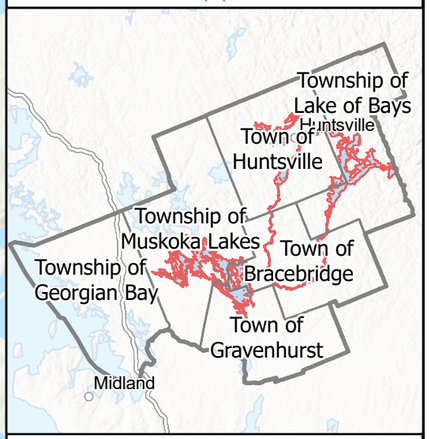
North Branch Muskoka River
B. Contents: $4,289,737
B. Structural: $13,254,498
Roads: $2,049,354
Bridges: $181,421 (3)
Culvert: NA
Water/W. Water: NA

South Branch Muskoka River
B. Contents: $3,477,831
B. Structural: $10,521,529
Roads: $8,050,327
Bridges: $308,454 (5)
Culvert: NA
Water/W. Water: NA

Bala
B. Contents: $3,252,712
B. Structural: $9,626,160
Roads: $828,736
Bridges: NA (0)
Culvert: NA
Water/W. Water: NA

Lake Muskoka
B. Contents: $147,460,563
B. Structural: $375,643,642
Roads: $9,711,974
Bridges: $211,312 (2)
Culvert: $143,109
Water/W. Water: $902,200

North and South Branch Muskoka River Bracebridge
B. Contents: $4,849,685
B. Structural: $9,119,457
Roads: $5,465,062
Bridges: $937,798 (8)
Culvert: NA
Water/W. Water: NA



Regulatory Flood Damage Estimate

Legend

Total Damages ($)

- < 15,000,000
- 15,000,000 - 35,000,000
- 35,000,000 - 70,000,000
- 70,000,000 - 200,000,000
- > 200,000,000

