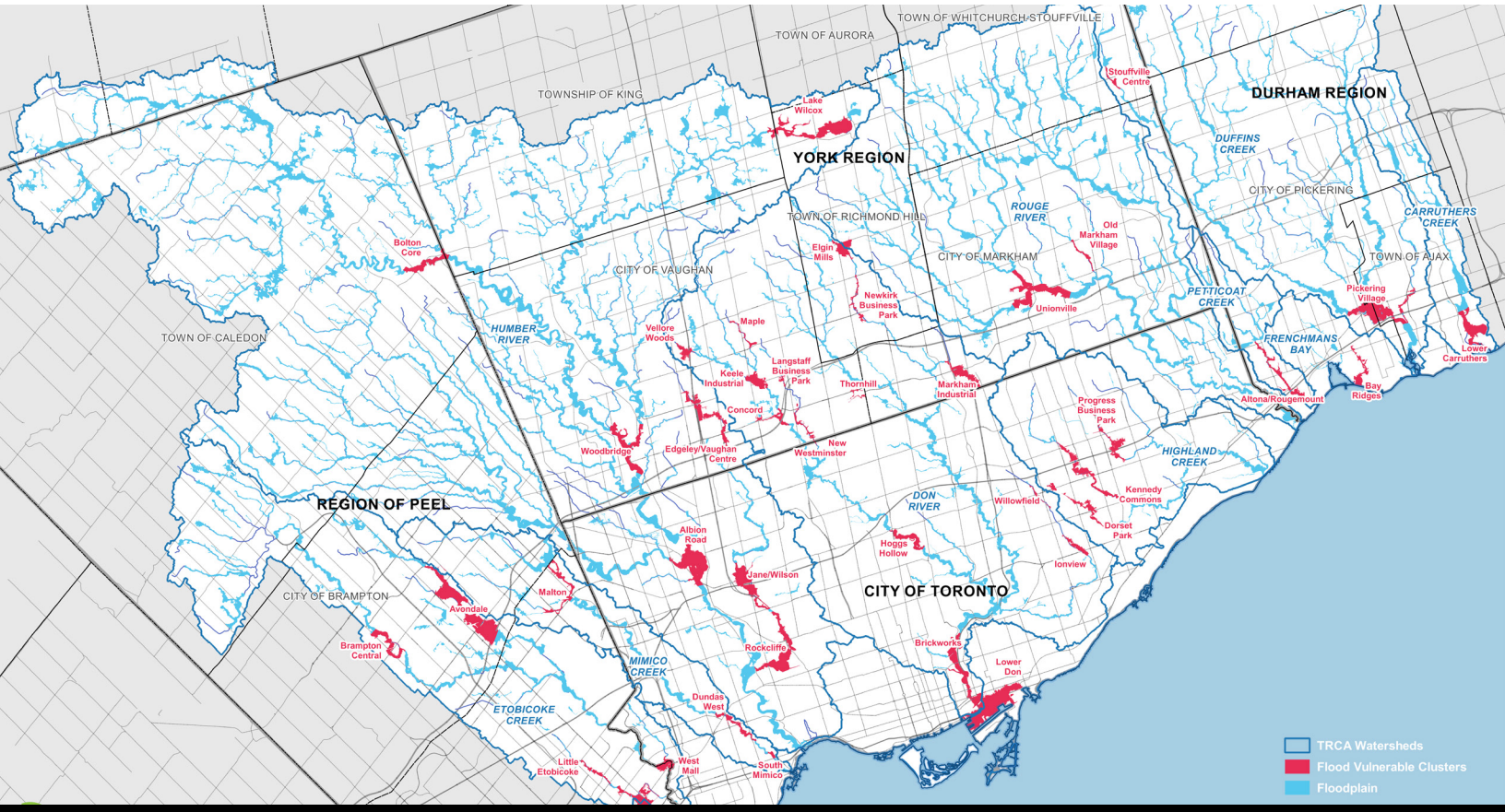
The Flood Risk Assessment and Ranking Study, was completed in 2019. As such, it utilizes the floodplain maps and models available as of mid-2018. Model and mapping updates that were finalized after that time are not reflected in the rankings, damages, or maps associated with the Flood Risk Assessment and Ranking study. As TRCA is continuously updating floodplain information, this information will become superseded over time. In the case of Newkirk Business Park, the entire cluster would be removed as the risk is no longer identified in updated mapping.

Note that the flood extents and return periods only apply to the areas within the cluster boundaries on the map as of 2018. To see the full extent of the current regulatory floodplain, please visit: https://trca.ca/conservation/flood-risk-management/flood-plain-map-viewer/.



#114571 REPORT

Toronto Flood Risk Ranking

Prepared for Toronto and Region Conservation Authority
by IBI Group
October 2019

Toronto and Region Conservation Authority Flood Risk Assessment and Ranking Project

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Executive Summary

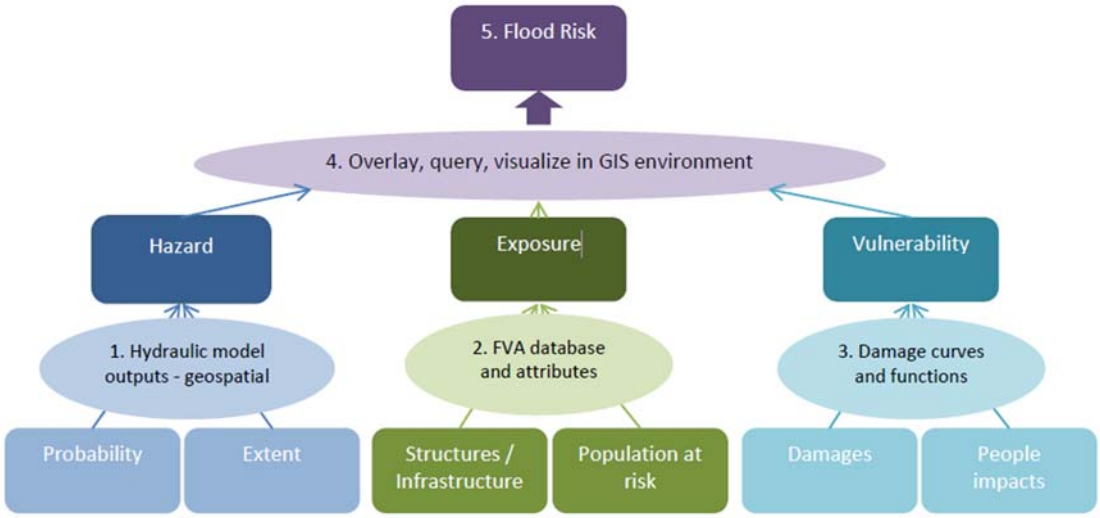
Introduction

Through its floodplain mapping program, the Toronto and Region Conservation Authority (TRCA) has identified vulnerable roads and buildings located in floodplains within its jurisdiction. These Flood Vulnerable Areas (FVAs) have been grouped together into 41 clusters. By ranking each of these clusters against one another, resources and attention may be allocated appropriately to increase flood resiliency across all clusters. The purpose of this project is to provide updated damage estimates and develop additional risk ranking factors. Flood risk factors were scored and ranked for each cluster.

Risk Quantification

Exhibit 3.1 shows an illustration of the overarching conceptualization of riverine Flood Risk that was utilized for this project. The quantification of Flood Risk requires an overlaying of the flood hazard dataset with exposed assets. Vulnerability of said assets can then be quantified as a function of the severity of the hazard relative to the exposure of the asset.

Exhibit 3.1: Conceptualization of Riverine Flood Risk



TRCA has generated a geospatial riverine flood hazard dataset for 41 of the most flood-vulnerable communities within its watersheds, which includes data for at least six design storm return-periods (2-year, 5-year, 10-year, 25-year, 50-year, 100-year) as well as the Regional Storm (Hurricane Hazel) and the 350-year where available.

The high-resolution nature of the resulting raster data was used to assign flood depths, velocities, and water surface elevations to the flood exposure dataset (building envelope polygons and road segment polylines) for the aforementioned return-period storm events and the Regional storm. The vulnerability functions were adapted from IBI Group's Provincial Flood Damage Assessment Tool developed for the Alberta Government in 2014. The functions included spatial and temporal indexing to estimate damages in the Greater Toronto Area in 2018 dollars.

In addition to the hazard information, the exposure database (buildings) also required the following attributes for the application of the correct vulnerability function:

- Building-use classification
- Structural classification
- Main floor area

- Presence of basement or underground parking
- Main floor elevation relative to grade
- Elevation of grade at building
- Number of units

Some of the attributes were calculated using assessment data from the Municipal Property Assessment Corporation (MPAC), while others, such as height of main floor, were estimated using Google Earth Pro Street View. The floor area was obtained from the GIS footprint with adjustments for garages or roof overhangs as required. Within the study area, a total of 9048 buildings were classified (excluding outbuildings such as garages and sheds).

The depth-damage functions were used to generate damage estimates for the following categories:

- Direct damage to structures and contents – based on restoration and replacement costs for each building type.
- Business interruption – based on estimated building restoration times and the associated loss of productivity or value added for each industry.
- Household displacement – based on estimated building restoration times and the associated temporary accommodation and related costs to households

Community impacts were assessed based on the number of inundated facilities providing community services. It was not feasible to inspect the potential community-service functions of all buildings within the study area. An additional challenge is that the study area covers multiple jurisdictions with varying available datasets. From a long list of community facilities and services, five key categories had consistent datasets that could be used to represent the impacts to community facilities.

- Emergency services (police, fire, and ambulance)
- Recreation facilities (indoor)
- Places of worship
- Schools (elementary, junior high, senior high)
- Community association buildings

Social vulnerability is an important aspect of flood risk. Physical and mental health impacts were researched and methods of quantifying them were explored. Based on the literature and available datasets, the following variables were identified for use in this assessment:

- Income – proportion of households with income under $20,000. This income amount was chosen as it corresponds to the available dataset and is just below the Low-Income Measure Threshold for a one-person household. The proportion is used to obtain a score relative to other clusters, so the actual threshold number was not considered critical.
- Family Type – Proportion of families with children. This metric was chosen as it considers the identified additional responsibility of household maintainers and children's sensitivity to their distress. As discussed above, it is assumed to be the best available indicator of age and gender related mental health impacts.
- Age – Proportion of residents over 65 years old. Age is used here as an indicator of pre-existing conditions and/or additional requirements during a disaster. As with income, it is used relatively and not intended to be a precise threshold.
- Hospital – Inundation of hospitals or care facilities as an indicator of a vulnerable population being exposed.
- Housing Tenure – Proportion of owner-occupied homes. Homeowners are assumed to face greater financial and emotional pressures in the post-flood recovery period.

When flooding affects public infrastructure, the impacts extend beyond the physical damage to the assets themselves. Impassible roads or loss of utility services can create delays for residents and businesses. The impact on roads was calculated using two metrics: overall inundation extent and number of impassible segments.

Risk Weighting and Scoring

Once all the identified impacts were quantified, a weighting and scoring matrix was devised to rank the relative impacts. The weighting and scoring matrix for the ranking of cluster risk was determined with consideration of literature review, past experience, expert input from TRCA and stakeholders, and data availability. The variables and the weighting used for this study are detailed in **Exhibit 4.9**. The weighting reflects the assumption that many additional impacts are directly associated to flooding of buildings and roads as well as the availability of data for other categories.

Exhibit 4.9: Risk Ranking Matrix

Category Weight	Total Points	Category	Weight of Variable	Variable
50%	50	Tangible Building-Associated	15	Direct non-residential damages
			15	Direct residential damages
			10	Business interruption
			10	Residential displacement
10%	10	Community Impacts	2	Emergency services
			2	Recreation facilities
			2	Cultural
			2	Schools
			2	Community associations
20%	20	Social Vulnerability	5	Income
			5	Family type
			5	Age
			2	Hospitals
			3	Tenure
20%	20	Infrastructure	8	Roads
			5	Public transit
			7	Utilities risk
15%	15	Preparedness and Resiliency	5	Active mitigation
			5	Growth potential
			5	Warning system penetration

*Total is 100 for the four risk categories; Preparedness and Resiliency can reduce score by up to 15

Damage Estimates

The total damages include direct damages to residential, commercial/industrial/institutional, as well as business interruption and residential displacement. **Exhibit 5.1a** details the summed tangible building related damage amount for each cluster.

Average Annual Metrics

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 AAD is obtained by calculating the area under the damage-probability curve, which depicts total damage versus the probability of occurrence. Annualized values for this project were calculated using a straight-line interpolation between events with a trapezoid area formula.

Non-monetized impacts were also annualized, including the annualized number of people affected, impassible road segments, and area of commercial buildings. A summary of the average annual metrics is provided in **Exhibit 5.8**.