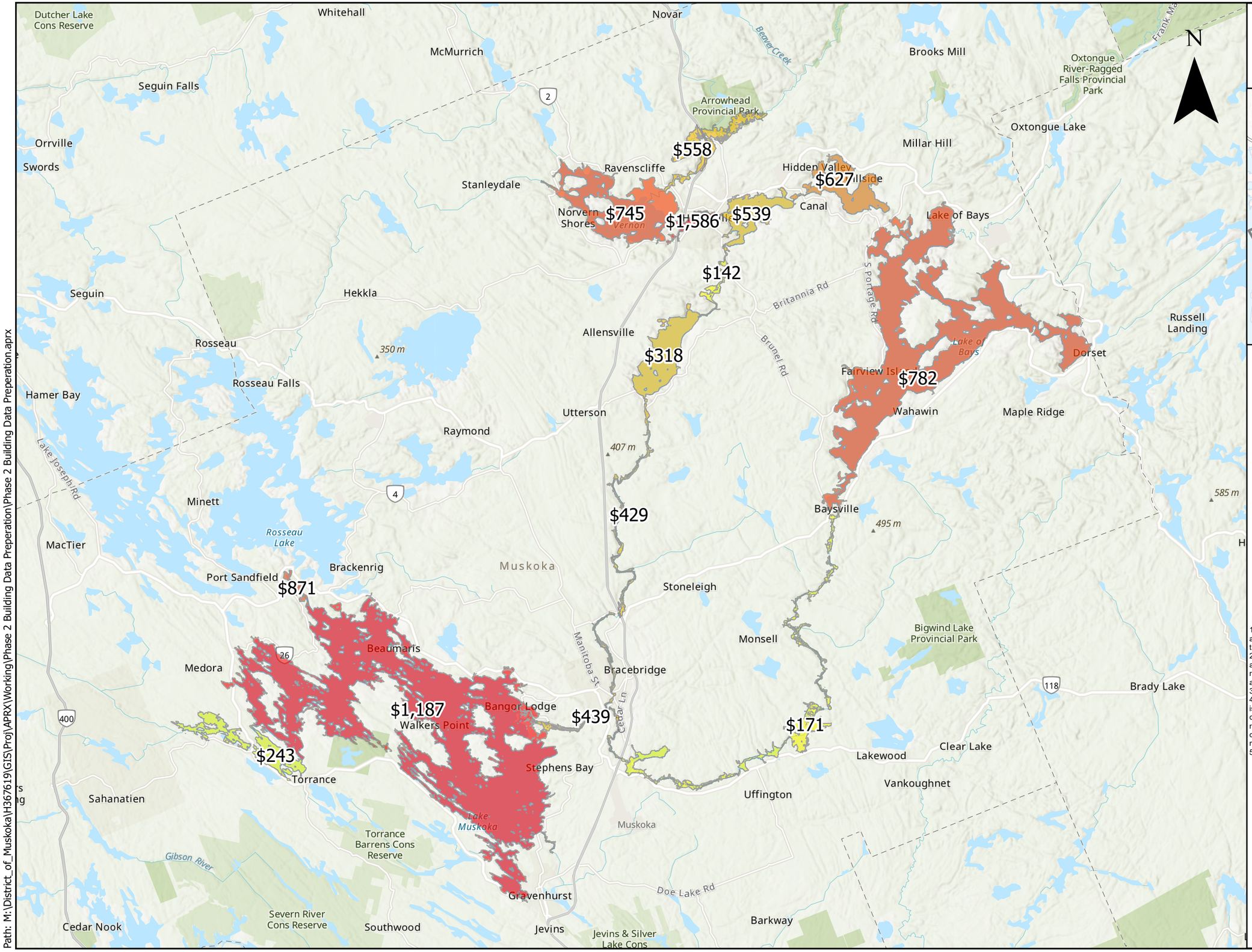
0 2.25 4.5 9 Km Scale: 1:240,000

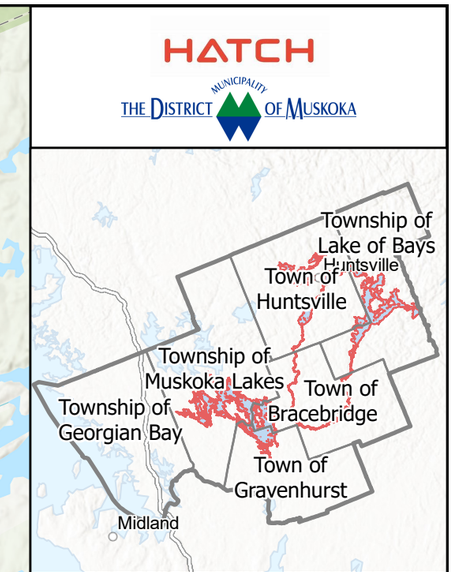
NOTES:

1. The total damages summarized in each area of this map represent an estimate of the tangible, direct flood damages that may result from the Regulatory Flood Event.
2. The methods applied to derive these damage estimates were approximate, and results should only be used as guidance for assessing relative flood risk. Real damages will depend on the actual magnitude and areal extent of flooding, and an assessment of post-flood damage.
3. Produced by Hatch for the District of Muskoka.
4. This map is for illustrative purposes only. Information contained herein is not a substitute for professional review or site survey and is subject to change without notice. The District of Muskoka and Hatch Ltd take no responsibility for, nor guarantee, the accuracy of the information contained on this map. Any interpretation or conclusions drawn from this map are the sole responsibility of the user.
5. Spatial reference NAD83 CSRS UTM Zone 17.

Figure 3-7
Summary Damage Map

Path: M:\District_of_Muskoka\H367619\GIS\Proj\APRX\Working\Phase 2 Building Data Preperation\Phase 2 Building Data Preperation.aprx





Regulatory Flood Damage Estimate Normalized by Shore Length (m)

Legend

Total Damages ($) / Shore Length (m)

- < 250
- 250 - 600
- 600 - 700
- 700 - 1000
- 1000 - 1600

0 2.25 4.5 9 Km Scale: 1:240,000

NOTES:

1. The total damages summarized in each area of this map represent an estimate of the tangible, direct flood damages that may result from the Regulatory Flood Event.
2. The methods applied to derive these damage estimates were approximate, and results should only be used as guidance for assessing relative flood risk. Real damages will depend on the actual magnitude and areal extent of flooding, and an assessment of post-flood damage.
3. Produced by Hatch for the District of Muskoka.
4. This map is for illustrative purposes only. Information contained herein is not a substitute for professional review or site survey and is subject to change without notice. The District of Muskoka and Hatch Ltd take no responsibility for, nor guarantee, the accuracy of the information contained on this map. Any interpretation or conclusions drawn from this map are the sole responsibility of the user.
5. Spatial reference NAD83 CSRS UTM Zone 17.

Figure 3-8
Map of Total Damages Normalized by the Length of Shoreline (m)

Path: M:\District_of_Muskoka\H367619\GIS\Proj\APRX\Working\Phase 2 Building Data Preperation\Phase 2 Building Data Preperation.aprx

3.4 Sensitivity Analysis

A sensitivity analysis was performed to evaluate the influence of different assumptions in the methodology. These assumptions include:

- Use of residential depth-damage curves for boathouse structures (see Section 2.2.8.1)
- Assuming an average terrain elevation for each building footprint, as a surrogate for floor elevation (see Section 2.3.2)
- Section 2.2.2.4 page.

These sensitivity checks, summarized in Table 3-7, illustrate the range in damage estimates that result from applying alternate assumptions from what is proposed as the base scenario. This variation demonstrates the uncertainty introduced by key assumptions, and how collection of additional data could reduce this range of uncertainty.

Table 3-7: Sensitivity Analysis on Total Building Damage Estimate

Sensitivity Check	Damage Estimate ($)
Base Scenario	863 M
Application of Boathouse Scaling Factors (see Section 2.2.8.1)	1.104 B
Use of Minimum instead of Average Building Elevation for floor elevation	1.124 B
Inclusion of All Mobile Homes (including those less than 34 m^2)	865 M

4. Closing

This report summarizes the development of a tool for assessing tangible, direct flood damages in select areas of the Muskoka River Watershed. Development of this tool leveraged a variety of resources, with the goal of developing an estimate of flood-related costs for various types of infrastructure.

Building depth-damage curves were derived from existing curves developed for municipalities throughout Alberta. Spatial and temporal indices were applied to scale these curves to reflect the current-day conditions in the Muskoka River Watershed. For other types of infrastructure, total damage estimates were based on rule-of-thumb approaches or replacement cost data (where available).

Total tangible direct damages associated with the Regulatory Flood within the study area was found to be approximately 1.065 billion dollars (including damages to buildings, roads, culverts, bridges, and water/wastewater facilities). A sensitivity analysis completed illustrates the bias introduced into the damage estimate by assumptions made in the approach.

The work completed as part of this study will serve to provide guidance when assessing the impacts of flood risk mitigation options.

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Appendix A
MPAC and Flood Damage Code Lookup Table

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MPAC Code	Residential (R) or Non-Residential (NR)	Flood Damage Code	
		Content Damage Curve	Structural Damage Curve
100, 110, 111, 211, 231, 242, 243, 244, 245, 261, 262, 301, 302, 303, 304, 305, 306, 307, 309, 311, 313, 314, 322, 332, 333, 334, 335, 336, 340, 341, 350, 352, 360, 361, 363, 364, 365, 366, 370, 371, 372, 373, 374, 375, 378, 379, 380, 381, 382, 383, 391, 392, 395, 486, 626	R	AA-1, AA-2, A-1, A-2, B-1, B-2, C-1, C-2, D, MA, or MW	
400, 402, 405, 438	NR	A1	S1
-	NR	B1	S5
-	NR	C1	S1
431	NR	C2	S1
-	NR	C3	S1
511, 541, 805	NR	C4	S1
435	NR	C5	S1
406, 407, 409, 410, 436, 705	NR	C6	S1
425, 426, 427, 428, 429, 430, 470, 471, 472, 473, 475, 476, 477, 478	NR	C7	S1
-	NR	D1	S1
408, 434	NR	E1	S1
750	NR	F1	S1
420, 421, 422, 423, 514, 516, 544, 598, 599, 715, 737, 738, 739, 740, 741, 744, 745, 746, 748, 749	NR	G1	S2
441, 444, 445, 446, 447, 448, 450, 451, 460, 461, 462, 463, 465	NR	H1	S3
411, 412, 413, 414, 713, 734, 736	NR	I1	S1
532	NR	J1	S1
432, 433	NR	K1	S1
210, 223, 232, 492, 500, 501, 502, 503, 504, 505, 506, 510, 512, 513, 515, 517, 518, 519, 520, 521, 523, 525, 527, 528, 529, 530, 531, 540, 545, 550, 551, 552, 553, 555, 556, 557, 558, 561, 562, 563, 564, 565, 566, 568, 575, 580, 590, 592, 593, 594, 595, 596, 806	NR	L1	S2

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MPAC Code	Residential (R) or Non-Residential (NR)	Flood Damage Code	
		Content Damage Curve	Structural Damage Curve
415, 416, 417, 711	NR	M1	S1
105, 155, 235, 490, 491, 493, 495, 496, 535, 559, 560, 591, 601, 602, 605, 608, 610, 611, 630, 631, 632, 700, 701, 710, 725, 730, 731, 733, 735, 760, 761, 762, 810, 812, 815, 822, 824, 826, 830, 832	NR	N1	S5
401, 403, 621, 623, 624, 625, 627	NR	O1	S5

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Appendix B
GIS Process – Structure Classification and Valuations

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Appendix B - GIS Process - Structure Classification and Valuations

A.1 Introduction

This process document outlines the approach used to assign certain attributes to the building footprint GIS layer for use in the flood analysis dashboard and stage-damage curve generation undertaken by Hatch Inc. as a part of the IWM suite of projects. The three processes documented here include classifying building type, generate building valuation estimate, and identifying flood zone.