Risk Ranking

To convert the AAD values into a score within the overall risk ranking matrix, the AAD for each cluster was converted into a relative score and then multiplied by the weighting for each of the four variables. Initially, the relative score was obtained by dividing a cluster's AAD by the highest cluster AAD amount. However, several clusters had much higher damage amounts than the majority. The result of the relative division was that most clusters had insignificant values. Therefore, a new relative score was obtained by dividing all values by the 90th percentile value of all scores, with a maximum value of one.

This had the effect of giving the top four clusters full score (relative score of one) and a clearer distribution of the remaining scores. This method was chosen because it maintains both the ranking of the scores and the magnitude of the difference between the damage amounts.

The relative score (from zero to one) was then multiplied by the variable weight to obtain each cluster's weighted score for the category. The results of ranking are detailed in **Exhibit 6.1**.

Tangible Building-Related Damage Totals

Total Damages

Cluster	Return Period							
	1:2	1:5	1:10	1:25	1:50	1:100	1:350	Regional
Albion Road	$0	$0	$0	$0	$107,000	$110,000	n/a	$63,121,000
Altona/Rougemount	$0	$0	$0	$0	$0	$0	n/a	$2,576,000
Avondale	$0	$5,442,000	$8,374,000	$47,803,000	$79,077,000	$100,317,000	$124,629,000	$149,998,000
Bay Ridges	$311,000	$328,000	$943,000	$2,690,000	$4,007,000	$6,186,000	n/a	$6,186,000
Bolton Core	$0	$228,000	$4,240,000	$6,959,000	$8,023,000	$9,423,000	n/a	$75,424,000
Brampton Central	$0	$0	$0	$0	$0	$0	$494,000	$71,607,000
Brickworks	$0	$500,000	$2,055,000	$5,092,000	$20,251,000	$32,310,000	$42,583,000	$50,546,000
Concord	$0	$0	$0	$278,000	$905,000	$905,000	n/a	$4,353,000
Dixie/Dundas	$0	$4,546,000	$33,620,000	$38,959,000	$42,326,000	$45,714,000	$60,021,000	$69,291,000
Dorset Park	$0	$0	$0	$1,672,000	$13,704,000	$19,399,000	n/a	$27,251,000
Dundas West	$0	$0	$0	$0	$23,000	$123,000	n/a	$28,921,000
Edgeley/Vaughan Centre	$0	$0	$0	$604,000	$2,580,000	$7,509,000	n/a	$245,177,000
Elgin Mills	$0	$207,000	$213,000	$213,000	$228,000	$228,000	n/a	$4,593,000
Hoggs Hollow	$0	$319,000	$509,000	$2,085,000	$2,670,000	$4,777,000	$6,234,000	$59,012,000
Ionview	$0	$0	$501,000	$2,130,000	$4,977,000	$6,701,000	n/a	$34,537,000
Jane/Wilson	$0	$631,000	$6,100,000	$14,370,000	$20,135,000	$34,268,000	$77,956,000	$124,254,000
Keele Industrial	$0	$0	$0	$0	$0	$0	n/a	$128,985,000
Kennedy Commons	$0	$20,000	$20,000	$769,000	$15,399,000	$26,378,000	n/a	$134,279,000
Lake Wilcox	$1,112,000	$1,488,000	$2,342,000	$3,313,000	$4,409,000	$5,439,000	$86,326,000	$99,447,000
Langstaff Business Park	$0	$0	$0	$0	$0	$9,000	n/a	$47,000
Little Etobicoke	$0	$0	$0	$0	$0	$0	$2,076,000	$5,585,000
Longbranch	$0	$5,000	$35,000	$35,000	$43,000	$52,000	$5,356,000	$10,542,000
Lower Carruthers	$187,000	$187,000	$188,000	$188,000	$188,000	$189,000	n/a	$10,766,000
Lower Don	$0	$352,000	$1,294,000	$2,606,000	$4,082,000	$26,711,000	$57,027,000	$424,569,000
Malton	$0	$740,000	$759,000	$868,000	$1,059,000	$1,124,000	n/a	$19,185,000
Maple	$1,200,000	$1,371,000	$1,515,000	$1,515,000	$2,114,000	$2,476,000	n/a	$5,530,000
Markham Industrial	$1,641,000	$5,554,000	$5,554,000	$36,087,000	$36,998,000	$57,528,000	n/a	$57,528,000
New Westminster	$0	$0	$228,000	$603,000	$1,262,000	$2,059,000	n/a	$21,329,000
Newkirk Business Park	$0	$0	$0	$1,051,000	$2,207,000	$2,623,000	n/a	$11,436,000
Old Markham Village	$0	$0	$0	$115,000	$115,000	$115,000	n/a	$2,154,000
Pickering Village	$82,000	$84,000	$10,874,000	$15,984,000	$20,452,000	$24,624,000	$31,828,000	$168,134,000
Progress Business Park	$0	$0	$12,000	$7,399,000	$23,764,000	$32,226,000	n/a	$53,980,000
Rockcliffe	$0	$1,853,000	$21,955,000	$61,888,000	$102,545,000	$173,051,000	$229,308,000	$313,239,000
South Mimico	$0	$0	$0	$0	$167,000	$412,000	n/a	$10,675,000
Stouffville Centre	$346,000	$346,000	$387,000	$447,000	$493,000	$650,000	n/a	$3,870,000
Thornhill	$1,459,000	$1,619,000	$2,022,000	$3,963,000	$4,853,000	$5,111,000	n/a	$4,866,000
Unionville	$7,000	$79,000	$209,000	$373,000	$992,000	$2,228,000	$3,309,000	$60,196,000
Vellore Woods	$0	$0	$0	$0	$0	$0	n/a	$38,424,000
West Mall	$0	$0	$0	$172,000	$368,000	$447,000	$16,778,000	$52,733,000
Willowfield	$0	$0	$0	$794,000	$1,578,000	$2,374,000	n/a	$2,374,000
Woodbridge	$0	$0	$98,000	$320,000	$1,786,000	$2,825,000	$5,196,000	$78,386,000
Total	$6,345,000	$25,899,000	$104,047,000	$261,345,000	$423,887,000	$636,621,000	n/a	$2,735,106,000

Summary of Average Annual Metrics by Cluster

Cluster	AA Damages	AAD Non-Residential	AAD Residential	AAD Non-Residential Direct	AAD Residential Direct	AAD Non-Residential Interruption	AAD Residential Displacement	AA Population	AA Commercial/Industrial m2	AA Institutional m2	AA Employees	AA Mean Road Depth*Length	AA Impassible Road Segments	AA Emergency Services	AA Recreation Facilities	AA Places of Worship	AA Schools	AA Community Centres	AA Go Stations	AA Long Term Care
Albion Road	$286,700	$11,700	$275,001	$10,783	$249,295	$916	$25,706	12.527	0.000	21.653	0.000	3,599.367	16.136	0.000	0.000	0.018	0.005	0.000	0.000	0.000
Altona/Rougemount	$11,593	$674	$10,919	$263	$10,405	$411	$514	0.386	35.677	0.000	0.573	192.580	0.935	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Avondale	$6,416,498	$6,332,853	$83,645	$4,128,973	$80,062	$2,203,880	$3,583	8.104	18,176.885	152.853	286.778	1,938.408	7.579	0.009	0.000	0.642	0.009	0.009	0.005	0.005
Bay Ridges	$441,942	$0	$441,942	$0	$427,636	$0	$14,306	10.881	0.000	0.000	0.000	1,185.643	6.314	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bolton Core	$1,212,328	$185,727	$1,026,601	$72,135	$991,401	$113,591	$35,200	46.483	100.687	21.234	2.692	4,310.840	12.513	0.009	0.000	0.000	0.000	0.000	0.000	0.000
Brampton Central	$68,715	$53,944	$14,771	$21,602	$13,061	$32,342	$1,710	2.188	95.495	14.745	1.612	117.860	4.459	0.000	0.005	0.005	0.000	0.000	0.000	0.000
Brickworks	$1,287,381	$1,287,381	$0	$637,606	$0	$649,775	$0	0.000	5,395.815	1.636	166.201	17,751.947	66.718	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Concord	$52,626	$546	$52,080	$385	$51,131	$161	$948	0.887	3.513	0.000	0.094	411.800	2.145	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dixie/Dundas	$6,518,333	$6,185,978	$332,355	$3,505,383	$283,627	$2,680,595	$48,728	137.588	22,537.328	0.000	426.502	9,093.547	17.741	0.000	0.000	0.014	0.000	0.000	0.000	0.000
Dorset Park	$579,370	$309,303	$270,067	$152,348	$256,280	$156,955	$13,787	14.005	1,968.429	40.329	35.691	515.908	4.353	0.029	0.000	0.005	0.005	0.000	0.000	0.000
Dundas West	$131,658	$11,610	$120,048	$4,989	$116,952	$6,621	$3,096	1.671	33.012	0.779	0.759	475.296	7.969	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Edgeley/Vaughan Centre	$1,237,487	$1,237,487	$0	$774,418	$0	$463,069	$0	0.000	1,985.543	60.017	28.392	781.416	3.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Elgin Mills	$94,938	$82,580	$12,376	$36,982	$10,606	$45,598	$1,770	0.378	3,598.000	9.000	53.000	140.153	0.856	0.000	0.000	0.000	0.005	0.000	0.000	0.000
Hoggs Hollow	$351,728	$44	$351,684	$16	$347,791	$28	$3,893	3.228	1.087	0.000	0.016	5.189	0.081	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Ionview	$419,019	$121,691	$297,328	$78,034	$280,100	$43,658	$17,228	29.177	373.032	0.550	6.084	228.100	1.433	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jane/Wilson	$2,250,945	$1,393,895	$857,050	$851,223	$757,837	$542,672	$99,213	138.821	1,658.766	1,391.407	41.028	56,026.868	31.535	0.273	0.000	0.227	0.014	0.000	0.000	0.000
Keele Industrial	$580,433	$580,279	$154	$358,883	$0	$221,397	$154	0.049	532.739	0.000	9.089	131.662	0.158	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Kennedy Commons	$1,120,954	$1,075,835	$45,119	$556,993	$42,170	$518,842	$2,949	7.766	5,014.832	5.389	95.813	495.949	2.052	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Lake Wilcox	$1,377,813	$17,858	$1,359,954	$8,870	$1,322,390	$8,989	$37,565	27.436	21.957	4.722	0.449	1,692.482	14.780	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Langstaff Business Park	$294	$294	$0	$199	$0	$95	$0	0.000	103.933	0.000	1.485	3.567	0.112	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Little Etobicoke	$14,527	$0	$14,527	$0	$13,855	$0	$672	0.509	0.000	0.000	0.000	142.091	7.600	0.000	0.000	0.000	0.000	0.000	0.000	0.005
Longbranch	$40,011	$6,558	$33,452	$6,558	$29,905	$0	$3,547	1.535	0.000	47.409	0.000	269.829	2.220	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lower Carruthers	$141,114	$0	$141,114	$0	$137,969	$0	$3,145	2.506	0.000	0.000	0.000	591.223	4.262	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lower Don	$1,219,167	$899,084	$320,083	$419,592	$296,180	$479,493	$23,903	18.233	3,764.686	19.894	71.999	5,935.093	35.425	0.005	0.000	0.000	0.000	0.000	0.000	0.000
Malton	$356,344	$1,791	$354,553	$739	$339,914	$1,052	$14,639	11.297	27.444	3.446	0.679	774.564	6.312	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Maple	$716,209	$0	$716,209	$0	$704,826	$0	$11,383	11.522	0.000	0.000	0.000	91.636	3.279	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Markham Industrial	$6,131,839	$6,123,359	$8,480	$4,026,971	$8,215	$2,096,387	$265	0.196	44,889.637	132.886	652.203	6,532.231	37.800	0.000	0.000	0.349	0.000	0.000	0.000	0.000
New Westminster	$176,853	$0	$176,853	$0	$169,805	$0	$7,048	5.449	0.000	0.000	0.000	86.703	0.580	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Newkirk Business Park	$151,524	$497	$151,027	$336	$144,082	$161	$6,945	10.611	5.764	0.000	0.082	241.770	3.193	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Old Markham Village	$17,094	$0	$17,094	$0	$16,797	$0	$297	3.953	0.000	0.000	0.000	305.852	4.470	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pickering Village	$2,355,521	$241,180	$2,114,342	$103,289	$1,995,115	$137,890	$119,227	103.079	348.872	0.000	6.328	526.760	7.493	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Progress Business Park	$1,202,459	$1,187,519	$14,939	$698,528	$13,656	$488,992	$1,284	69.699	5,200.457	145.298	100.638	782.592	4.470	0.000	0.000	0.023	0.005	0.000	0.000	0.000
Rockcliffe	$8,946,721	$5,525,352	$3,421,369	$3,346,379	$3,221,950	$2,178,973	$199,419	150.065	6,256.111	3,766.516	98.100	46,337.594	32.705	0.005	0.000	0.149	0.143	0.000	0.000	0.000
South Mimico	$54,467	$0	$54,467	$0	$52,684	$0	$1,783	0.904	0.000	0.000	0.000	8.446	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stouffville Centre	$204,491	$127,666	$76,825	$127,300	$73,128	$365	$3,697	2.769	92.714	444.745	1.423	125.402	1.375	0.000	0.000	0.000	0.000	0.005	0.000	0.000
Thornhill	$1,006,308	$424	$1,005,885	$137	$987,419	$286	$18,465	14.650	2.603	0.000	0.053	426.068	9.891	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Unionville	$153,338	$25,805	$127,534	$11,344	$122,250	$14,461	$5,283	4.666	870.609	4.749	19.193	24,432.372	43.287	0.000	0.000	0.014	0.000	0.000	0.000	0.000
Vellore Woods	$172,907	$0	$172,907	$0	$168,183	$0	$4,724	3.415	0.000	0.000	0.000	15.248	0.101	0.000	0.000	0.000	0.000	0.000	0.000	0.000
West Mall	$140,702	$126,605	$14,096	$68,702	$13,645	$57,903	$452	0.315	258.416	0.000	5.359	25.508	0.165	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Willowfield	$88,700	$129	$88,571	$96	$85,400	$33	$3,171	2.926	0.000	19.897	0.000	133.336	7.681	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Woodbridge	$167,797	$30,511	$137,286	$19,117	$133,712	$11,393	$3,574	13.153	18.858	33.578	0.459	5,080.173	16.921	0.005	0.005	0.009	0.000	0.000	0.000	0.000
Total	$47,898,846	$33,186,158	$14,712,706	$20,029,172	$13,969,433	$13,156,986	$743,273	873.026	123,372.901	6,342.732	2,112.773	191,963.072	430.138	0.333	0.009	1.466	0.183	0.014	0.005	0.009

Summary of Cluster Scores and Ranking by Category

Cluster	Building Associated		Community Impacts		Social Vulnerability		Infrastructure		Total	Rank
	Score	Rank	Score	Rank	Score	Rank	Score	Rank		
Rockcliffe	50.00	1	2.50	3	18.00	1	11.50	1	82.00	1
Jane/Wilson	44.86	2	2.90	2	17.60	5	11.36	4	76.72	2
Dixie/Dundas	39.31	3	0.04	13	18.00	1	9.67	8	67.02	3
Pickering Village	28.94	4	0.00	19	17.73	4	4.65	16	51.32	4
Bolton Core	27.39	5	0.07	11	15.12	6	6.93	11	49.51	5
Avondale	27.17	6	4.19	1	4.08	15	10.28	6	45.73	6
Progress Business Park	20.38	12	0.13	9	18.00	1	4.39	20	42.91	7
Lower Don	25.64	7	0.03	15	6.43	9	10.11	7	42.21	8
Lake Wilcox	25.29	8	0.00	19	6.95	8	6.05	12	38.30	9
Markham Industrial	25.20	9	1.09	6	0.02	37	10.37	5	36.67	10
Brickworks	21.24	10	0.00	19	0.00	38	11.50	1	32.74	11
Thornhill	19.92	13	0.00	19	4.67	10	4.90	13	29.49	12
Kennedy Commons	19.23	14	0.01	16	3.07	17	3.97	27	26.28	13
Edgeley/Vaughan Centre	20.77	11	0.00	19	0.00	38	4.21	23	24.98	14
Ionview	10.89	17	0.00	19	9.45	7	3.78	31	24.11	15
Albion Road	10.83	18	0.12	10	4.14	14	7.06	10	22.15	16
Dorset Park	12.66	16	0.29	8	4.38	12	4.26	22	21.60	17
Maple	13.74	15	0.00	19	3.04	18	3.94	29	20.71	18
Bay Ridges	10.30	19	0.00	19	4.59	11	4.79	14	19.69	19
Woodbridge	3.49	28	2.06	4	4.19	13	7.80	9	17.55	20
Unionville	3.69	27	0.04	13	1.89	21	11.50	1	17.12	21
Malton	9.09	21	0.00	19	2.91	19	4.61	17	16.62	22
Keele Industrial	9.77	20	0.01	16	0.00	38	3.58	36	13.36	23
Newkirk Business Park	4.05	25	0.00	19	3.47	16	4.00	26	11.51	24
Hoggs Hollow	6.32	22	0.01	16	1.04	26	3.51	40	10.89	25
Stouffville Centre	4.34	24	1.00	7	1.10	25	3.72	32	10.17	26
New Westminster	4.46	23	0.00	19	1.49	22	3.61	35	9.56	27
Brampton Central	1.53	34	2.01	5	0.78	29	4.10	25	8.42	28
Vellore Woods	3.81	26	0.00	19	0.84	28	3.52	38	8.17	29
Willowfield	2.14	32	0.00	19	1.31	23	4.50	18	7.95	30
Dundas West	2.79	30	0.00	19	0.45	32	4.68	15	7.92	31
Lower Carruthers	2.93	29	0.00	19	0.58	30	4.28	21	7.79	32
Little Etobicoke	0.39	38	0.00	19	2.16	20	4.49	19	7.04	33
West Mall	2.43	31	0.00	19	0.04	36	3.53	37	6.00	34
Longbranch	1.51	35	0.00	19	0.50	31	3.89	30	5.91	35
Elgin Mills	1.99	33	0.06	12	0.09	27	3.67	34	5.80	36
Old Markham Village	0.33	39	0.00	19	1.29	24	4.18	24	5.80	37
Concord	1.04	37	0.00	19	0.20	33	3.94	28	5.18	38
South Mimico	1.28	36	0.00	19	0.09	35	3.51	41	4.88	39
Altona/Rougemount	0.31	40	0.00	19	0.12	34	3.70	33	4.13	40
Langstaff Business Park	0.00	41	0.00	19	0.00	38	3.52	39	3.52	41

1 Introduction

1.1 Background

Through its floodplain mapping program, the Toronto and Region Conservation Authority (TRCA) has previously identified numerous vulnerable roads and buildings located in floodplains within its jurisdiction. TRCA originally estimated that there were approximately 10,000 Flood Vulnerable Areas (FVAs), which have been grouped together into 41 clusters to further define their attributes and risk exposure. By ranking each of these clusters against one another, resources and attention may be allocated appropriately to increase flood resiliency across all clusters.

1.2 Purpose

The purpose of this project is to provide updated damage estimates and develop additional risk ranking factors based on background research, expert knowledge, and stakeholder input to quantify flood risk at the cluster level using TRCA's updated geodatabase of FVAs.

The updated database will contain information on flood risk at the level of individual vulnerable structures that can be 'rolled up' to inform risk rankings for each of TRCA's 41 FVA Clusters. This project will also provide valuable data for further analysis to allow remediation and mitigation efforts to be focused where maximal benefits will be realized by providing the baseline for damage avoidance estimates that can inform the benefit side of a benefit/cost analysis for mitigation projects.

The resulting data will also be leveraged to co-develop site-specific emergency response plans for the highest-risk flood vulnerable clusters in cooperation with TRCA's partner municipalities and enable TRCA to provide detailed inundation mapping and generate impacted address lists for municipal emergency responders during flood events. In addition, the resulting data will directly support TRCA's Flood Risk Outreach Strategy in communicating flood risk to affected communities.

1.3 Scope and Deliverables

This project encompasses 41 Flood Vulnerable Areas in the Greater Toronto Area. The following tasks comprise the scope of the project.

- Perform a background review of all materials provided by TRCA, as well as research and review additional materials relevant to flood risk assessment best practices, infrastructure damage quantification, intangible damages, and socio-economic risk factors.
- Check the quality of inventory data for FVAs.
- Convert event-specific damages to average annualized damages.
- Convert event-specific population displacement and business-interruption damage estimates to average annualized damages.
- Determine which additional risk factors should be considered in the risk assessment process.
- Roll-up structure-level data to the cluster level to quantify flood risk for each cluster.
- Engage with stakeholders to assign a weighting to each additional risk factor.
- Determine and populate a risk ranking matrix for each of the clusters with risk scores and rank the risk of each cluster according to the developed matrix.
- Review previous studies on mitigation options within each cluster.
- Produce risk factsheets summarizing the key points for each cluster.

2 Toronto and Region Conservation Authority

2.1 Purpose

Amongst other objectives, the TRCA is mandated with responsibilities to reduce risk to life and property damage caused by riverine flooding in the Greater Toronto Area. TRCA has implemented a variety of measures to address flood risks in their watersheds, including:

- regulation of land development in floodplains;
- interfacing with municipal land use planners to solve urban redevelopment constraints and infrastructure upgrading for resilient communities;
- development of floodplain mapping and hydrologic modelling;
- development of flood risk and mitigation plans;
- operation of a “Flood Forecasting and Warning” program, which includes the issuance of flood warning messages;
- monitoring of watershed conditions (including streamflow, precipitation, snowpack and meteorological data);
- operation of flood control structures; and
- providing technical support and advice to assist municipalities in the development of emergency management plans to minimize flood risks.

2.2 Jurisdiction

Under the Conservation Authorities Act, TRCA has regulatory jurisdiction over nine watersheds and a portion of the Lake Ontario shoreline. Containing all or parts of eighteen different municipalities, it is one of the largest of the 36 conservation authorities in Ontario and is certainly among the most urbanized with the highest population and population density. Draining from the Oak Ridges Moraine, Peel Plains, South Slope, and Iroquois Sand Plain, TRCA’s watersheds are:

- Carruthers Creek
- Don River
- Duffins Creek
- Etobicoke Creek
- Mimico Creek
- Highland Creek
- Humber River
- Mimico Creek
- Petticoat Creek
- Rouge River

The jurisdiction also includes small areas that drain directly to Lake Ontario, such as Frenchman’s Bay.

TRCA’s participating or member municipalities include:

- City of Toronto
- Regional Municipality of Durham
- Regional Municipality of Peel

- Regional Municipality of York
- Township of Adjala-Tosorontio
- Town of Mono

The local municipalities that are located either wholly or partly within the jurisdiction include:

- Town of Caledon
- City of Brampton
- City of Mississauga
- Township of King
- Town of Aurora
- City of Vaughan
- Town of Richmond Hill
- Town of Whitchurch-Stouffville
- City of Markham
- Township of Uxbridge
- City of Pickering
- Town of Ajax

The full jurisdiction can be seen in **Exhibit 2.1**.

2.3 History of Flood Management

Pre-Hurricane Hazel, many residents settled near water because it was convenient, and there was not an in-depth understanding of the severity of damage that could result from a flood of such magnitude. In October of 1954, Hurricane Hazel brought Toronto and area the most devastating flooding in its recorded history. Hurricane Hazel delivered over 280 mm of rain to Southern Ontario, with the majority falling within the last twelve hours of the storm. This caused many rivers within the in the city to flow four times higher and faster than ever before. In the aftermath of the hurricane, 81 people were killed, and thousands were left homeless.