A.2 GIS Process 1: Classifying Building Type

1. Save most current building footprint feature class as new GIS layer
2. Modify new layer to include the following columns:
    a) Area square feet
    b) Building Class
3. Calculate the geometry (area) of all the buildings into the Area square foot column
4. Update all records as “residential” in the Building Class column
5. Select all buildings in the new layer with a footprint of < 200 ft^2
6. Update Building Class column with value of “Shed”
7. Remove selection
8. Select all buildings in the new layer with a footprint of < 400 $ft^2$and Building Class not equal to Shed
9. Update Building Class column with value of “Outbuilding”
10. Remove selection
11. Select all buildings that intersect the waterbody polygon layer
12. Update Building Class column with value of “Boathouse”
13. Remove selection
14. Open Parcels Prime and Property Codes layers
15. Run spatial join (classified building footprint <> parcels) to assign roll number (parcel unique ID) to each footprint using the centroid intersect method. This method will negate issues arising from footprints that overlap two parcels (see structure D on example below).

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16. Run spatial join on remaining footprints that do not intersect parcels by proximity to assign closest roll number (see structure B on example below). NOTE* exclude all first nations land from this step. Leave all FN lands with “44” as roll number.
17. Run attribute join on buildings layer with the property codes layer where PropertyNum = PropertyNum.
18. Add all fields from property code layer to building layer.
19. Remove join.
20. Using new layer, select all buildings with a Class Description (from the property codes) as “Commercial”
21. Update Building Class column with value of “Commercial”
22. Using new layer, select all buildings with a Class Description (from the property codes) as “Industrial”, or “Institutional”, or “Special Purpose”
23. Update Building Class column with value of “Industrial\Institutional\Special Purpose”

A.2.1 Identified Difficulties

- Hard to determine difference between large detached garages and residences
- There might be new structures built since 2018 that are not captured within our most up to date building footprint GIS dataset

A.2.2 Assumptions

- Any footprint <200 ft^2 is a shed
- Any footprint >200 and <400 ft^2 is an outbuilding
- Any footprint that intersects a waterbody polygon is a boathouse
- The centre point of each building footprint overlaps the correct parcel
- The MPAC property code classifications for commercial, industrial, institutional, and special purpose, are all accurate
- If the center point of a building was not within a parcel, it was assigned the roll number of the nearest parcel

A.3 GIS Process 2: Generate Building Valuation Estimate

1. Make a copy of the classified building layer from the above process
2. Select all sheds and remove from dataset
3. Sum footprint area by roll number using frequency tool to get total footprint area per parcel.

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4. Run attribute join using roll number as primary key (classified building footprint <> frequency result table) to update new field in classified building footprint layer for total footprint area for all structures on parcel.
5. Run attribute join using roll number as primary key (classified building footprint <> parcels) and update new field in footprints to assign property total assessed value taken from parcels
6. Run field calculation to update “Estimated Building Value” field (Footprint Area / Total Footprint Area * Total Assessed Value)
7. At this point we will have footprints with the following attributes (showing records for the example below with fabricated attribute values)

Structure ID (example)	Parcel Roll Number	Building Class	Flood Zone	Footprint Area (ft^2)	Total Footprint Area (ft^2)	Total Assessed Value	Estimated Building Value
A	44420300120230	Residential	Static Floodline Elevation	2500	5400	$1,500,000	$694,444
B	44420300120230	Boat House	Static Floodline Elevation	1000	5400	$1,500,000	$277,777
C	44420300120230	Outbuilding	Static Floodline Elevation	300	5400	$1,500,000	$83,333
D	44420300120230	Outbuilding	Static Floodline Elevation	400	5400	$1,500,000	$111,111
E	44420300120230	Outbuilding	Static Floodline Elevation	1200	5400	$1,500,000	$333,333