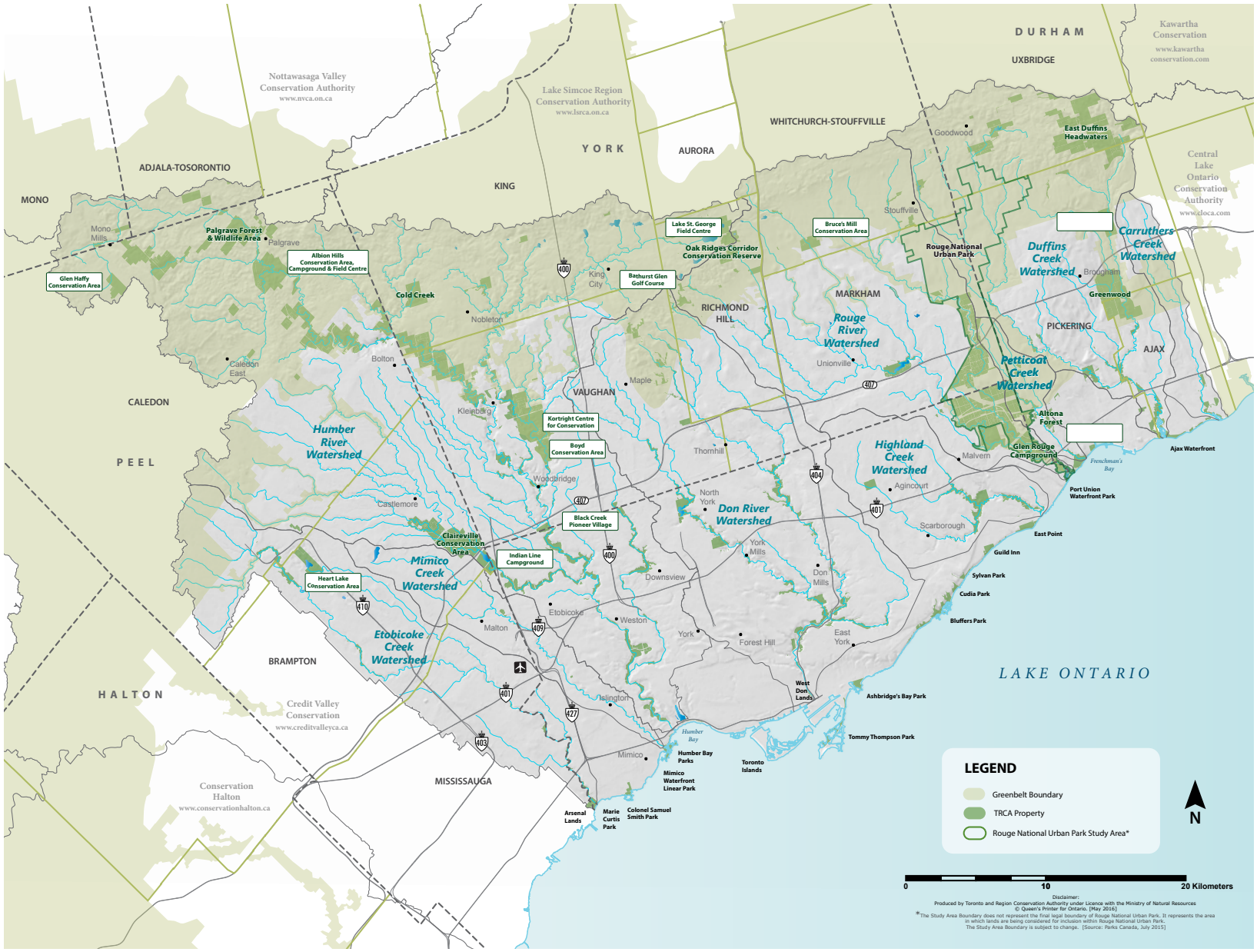
Hurricane Hazel was estimated to have caused $1 billion worth of damage in today's dollars, but in the aftermath of the devastation came the many floodplain regulations and flood management principles in place in the GTA today.

Hurricane Hazel jump-started the Metropolitan Toronto and Region Conservation Authority's (MTRCA's) flood control program. After Hurricane Hazel, the Provincial government amended the Conservation Authorities Act, enabling the MTRCA to acquire lands for conservation and recreation purposes. In 1959 the Plan for Flood Control and Water Conservation was finalized, which identified locations for flood control dams and channels, the acquisition of flood plain lands (to transfer the liability of floodplain land from private hands to the Authorities and to acquire lands necessary for the construction of flood protection works), and the creation of a flood warning system.

Provincially, the development and implementation a flood plain planning policy was initiated. Within this process the Province of Ontario began the development of flood plain regulations and the updating of the Conservation Authorities Act to allow for regulations to restrict future development and land use within flood hazard areas, thereby reducing potential flood damage.

In recognition of the impact of urbanization on the hydrologic cycle, the stormwater management program was initiated in 1980 to mitigate impacts related to flooding and erosion. The program continued to evolve to include water quality and temperature impacts, source controls, and retrofitting of facilities which did not meet current design standards.

TRCA Jurisdiction



2.4 Current Context

The majority of valley and stream corridors within TRCA's jurisdiction are subject to the *One Zone Concept* of flood plain management (**Exhibit 2.2**). In this approach the entire area within the Regulatory floodplain is considered to the one management zone. It is the most restrictive and effective way to manage flood hazards from a risk management perspective (Toronto and Region Conservation Authority, 2014). This contrasts with the *Two Zone Concept* (**Exhibit 2.3**) which outlines a further flood fringe in which development and site alteration may be permitted, subject to specific conditions, including floodproofing.

Exceptions to the One-Zone and Two-Zone approaches exist where a *Special Policy Area* approach is employed by the Province in appropriate cases where it has been demonstrated that the One-Zone or Two-Zone approaches are too restrictive and would not allow for the continued social and economic viability and revitalization of historical communities located within the flood plain. Where a *Special Policy Area* is adopted, TRCA, the member municipality, and the Province agree to relax provincial flood proofing and technical standards and accept a higher level of risk. Area-specific policies in the municipal official plan are intended to provide for the continued viability of existing land uses while being sufficiently protective against flood hazards (Toronto and Region Conservation Authority, 2014).

While current flood plain regulation policies in conjunction with the stormwater management program have served well to prevent the introduction of additional risk to flood hazard lands, there are communities within flood hazard lands which were developed prior to current regulations and practices that remain at risk to riverine flooding.

Exhibit 2.2: One Zone Concept, Flooding Hazard Limit (Ontario Ministry of Natural Resources, 2002)

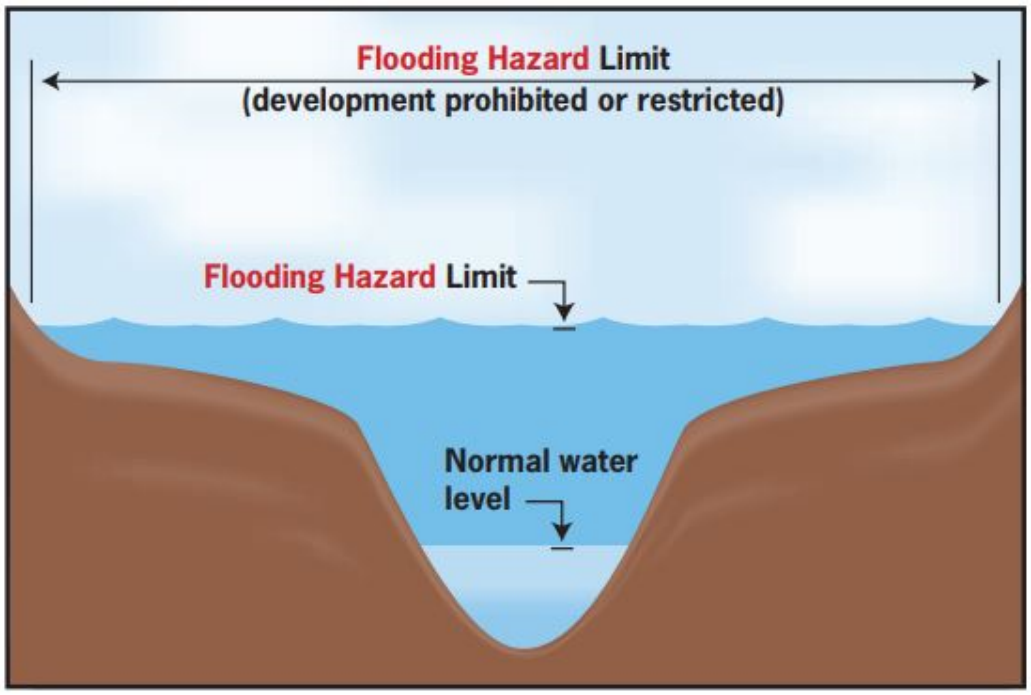
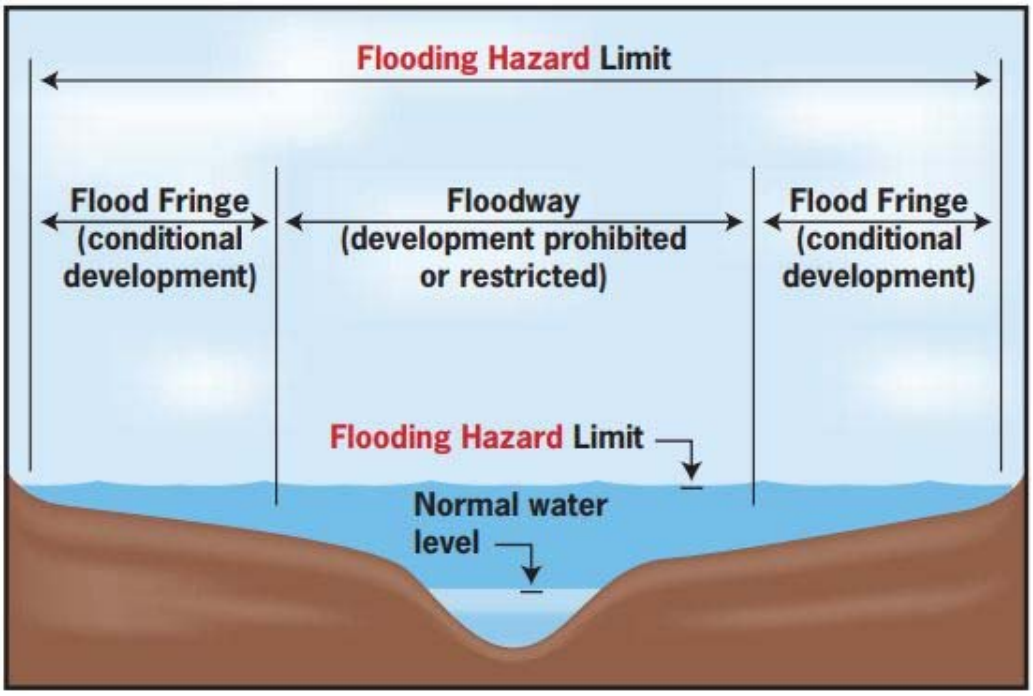


Exhibit 2.3: Two Zone Concept, Flooding Hazard Limit (Ontario Ministry of Natural Resources, 2002)



3 Flood Vulnerable Areas

3.1 Background

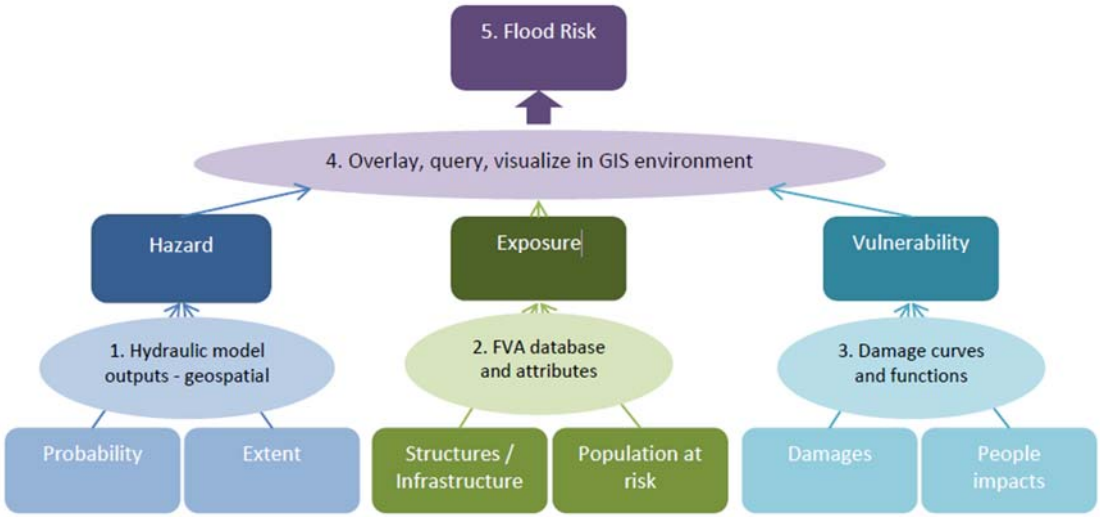
TRCA has a floodplain mapping program, throughout which it had previously identified almost 10,000 roads and structures within its jurisdiction as being at risk of riverine flooding. Vulnerable structures and roads within the Regulatory floodplain are then counted to determine Flood Vulnerable Areas (FVAs). The Regulatory floodplain is the area that is subject to flooding under an extreme event and is defined as the greater of the 100-year flood, or the historic regional storm of record, Hurricane Hazel (Toronto and Region Conservation Authority, 2018). Many of these FVAs also have, and will continue to experience, riverine flood conditions under less extreme storm events, and these occurrences present both risk to life and economic risk.

In 2015, the federal government established the National Disaster Mitigation Program (NDMP), allocating $200 million over five years toward initiatives aimed at reducing the impacts of natural disasters, specifically flooding. Funds are allocated to approved projects on a cost-sharing basis; the project proponents must contribute 50% of the project costs from existing or confirmed funding. For the initial call for funding in 2015-2016, TRCA was successful in securing matching funds for projects in the Risk Assessment and Flood Mapping streams which enabled an update to the FVA database and Flood Risk Assessment Project. This project combines the updated FVA database with improved resolution topographic data from LiDAR digital elevation datasets, new flood hazard datasets generated from current TRCA hydraulic models (many of which are high-resolution 2-dimensional hydraulic models built using the new digital elevation datasets as a base) and new damage estimation functions and methodologies which have emerged within the last five years. The information produced by this flood risk assessment will provide improved estimation of functional and regulatory flood risk at a granular level, which is important for risk mitigation and remediation planning, and for emergency and disaster response planning.

3.2 Flood Risk Conceptualization

Exhibit 3.1 shows an illustration of the overarching conceptualization of riverine Flood Risk that was utilized for this project. The quantification of Flood Risk requires an overlaying of the flood hazard dataset with exposed assets. Vulnerability of said assets can then be quantified as a function of the severity of the hazard relative to the exposure of the asset. Section 3.4 describes the riverine Flood Hazard dataset that was used, while Section 4 describes the Exposure and Vulnerability datasets and methodologies that were employed.

Exhibit 3.1: Conceptualization of Riverine Flood Risk



3.3 Floodplain Mapping and Vulnerable Areas

In order to fulfill its mandate to reduce risk to life and property damage caused by riverine flooding within its watersheds, TRCA has implemented a variety of measures to address flood risks. One of these measures is the regulation of land development within floodplains. To support the mapping of the Regulatory Flood Hazard, TRCA has modeled the riverine flood hazard for the river systems within its watersheds, enabling them to take a lead role in flood and water management. TRCA continues to update this flood hazard information to account for changes in watershed and river characteristics (e.g., urbanization, channel and watercourse crossing modifications) technological innovations (e.g., detailed LiDAR data, improved hydrologic and hydraulic modeling software) and climate change (e.g., current IDF curves).

The first step in preparing flood mitigation is understanding the benefits and costs of each option. In order to do this, it is imperative that we understand the nature of the floodplain and the surrounding communities. TRCA has been able to generate a geospatial riverine flood hazard dataset for 41 of the most flood-vulnerable communities within its watersheds, which includes data for at least six design storm return-periods (2-year, 5-year, 10-year, 25-year, 50-year, 100-year) as well as the Regional Storm (Hurricane Hazel) and the 350-year where available.

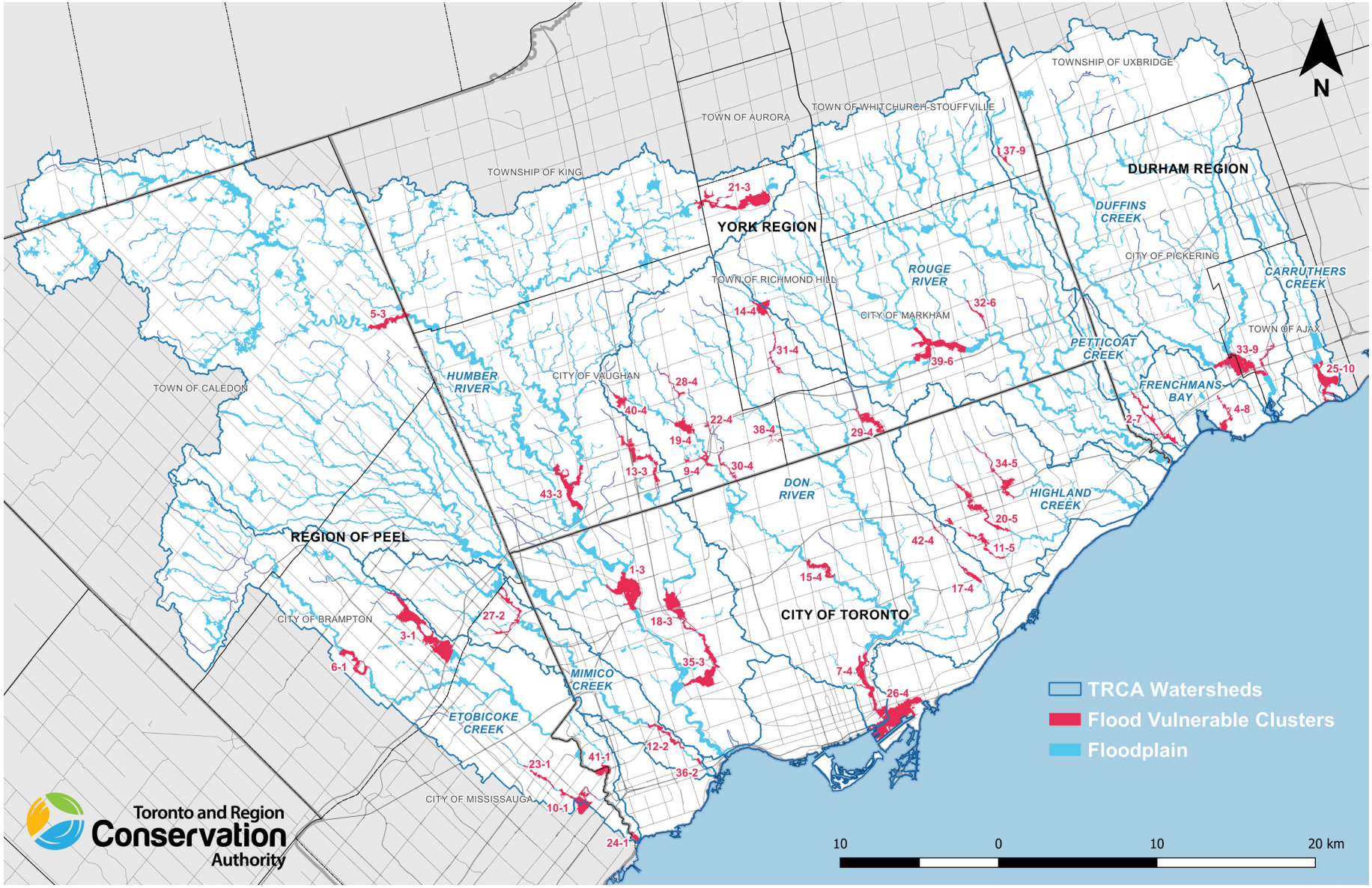
An original database of FVAs was created in the early 2000s that took stock of all of the buildings and roads located within the Regulatory floodplain. This database has recently been updated with matching funds from the National Disaster Mitigation Program, expanding it to include inundation areas, flood depth, velocity, and water surface elevation data in geospatial format for various return-period storm events.

Across TRCA's jurisdiction, there are over 8,000 structures that have been grouped into 41 clusters. A map of these clusters is available in **Exhibit 3.2**.

3.4 Flood Hazard Dataset

In order to support TRCA's floodplain mapping program, a watershed-scale hydrology study is conducted for each watershed, which includes watershed-scale hydrologic modeling. These hydrologic models use design storms (at the 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year), and the Regional storm as precipitation inputs, and generate flow hydrographs and peak flows at various points along the rivers within the watershed. These peak flows are input into hydraulic models of the river systems (HEC-RAS and MIKE Flood models) and the hydraulic models are used to generate geospatial flood depth, velocity, and water surface elevation raster data for each of the above-mentioned design storms and the Regional storm. The high-resolution nature of the resulting raster data was used to assign flood depths, velocities, and water surface elevations to the flood exposure dataset (building envelope polygons and road segment polylines) for the above-mentioned return-period storm events and the Regional storm. The metadata for the hydraulic models that were used to generate these flood hazard datasets can be found in **Appendix A**. A detailed description of the hydraulic analysis methodology can be found in **Appendix B.** A detailed description of the method used to assign the hydraulic data to the exposure dataset can be found in **Appendix C**.

TRCA Flood Vulnerable Areas



4 Flood Impact Assessment

4.1 Risk Assessments

Municipalities and the Province of Ontario are required to generate a Hazard Identification and Risk Assessment (HIRA) for their respective jurisdictions. The provincial methodology requires a numeric rating to be assigned to each type of hazard (e.g., flood, fire, and earthquake) for both probability and consequence. Typically, these ratings are subjectively applied based on descriptive criteria. The ratings are then multiplied to determine a risk ranking for that particular hazard. The Province of Ontario also assigns an additional modifier for changing risk to account for future trends and possible uncertainties around either the likelihood or the impact of a hazard occurring in the future. HIRAs are generally prepared to guide municipal emergency response planning. TRCA participates in the HIRA process where invited by municipalities, particularly as subject matter experts in the area of riverine flooding.

Another type of risk assessment, typically undertaken at the federal or provincial level, seeks to broadly compare locations (e.g., municipalities, regions, or clusters) in terms of their risk for a particular hazard. This can inform which areas need a greater level of study for that given risk. The Ontario Ministry of Natural Resources and Forestry has been working on a methodology to describe vulnerability to hazards, based on census data, for regions and municipalities across Ontario. This can also help inform which regions require more resources in order to achieve equity across the entire study area.

The TRCA Flood Risk Assessment project is a more detailed type of risk assessment, which attempts to assess and quantify, in greater detail, the impacts from flooding. This type of risk assessment leverages the already developed floodplain mapping for the Regulatory storm, and the underlying hydraulic models that include flood depth and velocity information for various storm return periods. TRCA's Flood Risk Assessment project relies on the structure-scale information that is provided in the updated FVA Database. Such a detailed scale for risk assessment is necessary because of the highly dendritic river systems in TRCA's jurisdiction.

4.1.1 Categorization and Quantification of Damages

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

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

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

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

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

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

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

The risk ranking matrix will incorporate the tangible and intangible factors that have already been calculated at a structural level, and will supplement these calculated damages with additional intangible factors that can be calculated for each cluster. While there may not be a dollar value for these factors, each factor can be given a score relative to the other clusters and ranked accordingly. Each factor can also be weighted based on its relative importance to the other factors in order to be able to come up with a total risk score for each cluster.

4.1.2 Selection of Direct Damage Methodology

Several depth-damage functions were investigated by TRCA, including the Ontario Ministry of Natural Resources and Forestry (MNRF) curves. The MNRF curves were last updated in 2007 but were based on data collected in the 1980s. While TRCA's previous flood damage calculations used the MNRF depth curves, it was noted that the damages for ICI buildings seemed to be over-estimated. Between October and December 2016, TRCA staff reviewed the depth-damage methodologies below in order to select the preferred direct damage estimation methodology:

- Ontario MNR Flood Damage estimation
- Hazus Canada
- HEC-FIA
- IWR Report 92-3
- Alberta PFDAS (Provincial Flood Damage Assessment Study – also known as the IBI curves), which include both structure and content curves
- ER2 (University of New Brunswick Rapid Risk Assessment)

TRCA determined that the Alberta damage functions (aka the IBI curves), represented the best available and applicable example for the GTA. This was further corroborated by an acknowledgement by MNRF of errors in their damage estimation guidance, and furthermore by the study *When Big Storms Hit* by the Intact Centre for Climate Adaptation July 2017. Note that inflation adjustment and location indexing has been undertaken as a part of this study to ensure the curves are applicable to the current year and location (see Sections 4.2.3.1 and 4.2.3.2 for a description of the indexing approach).

4.1.3 Literature Review

Prior to developing its own risk ranking matrix, IBI Group undertook a thorough literature review. A brief summary of the most relevant documents has been included in **Appendix D**.

4.1.4 Variable Development, Metrics, and Grouping

In order to develop the most appropriate risk ranking matrix, IBI Group compiled a list of variables taken from the available literature and past experience to create a master list of variables. From here, each variable was evaluated based on its applicability to TRCA's jurisdictional area and the type of watershed.

Initially, 55 variables were compiled, however some variables were deemed to be redundant, unnecessary, or too difficult to quantify and compare, and were not included in the list of variables used in the stakeholder engagement workshop.

The variables were further refined after subsequent internal meetings and consultations between IBI Group and TRCA, where metrics and available data for each variable were discussed. Ultimately, a total of 29 variables were established.

An important step in the refining process was determining which metrics would be used to measure each variable. Defining the metrics also helped determine if reliable and suitable data were available for that variable, and if they could reasonably be measured and compared across clusters.

Once the final list of variables was determined, they were grouped into categories, with those having similar attributes being grouped together. The following six categories emerged:

- Tangible building-associated impacts
- Community impacts
- Social Vulnerability
- Infrastructure
- Preparedness and awareness
- Recovery and resiliency

After gathering data for each category, the last two categories (Preparedness and awareness and Recovery and resiliency) were combined into one category: *Preparedness and Resiliency*. Whereas the other four categories add to the overall risk ranking score, this category offers opportunities for clusters to decrease their risk ranking score by implementing strategies that enable communities to becoming more resilient to flooding.