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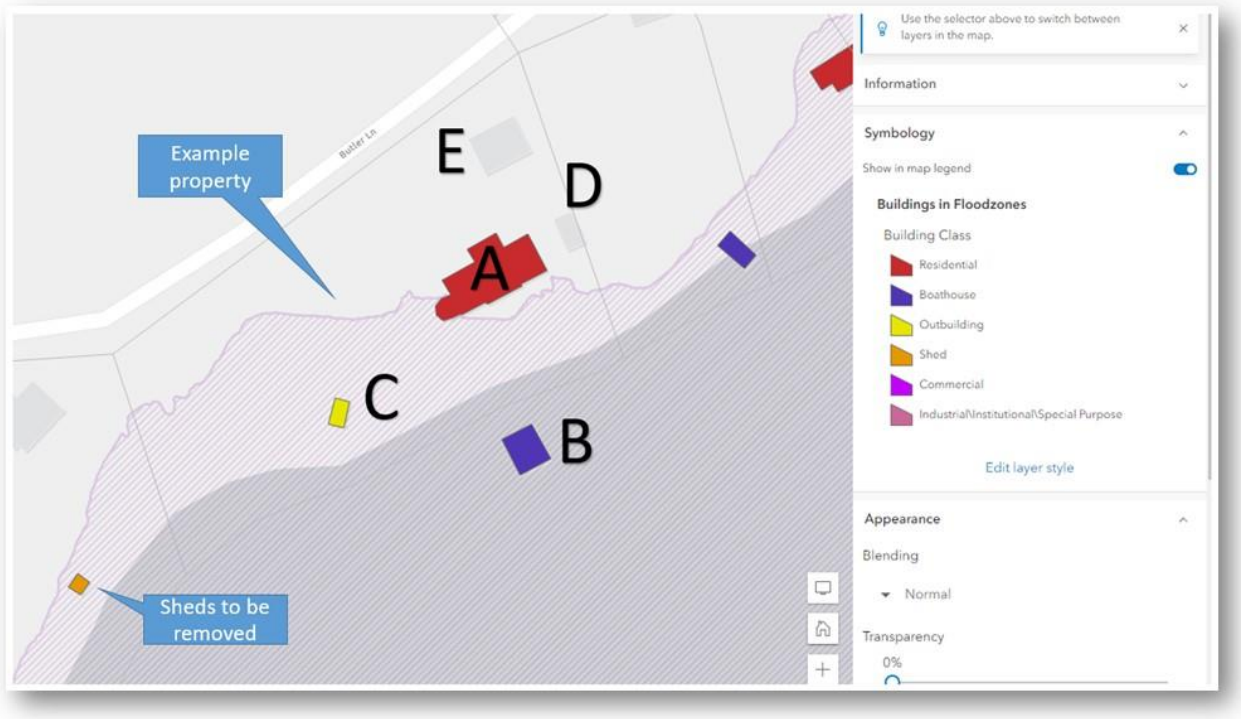
Example



Note: In the resulting layer, Buildings D and E will have a building class assigned.

This process generates an estimated value based on the following understandings:

1. This process uses the most current version of the building footprint GIS layer (currently based on the 2018 air photos) and does not necessarily capture all buildings. Also, the most current assessed values of the properties are used at the time of generation, but these will need to be updated as time progresses.
2. Assessed value is different from market value.
3. Assessed value incorporates the price of the land, where this process distributes the value across only the buildings, but this might make up for the difference noted in #1 to a certain degree.
4. The way that the value of the property has been distributed across all buildings does not factor in structure attributes such as number of stories, basement, electrical, plumbing, winterization, etc.
5. It was assumed that sheds (<200 ft^2) would not have any of the above noted significant structure attributes which contributes to a structure's value, so they were removed to ensure the valuation was distributed across buildings appropriately.

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A.4 GIS Process 3: Identifying Flood Zone

1. Modify new layer to include the following columns:
    a. Flood Zone
    b. Flood Study
2. Select flood zone by attribute starting with the “Horizontal Buffer” study type.
3. Select buildings by location using selected flood zone.
4. Update building selection to “+15m Horizontal Buffer” in the Flood Zone column.
5. Perform the above three steps for all the different flood zone types in this order:
    a. Horizontal Allowance = +15m Horizontal Buffer
    b. 100 Year Flood Level = 100 Year Flood Elevation
    c. Static Flood Line = Static Floodline Elevation
    d. Flood Line = Floodline
    e. Flood Fringe = Floodway (this one was mislabeled by Hatch)
6. Select flood zone by attribute “Phase 1” in Phase field.
7. Select buildings by location using selected flood zones.
8. Update building selection to “Phase 1” in the Flood Study column.
9. Perform the above three steps (6, 7, 8) for Phase 2.

Note:

- Phase 1 = 7298 building footprints
- Phase 2 = 3493 building footprints

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