The development of the risk variables and methodology for assessment are discussed in the remainder of Section 4, with results and ranking presented in Section 5.

4.1.4.1 Stakeholder Engagement Workshop

Unlike direct damages, many indirect damages are subjective, localized, and value-driven. As such, it is important that local experts and members of the community define which variables are most important in the local context.

IBI Group and TRCA hosted a stakeholder engagement workshop to get local expertise and insight into the values of the people that live in the at-risk communities. Participants were asked to give each variable a score on a scale from 1 to 10 based on how important they perceived that variable to be, with 1 being least important, and 10 being most important. After each variable was given a score, an aggregate score would be calculated for the entire category based on the variables within it. If the participant felt that a particular category deserved a higher score, they could change the scores of the individual variables within each category accordingly.

Beyond this, IBI Group hoped to gain participant input during and after the workshop to refine the metrics and definitions initially proposed for each variable. Feedback was also requested regarding the availability and reliability of data for each variable to ensure that they are logical, relevant, and clearly understood.

Approximately 60 stakeholders were invited to participate in the workshop, and 23 were in attendance, including the workshop facilitators. In the weeks following the workshop, only four participants sent in feedback with scores and comments for the risk ranking variables. Although more engagement and feedback was anticipated following the workshop, it was a valuable opportunity to discuss the project at this stage. It provided an opportunity to focus on the selection of variables from multiple viewpoints, to critically reflect on the data available, and to assess the relationship between variables.

The discussions of variable selection and weighting process revealed the need to distinguish between hazard and risk when conducting flood impact assessments. Residents' safety is a clear example where the significance of the hazard can often overshadow risk-based weighting and relative ranking of multiple areas. In the context of urban riverine flooding, the risk to life is actually very low but is confounded with the hazard a flood poses and the number of people normally in the affected areas. Another consideration for discussions of impact ranking is the relationship between variables. If multiple variables are somehow related to a single factor, the effort to identify and then determine methods of quantification may be redundant or only serve to compound the main driver of the risk, such as damage to buildings or the population impacted.

4.2 Tangible Building-Associated Impacts

This category accounts for the monetarily quantifiable damages resulting from floodwaters entering residential, commercial, industrial, and institutional buildings. This includes damage to the contents and structures, as well as costs for residential displacement and business interruption.

These damages have been estimated as a function of depth at the building location by applying the synthetic depth-damage curves for the building's use and structure type. For direct damage to contents and structure, the depth of flooding determines the components affected, while residential displacement and business interruption is determined by an estimate of time to restore those components (building recovery time).

There are three main inputs for estimating these damages with IBI Group's Rapid Flood Damage Assessment Tool (RFDAT): the inventory of buildings, the depth-damage functions, and the flood elevation table. Together, this locates the building, determines the flood depth, and calculates damages based on the appropriate damage curve.

4.2.1 Damage Estimates – Financial Impact

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

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

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

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

Due to limited budgets, time, and a lack of reliable data, no flood damage estimate can ever be considered complete. TRCA is working to reduce the amount of at-risk assets. Therefore, the primary purpose of this study is to inform decisions on mitigation options based on reducing impacts, not to reach a conclusion on the economic impact of flooding. As such, the assessment of damages takes a financial impact approach, rather than an economy-wide perspective. Financial impact refers to the sum of losses

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

[4] Green, Colin, Christophe Viavattene, and Paul Thompson. "Guidance for assessing flood losses." Guidance for assessing flood losses. CONHAZ Consortium, 2011.

experienced by individuals or organisations as a result of a flood. The scale of this study is the flood-affected area and the goal is to reduce the damages upon impacted properties and individuals.

The flood damage estimates utilized current building information such as location, size, and elevation. However, no adjustments were made based on the current level of basement development or condition of the structure. Furthermore, the reconstruction and replacement costs are not depreciated. The costs are to bring the flooded structure and contents to a standard level of development.

4.2.2 Building Inventory

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. TRCA has generated a geodatabase of building footprints for structures within the regulatory floodplain. This geodatabase includes a variety of data that assists the calculation of flood damages, in addition to other building attribute data. This exposure dataset was recently updated for use with the RFDAT in order to determine flood damages. The inventory was compiled as described below.

In addition to the location and identifying attributes, the building inventory must, at a minimum, contain the following information for each building or parcel to be assessed:

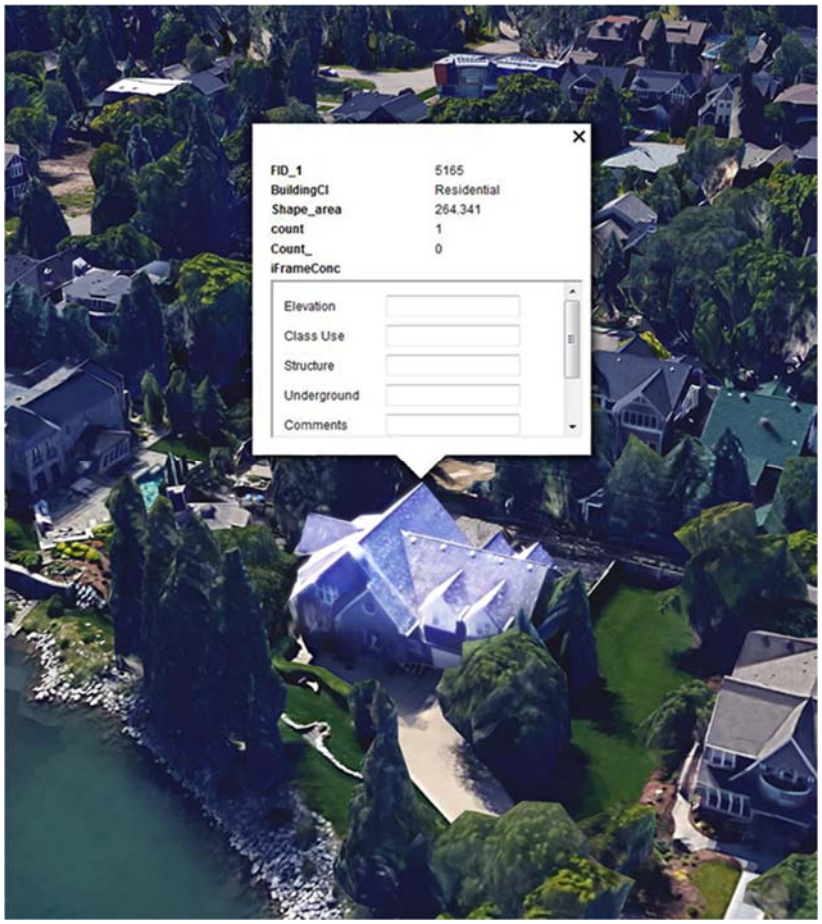
- Building use classification
- Structural classification
- Main floor area
- Presence of basement or underground parking
- Main floor elevation relative to grade
- Elevation of grade at building

The total number of residential units on the main and upper floors and the amount of commercial space on upper floors is also required for the residential displacement and business disruption functions. TRCA began by compiling a long list of attributes based on those required by all of the models they assessed, and then adjusted them to ensure they had all of the data required to use the RFDAT. Some of the attributes were calculated using assessment data from the Municipal Property Assessment Corporation (MPAC), while others were either verified or determined using ‘visual verification’ via Google Earth Pro.

4.2.2.1 Populating the Inventory Fields

To facilitate the visual classification of buildings, IBI Group has developed a tool that allows entry of building attributes directly from Google Earth. Shapefiles can be converted into kml files (files compatible for use in Google Earth), and viewed in Google Earth Pro. In that file, one of the fields contains HTML code that creates a popup window with the required fields when a user clicks on a building. An example of the Google Earth Tool is illustrated in **Exhibit 4.1**. A full list of building inventory attributes can be found in **Appendix E**.

Exhibit 4.1: Building Classification Tool in Google Earth



The following fields were used for this study:

- *Offset*: the height of the main floor from grade
- *Offset basis*: the location on the building footprint polygon from which the elevation was measured (e.g., max, min, or mean), relating to the assumed offset variations around the perimeter of the building.
- *Class Main:* the class of building's main floor according to the depth-damage curves.
- *Class Upper:* the class of the building's upper floors according to depth-damage curves. (See **Appendices F and G** for classification scheme and damage curves)
- *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: special notes relating to the building. 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 and were labeled NS (No Street View).

Buildings can have varying grades around the perimeter. A home with a walkout basement is a simple example. The offset basis field is an important addition to the classification process that increases the accuracy of positioning the building's elevation in relation to the flood levels. Instead of a single point sample, the flood depth was analysed in GIS to determine the maximum, minimum, and mean elevation. The person entering the offset generally cannot see the entire perimeter of a building but it is relatively simple to determine if they are viewing the highest or lowest point based on surrounding grades. Therefore, if a building is entered with a main floor offset basis of "max", the "min" flood depth was applied for the damage curves. In the few cases that a building could not be viewed, a default typical front entrance height was used in combination with the minimum flood depth, assuming the entrance is the highest grade level. The default height depended on the type of building. It was assumed to be 0.1m for non-residential buildings and 0.6 for residential buildings with basements.

The unit count was not visually estimated for all buildings. In most cases, an accurate unit count was available in the MPAC data. However, in the case of some large condominium and townhome projects, the number was a total for several buildings, including some that were not flooded. In this case, the number was estimated by inspecting the affected building.

4.2.2.2 Study Area Buildings

Within the study area, a total of 9048 buildings were classified (excluding outbuildings such as garages and sheds). Of these, 1529 are non-residential (commercial, industrial, and institutional), and 7519 are residential buildings, including 267 multi-family structures. This count is of buildings inventoried for the project and does not represent the number of buildings damaged for any particular event. **Exhibit 4.2** details the residential building types.

Exhibit 4.2: Residential Building Inventory Classification

Class	Total	One Storey	Two Storey	Split-Level	Basement
AA	164	6	158	0	161
A	852	48	802	2	847
B	4221	866	3140	195	4197
C	2012	1070	891	51	1988
D	3	3	0	0	0
M	195	n/a	n/a	n/a	78
N	72	n/a	n/a	n/a	59

4.2.3 Direct Depth-Damage Curve Indexing

The synthetic depth-damage curves for structures and contents were developed in Alberta in 2014[5]. The associated cost estimates can change over time and vary between communities. Therefore, the require adjustments and IBI Group has developed a flood-specific methodology for spatial and temporal indexing of damage curves.

4.2.3.1 Contents

Custom indexes were developed in recognition that existing, commonly employed indexes were not sufficient to account for the specific type of damages seen in 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.

[5] Provincial Flood Damage Assessment Study. Prepared for the Government of Alberta, Environment and Sustainable Resource Development by IBI Group and Golder Associates (February 2015). NEOS Catalogue Key 7032365. Available at https://open.alberta.ca/publications/7032365

The CPI is commonly used to convert past dollar amounts into current amounts for a variety of purposes. However, it is recognized that this measure may not accurately reflect changes in flood damage values. Even if specific flood-affected subcategories of the CPI are selected, the nature of the CPI is to measure pure price changes of standardized goods. It intentionally does not account for changes in quality, technology, or consumer behaviour. Therefore, the indexed price for the goods of interest may decline over time where in reality the quality and/or quantity of goods in a household has increased.

The Survey of Household Spending (SHS) is a better indicator of the change in household content value. Average household expenditures are measured annually in categories similar to the CPI and are available at the provincial level. If average household spending on televisions, for example, remains the same, it is assumed that there will be the same dollar value of television equipment in the household, even if the CPI of an unchanging television set falls. This index can be used to adjust values between years and provinces.

Weighted categories of spending were derived from the residential contents survey to represent goods damaged by floodwaters. The 2016 SHS is the latest available release at the time of damage calculation. Adjusting the Alberta household content values to Ontario values is performed with the following formula:

$$\text{ON damages} = \text{AB 2014 damages x } \left(\frac{\text{Weighted 2016 ON spending}}{\text{Weighted 2014 AB spending}}\right)$$

Content value of non-residential properties is less variable between locations, particularly between major centres. The CPI goods aggregate (excluding food and energy) indicates that the January 2014 index was 95.8 and the January 2018 index was 101.7. Accordingly, an index value of 1.06 will be applied to the non-residential content values. The residential content damages adjusted to Ontario can be found in **Exhibit 4.3**.

Exhibit 4.3: Residential Content Damage Adjustment: Alberta to Ontario

Category	2014 SHS AB	2016 SHS ON	Weight	Weighted SHS 2014 AB	Weighted SHS 2016 ON	ON 2016 /AB 2014 Index
Furnishings and equipment	$2,359	$2,578	0.59	$1,392	$1,521	
Clothing and accessories	$4,378	$3,564	0.21	$919	$748	
Recreation*	$1,444	$1,183	0.20	$289	$237	
Total	$8,181	$7,325	1.00	$2,600	$2,506	**0.96**
*not including services and vehicles						

4.2.3.2 Structure

The cost of labour and materials for construction and restoration varies across the country and over time. Two sources of data were employed to adjust the Alberta structural damage amounts for use in Ontario: The 2014 Altus Construction Cost Guide and Statistics Canada Construction Price Indexes. The construction cost guide accounts for geographic differences and the price indexes allow for adjustments from 2014 to 2017.

2014 GTA construction costs per square foot for each class of building were divided by the 2014 Calgary costs to provide a 2014 ratio. A second ratio was obtained by dividing the 2017 GTA construction price index for each class of building by the 2014 GTA construction price index. The product of these two ratios provides an index to adjust structural damages from 2014 Calgary costs to 2017 Toronto costs. The results of this calculation are illustrated in **Exhibit 4.4**.

Exhibit 4.4: Structural Damage Adjustment: Alberta to Ontario

Type	ON/AB Index
Office	1.010
Retail	0.914
Institutional	1.001
Hotels	1.004
Parking Structures	1.077
Apartments	0.965
Houses	1.144
Industrial	0.861

4.2.3.3 Incorporation in Damage Model

In addition to the building attributes, the inventory input file contains fields for indexes to be applied to one or all of total damages, structural damages, and content damages. For each building, the appropriate index was added for structures and contents.

4.2.4 Indirect Depth-Damage Curves

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.

This can be a complex and in-depth process, and those complexities have led various agencies to estimate indirect damages as a percentage of direct damages. The ratios are based on literature review, 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.

4.2.4.1 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 to the building due to evacuations, road closures, or loss of utility services. The impact of a major flood event on business 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 section that follow. Other factors that may contribute to business losses are variable, such as the cost of loans versus 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.

4.2.4.1.1 Loss as a 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 as profits. Sales, profits, and expenses are all components of value added, which is a better measure for the net of flows in a company (FEMA, 2015).

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 (Messner, et al., 2007). Labour productivity is the ratio between an industry's value added and hours worked. It thus allows loss to be measured by duration.

Not all businesses operate in a similar manner however. For example, offices do not operate like a factory, and the temporary closure of offices would not cause a shutdown of related production. On the other hand, small businesses such as retail and restaurants that suffer direct inundation of their buildings would certainly experience loss for a greater period of time than the average office building. With productivity and restoration time assumptions detailed below, a business interruption depth-damage curve was created and applied to each commercial building in the 41 cluster areas.

4.2.4.1.2 Productivity Values

Statistics Canada provides hourly labour productivity per worker for various industry classifications at the provincial level.[6] Daily productivity per square metre of floor area can be determined by dividing the employee productivity amount by the typical floor area per employee and then multiplying by the daily operating hours, as detailed in **Exhibit 4.5**.

Exhibit 4.5: Example of Daily Productivity per Square Metre

Classification		m² per Employee	Productivity ($/hour)	Operating Hours/Week	Productivity/ Day/m²
A1	General Office	26	$52.85	45	$9.98
C7	Retail	33	$32.88	65	$9.25
I1	Restaurant	33	$20.75	80	$7.19
L1	Warehouse/Industrial	70	$49.44	65	$6.56

The General Office productivity value for the Province of Ontario was calculated as a weighted average based on the labour force composition of the province from the National Household Survey. The number of workers in each industry 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) is used.[7]

Productivity is not a measure applied to the public sector. Damages associated with buildings identified as public (e.g., schools, government offices, and hospitals) are considered as part of the intangible impact evaluation.

4.2.4.1.3 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.

Building Restoration

Few methods of determining the average length of disruption have been explored 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-

[6] 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.
[7] Statistics Canada CANSIM Table 380-0066 Price indexes, gross domestic product.

existing deficiencies. As with the direct damages, it is important to only consider the restoration to a previous state of operations.

IBI Group had previously performed a comprehensive literature review and an assessment of the various metrics for measuring building restoration times (IBI Group, 2015). 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.

Building 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's space takes seven months to fully restore, its component resources, including staff, are unlikely to be completely lost to the economy for the entire period. A flood event is a disruption of operations, after which complex adjustments and alternate activities take place during recovery.

The 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 can be calculated as:

$$L = n \times (1 - \frac{n}{\left(\frac{d}{p}\right)})$$

Where d is the maximum number of disruption days; and p is the percentage of the maximum recovered productivity. **Exhibit 4.6** illustrates the result of this method with the following assumption 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.

Exhibit 4.6: 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 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 estimated during the building inventory classification process.

4.2.4.1.4 Incorporation in Damage Model

The estimates of depth to productivity days lost 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.

4.2.4.2 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 fuels. 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 4.4**.

4.2.4.2.1 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 are assumptions made to estimate the costs per household:

- Half of displaced households will find accommodation with friends, family, or a shelter.
- The remainder of households will spend up to 14 days in a hotel. Average daily hotel room costs used for the GTA are assumed to be $120.
- During the first 14 days, each individual will spend an extra $50 per day.
- The number of people per single unit is 2.8, and the number of residents per apartment is 1.8.[8]
- Households requiring alternate accommodation beyond 14 days will rent another unit of the same type. The average regional market rent per month for apartments and houses is assumed to $950 and $1,200 respectively.[9]
- A one-time moving expense of $500 per household is included for households requiring accommodation beyond 14 days.

4.2.4.2.2 Displacement Period

Displacement times can vary greatly between buildings with similar inundation levels. As discussed above in regard to business interruption, the reconstruction process generally involves much more than restoring a building to its previous state.

Data on secondary suites in the study area was not readily available, but it is assumed that the majority of finished basements do not contain essential living spaces, such as kitchens, and that 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

[8] Average household size, 2016 Census
[9] Estimated from CMHC and local listings.

completing actual repairs, particularly when a large area is inundated and there is a backlog of inspections.

For multi-family units that are not directly damaged, restoration of electricity and life-safety systems determines 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 can range from days to several weeks (IBI Group and Golder Associates, 2015).

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 duration of displacement considers the time to complete repairs plus general average expected delays including contractors, materials and equipment, and inspections for all return periods. These estimates are illustrated in **Exhibit 4.7**.

Exhibit 4.7: Estimated Average Residential Displacement Periods[10]

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

4.2.4.2.3 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 particular household. However, the landlord of the flooded unit will lose that rental income. The loss of income will be for a duration equal to the estimated displacement times, so the full displacement costs for all households regardless of tenure was used.

4.2.4.2.4 Incorporation in Damage Model

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

The damages are 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. The number of units is estimated and recorded during the visual classification. Costs associated with residential buildings that are only evacuated (and not flooded) are not computed in the damage model.

4.3 Community Impacts

If two flooded communities had a similar number of affected households and similar demographics, the impact may not be equal if one also lost its school, for example, and the other did not. Facilities such as schools, community centres, and places of worship not only serve residents in their daily lives but also have important functions for response and recovery during and after a flood event. They are often used for registration for recovery programs, dissemination of information from officials, and distribution of resources.

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

It was not feasible to inspect the potential community-service functions of all buildings within the study area. An additional challenge is that the study area covers multiple jurisdictions with varying available datasets. From a long list of community facilities and services, five key categories had consistent datasets that could be used to represent the impacts to community facilities.

- Emergency services (police, fire, and ambulance)
- Recreation facilities (indoor)
- Places of worship
- Schools (elementary, junior high, senior high)
- Community association buildings

The flood impact to these facilities was determined through GIS analysis. All facilities were represented by a point and a count was obtained by overlaying flood inundation shapefiles for every modeled event in each cluster. A facility was considered impacted and counted if it was within the inundation area (there was no severity level).

4.4 Social Vulnerability

Flooding has a number of intangible impacts on households. Quantification of these impacts for a flood event is challenging, and can even be controversial. Floods do not lend themselves well to controlled studies that connect population and flood characteristics to outcomes (Tapsell, Tunstall, & Priest, 2009). 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.

4.4.1 Physical Health

Public safety is of course the top priority for floodplain management. As such, it is often ranked by stakeholders as the most important variable in risk assessments. However, epidemiological evidence on the health impacts of flooding are surprisingly lacking.[11,12] As such, there are limited data upon which predictive models can be built and the few that exist are related to the risk to life.[13] Globally, floods are the leading cause of natural disaster fatalities but the factors that contribute to flood-related mortality are diverse and multifaceted.[14]

IBI Group has conducted an extensive literature review on flood risks to a population and found that available risk-to-people models are not applicable to riverine flooding in Canada. Although depth and velocity are contributing factors that we can model, the probability of death or injury is primarily associated with individual behaviour or circumstances. Therefore, it is considered a function of the size of the exposed population and number of affected buildings and roads. As such, no separate physical risk assessment has been conducted for this study.

4.4.2 Mental Health

There is a growing recognition that the psychological effects of a flood event on residents can be significant. Mental health studies relating to disasters come mainly from developed or industrialised countries where evidence suggests that mental health impacts are the most significant effect on households and communities.[15]

The University of Waterloo, the Intact Centre on Climate Adaptation, and Manulife recently published a study examining the impact of flooding on mental health and lost time from work (Decent & Feltmate,

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[11] Ahern, Kovats, Wilkinson, Few, Matthies. Global Health Impacts of Floods: Epidemiologic Evidence. Epidemiologic Reviews, 2005; 27: 36-46.
[12] Alderman KB, Turner LR, Tong S. Floods and human health: A systematic review. Environment International, 2012; 47: 37-47.
[13] Hammond, Michael J., et al. "Urban flood impact assessment: A state-of-the-art review." Urban Water Journal 12.1 (2015): 14-29.
[14] Jonkman, S. N., and J. K. Vrijling. "Loss of life due to floods." Journal of Flood Risk Management 1.1 (2008): 43-56..
[15] Tapsell, Sue. Developing a conceptual model of flood impacts upon human health. Middlesex University, 2009.

2018). The study examined the health effects on flooded and non-flooded residents three years after flooding in Burlington, Ontario, where severe precipitation caused atypical flooding in August of 2014.

The study found that flooded household members experienced significantly higher worry and stress (47% of those surveyed) within the first 30 days of experiencing a flood compared to those who were not flooded (11% of those surveyed). Furthermore, three years after flooding occurred, almost half of the respondents that experienced flooding still became worried when it rained compared to only 3% of those from the non-flooded households. These results indicate that flooding in homes bears risks beyond just those related to property damage, but also to the long term mental and physical health of flooded residents (Decent & Feltmate, 2018). Three factors contributed to elevated levels of worry and stress in the first 30 days following the flood: difficulty liaising with insurance providers; worsening or existing health issues; and water height in the basement. It is logical then that these mental health impacts are also likely to worsen as flooding increases in frequency and severity across the country in accordance with the frequency and severity of extreme weather events, unless actions are taken to increase resilience measures (Insurance Bureau of Canada, 2018).

This study was also the first in Canada to quantify the number of days that household members were forced to take off of work due to flooding. 56% of the flooded households surveyed in Burlington (of those that had at least one working member) took an average of seven days off work. This number was 10 times the average number of days taken off work for non-flooded Ontario households (Decent & Feltmate, 2018). Additionally, the study proposes that when these workers return to work they will still be worried and distracted due to lingering financial impacts and stress from the flood event.

One major psychological impact of disasters is post-traumatic stress disorder (PTSD). A 2005 global review of studies published from 1980 to 2003 found that the prevalence of PTSD after a disaster is 30-40% for direct victims, 10-20% among rescue workers, and 5-10% in the general population.[16] Flood-specific incidences among victims have been reported at 19% following the 1997 California floods and 22% following the 1993 Midwest Floods.[17] A Canadian study utilized telephone surveys four months after the floods in Saguenay Quebec. The prevalence of PTSD was almost 20% in the flooded population, compared to 3.8% in a control group.[18]

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

- anxiety (e.g., during heavy rainfall);
- increased stress levels;
- sleeping problems;
- depression;
- panic attacks;
- flashbacks to flood;
- difficulty concentrating on everyday tasks;
- lethargy/lack of energy;
- feelings of isolation;
- increased use of alcohol or other drugs;
- nightmares;
- anger/tantrums;

[16] Galea, Sandro, Arijit Nandi, and David Vlahov. "The epidemiology of post-traumatic stress disorder after disasters." Epidemiologic reviews 27.1 (2005): 78-91.
[17] Ahern, Mike, et al. "Global health impacts of floods: epidemiologic evidence." Epidemiologic reviews 27.1 (2005): 36-46.
[18] Auger, Caroline, et al. "[Post-traumatic stress disorder. After the flood in Saguenay]." Canadian Family Physician 46.12 (2000): 2420-2427.

- mood swings/bad moods;
- increased tensions in relationships; and
- thoughts of suicide.

Perhaps the most comprehensive study of the intangible health impacts of flooding was conducted in 2002 by the UK Department for Environment, Food, and Rural Affairs and the Environmental Agency.[19] 1,510 households were interviewed in 30 locations across England and Wales that had been subject to flooding in the previous five years. The study included households that had been flooded (983) or were at risk of flooding (527). The level of flooding previously experienced was relatively severe with a mean depth of 55 cm in the main room of the house.

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

In subjective terms, acknowledged health effects were rated among the lesser effects of flooding on the households but, in contrast, the stress of the flood event itself features as one of the most serious effects, along with all the problems and discomfort whilst trying to get the house back to normal and having to leave home. **Exhibit 4.8** summarizes the subjective rating of severity of the effects of flooding.

Exhibit 4.8: Subjective Rating of Severity on Households

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

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

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

[19] Floyd, P., and S. Tunstall. "The appraisal of human-related intangible impacts of flooding." Report of Project FD (2005).

People have an emotional attachment to their homes and it is often perceived as a static, safe, and personal space. Flooding transgresses the boundaries of home and can be a shock that undermines an individual's sense of self and place.[15] When flood victims were unaware of the risk prior to flooding, they can be left with an extreme sense of insecurity and a new relationship with their community and home as places once familiar are now unfamiliar and fearful.[20]

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

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

Some of the UK research reports a community-wide tendency for people to feel less positive about their surroundings and a sense of community breakdown with some residents stating that "nobody helped" or even "I wish I never heard of [this town]".[20] This is in stark contrast to the overall reaction and display of resiliency after the floods in Calgary, Alberta in June of 2013. Thousands of people volunteered to assist residents with the cleanup and recovery. Social and traditional media was filled with feel-good stories about help and appreciation, including that towards municipal staff and officials.

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

Outside support is one of the many aspects of social vulnerability. Social vulnerability is widely recognized as a major factor that will influence or modify the impact of floods on individuals. It refers to the degree to which some people, or classes of people, are more susceptible to, or suffer a greater degree of harm from, some hazards than do other people.[21] Overall, this is of particular concern when the most vulnerable are those who are at risk of not meeting basic needs, such as in developing countries, or when there is a great disparity of resources and segregation within the population, such as in New Orleans. For mental health impacts, there are a number of indicators that have been shown to influence the risk for distress.

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

Floods have been shown to have more adverse impacts on women than men, including increased incidences of PTSD.[15] It is suggested that women, regardless of employment status, take a greater role, both materially and emotionally, in management of the household leading to greater distress. Another similar theory is that during and after a disaster, women are commonly relegated to the private domain and closer to the disruption while men take on more decision-making roles.[22] Traditional roles also appear to influence the impact on men. Dealing with a disaster can change self-perception from the identity as protector of the family to helplessness.

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

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

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

Age is a commonly cited risk factor for psychological impacts but the literature is inconsistent as to how. A clear distinction between physical and mental impacts is not always made but is important when assessing risk to children and the elderly. Many suggest that there is a greater psychological impact on the elderly. The reasons are unclear but may be related to length of time in their residence. Others suggest that children are also at greater risk of distress but again, they point to related factors such as increased sensitivity to other family members' stress. Several comprehensive reviews conclude that middle aged adults are most at risk because they have greater stress and burdens before the disaster strikes and they assume even greater obligations afterwards.[23] It is even suggested that rather than viewing older adults as an at-risk group, they could be viewed as a resource with greater life experiences to draw from, experience in local issues or strategies, a wide network of friends and family, and personal strength drawn from many years of life.[15]

Taken together, evidence on gender and age-related impacts indicates that family structure is likely the best indicator of demographic factors that may contribute to a more or less severe mental health impact of flooding. While a family can provide an individual with support, families with children at home would generally experience the highest level of distress.

Socio-economic status, including income and education level, has been found to affect disaster resiliency significantly. Lower socio-economic status is consistently associated with greater post-disaster distress. Financial stress is a major factor impacting people's psychological health and well-being following flooding. High-income earners may be more likely to consider themselves 'self-insured' because they could afford to replace things straight away, pay extra bills, and have more choice about their alternative accommodation.[24] Of particular concern for the economically vulnerable is the potential for floods to throw households into a poverty trap in which the initial set-back creates further obstacles for recovery in an amplifying feedback loop.

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

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

4.4.3 Assessment of Social Vulnerability for Cluster Risk Ranking

For previous studies, IBI Group has conducted review of intangible flood impacts and evaluation techniques. The impacts assessed included mortality, injury, disease, infection, exposure, mental health, quality of life, and environmental damage. The primary goal was to quantify and monetize the intangible impacts for use in a triple-bottom-line benefit/cost analysis.

Many attempts were made to use appropriate quantitative means to estimate the probabilities for each intangible 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 a transfer of values from other sources, most of which have little or no relation to flooding or to the local context. The values would have questionable meaning or relation to local stakeholders. Furthermore, the attempt to individually monetize health and wellness impacts yielded values that were insignificant relative to the direct damages. This is not to suggest that these factors are not important, but that the physical risks in the Canadian context are actually rather low.

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

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

The overall total impact on affected households, however, is obviously significant. In addition to a comprehensive health assessment, the DEFRA study included a survey of flooded households' willingness-to-pay (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. The 2015 study found a mean WTP value of £653 per household per year, or approximately $1,300 CAD. The more recent study results are significantly higher as the research was conducted after more severe flooding during 2007 and focused on a wider range of intangible impacts.

The purpose of monetization is to provide benefits for a benefit/cost analysis of proposed mitigation measures. This study does not include benefit/cost analyses. Therefore, to avoid the inherent risks of reporting monetizing intangibles, these impacts are scored according to the average-annualized number of affected residents in each cluster. In other words, a greater number of affected people would lead to a greater potential for intangible damages. However, as discussed above, there are some demographic indicators that could exacerbate the impacts. Relevant variables that are statistically available include:

- Income – proportion of households with income under $20,000. This income amount was chosen as it corresponds to the available dataset and is just below the Low-Income Measure Threshold for a one-person household. The proportion is used to obtain a score relative to other clusters so the actual threshold number was not considered critical.
- Family Type – Proportion of families with children. This metric was chosen as it considers the identified additional responsibility of household maintainers and children's sensitivity to their distress. As discussed above, it is assumed to be the best available indicator of age and gender related mental health impacts.
- Age – Proportion of residents over 65 years old. Age is used here as an indicator of pre-existing conditions and/or additional requirements during a disaster. As with income, it is used relatively and not intended to be a precise threshold.
- Hospital – Inundation of hospitals or care facilities as an indicator of a vulnerable population being exposed.
- Housing Tenure – Proportion of owner-occupied homes. Homeowners are assumed to face greater financial and emotional pressures in the post-flood recovery period.

These statistics were obtained by TRCA from Environics for each cluster. The proportion of residents in each category was indexed to provide a relative measurement between clusters. This creates a multiplier to apply to the affected population for each flood event. For the risk scoring and ranking, these variables were not all weighted evenly (see section 4.7).

4.5 Infrastructure

When flooding affects public infrastructure, the impacts extend beyond the physical damage to the assets themselves. Impassible roads or loss of utility services can create delays for residents and businesses.

4.5.1 Transportation

TRCA provided an analysis of road inundation with a shapefile containing each cluster's road segments with the following details:

- Road segment classification (local, collector, arterial, freeway)
- Road segment length
- Flood depth for each event (max, min, mean along road segment)
- Flood velocity for each event (max, min, mean along road segment)

The impact on roads was calculated using two metrics: overall inundation extent and number of impassible segments. According to MNRF vehicular access flood risk factors, depths of greater than 0.3 m or velocities of greater than 4.5 m/s can impact passenger vehicles.

For the overall inundation extent, each road segment's mean depth was multiplied by the segment length. Impassible segments were counted if either the max depth was greater than 0.3 m or the max velocity exceeded 4.5 m/s.

In addition to roadways, public transit in the study area includes rail. For this study, the number of affected GO Transit stations was assessed. An analysis of all rail line segments was not possible.

4.5.2 Utilities

A flood event can damage utilities and lead to a loss of electric, gas, communication, or water services for residents and businesses outside of the inundated area. The extent of this impact depends on the nature of the service's network. Electric grids, for example, vary in the granularity to which they can be isolated during a flood, affecting the ability of a provider to shut down power only to the affected households.

Loss of utilities is a major flood impact. However, a detailed assessment of utilities, the threshold at which they would be affected, and the extent of the resulting loss of services is beyond the scope of this study. The available data on facility and line locations was not sufficient to make responsible assumptions with.

Nonetheless, this variable has been retained in the scoring and ranking criteria for future consideration. Each cluster was given the same score of 50% of the variable's weight.

4.6 Preparedness and Resiliency

The flood inundation modelling that was used to determine the flood hazard for each return period across the clusters reflected any structural mitigation that was in place, such as dykes or other barriers. However, the value of non-structural actions has increasingly been recognized for reducing the impact of a flood within a community.

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

Non-structural measures may include contingency actions such as moving contents or sandbagging; regulations and property level floodproofing, warning systems, and general education and awareness programs. Contingency actions can reduce direct damages and require awareness and forecasting. As discussed in Section 4.4.2, preparedness can also reduce the mental health impact and greatly contribute to community resiliency and recovery.

The identified variables in this category include: active or non-structural mitigation measures, growth potential, and warning system penetration. Because variables in this category contribute to a reduction of flood impacts, the points scored here would be deducted from the overall impact score. However, insufficient data is available to perform this assessment on each cluster. It is retained as a feature of this study to contribute to the intent of the category – to increase awareness of the potential for active mitigation, the regulation of growth or intensification, and the value of preparedness.

4.7 Risk Ranking Matrix – Weighting and Scoring

The weighting and scoring matrix for the ranking of cluster risk was determined with consideration of literature review, past experience, expert input from TRCA and stakeholders, and data availability. It is intended to be a dynamic matrix that can be updated or adjusted in the future. The variables and the weighting used for this study are detailed in **Exhibit 4.9**. The weighting reflects that many additional impacts are directly associated to flooding of buildings and roads as well as the availability of data for other categories.

Exhibit 4.9: Risk Ranking Matrix

Category Weight	Total Points	Category	Weight of Variable	Variable
50%	50	Tangible Building-Associated	15	Direct non-residential damages
			15	Direct residential damages
			10	Business interruption
			10	Residential displacement
10%	10	Community Impacts	2	Emergency services
			2	Recreation facilities
			2	Cultural
			2	Schools
			2	Community associations
20%	20	Social Vulnerability	5	Income
			5	Family type
			5	Age
			2	Hospitals
			3	Tenure
20%	20	Infrastructure	8	Roads
			5	Public transit
			7	Utilities risk
15%	15	Preparedness and Resiliency	5	Active mitigation
			5	Growth potential
			5	Warning system penetration

*Total is 100 for the four risk categories; Preparedness and Resiliency can reduce score by up to 15

5 Assessment and Results

5.1 Tangible Building-Related Impacts

5.1.1 Data Cleaning, Formatting, and Processing

TRCA had filtered their original building dataset into a shapefile of polygons for all clusters. IBI Group added the Google Earth data entry field to this shapefile for TRCA to identify the necessary attributes for each building. In total, this file contained 11,409 structures. When the data entry was complete, IBI Group began processing the entries and formatting the file for use with the RFDAT.

Cleaning and formatting the data required considerable effort. The first step was to ensure that the fields had valid data and correcting any obviously erroneous entries. The file was then filtered to remove buildings that were identified as not being relevant, including outbuildings. Afterwards, the file contained approximately 8,903 buildings. During the inventory data collection process, TRCA identified an additional 145 buildings which were added to the master list, for a total of 9,048. A later update in the hazard tables resulted in 77 buildings that were previously omitted being added back to the inventory. The final inventory had 9,125 buildings.

The next step was to attempt to fill in missing fields. Fields were missing either because the view was obscured or the field was missed during entry. Where a missing input field could reliably be substituted with values from MPAC assessment data, these values were looked up. In other cases, IBI Group manually entered values through a combination of re-examining available views in Google Earth, interpretation of assessment data, and even internet searches using the building address. If no additional information was available to inform the main floor offset, the typical height for the type of property was entered. The data was then formatted as required for input into the RFDAT, including the addition of elevation data and damage curve indexing. The indirect damage calculations require a modified inventory data set, which was also created.

The flood tables containing depths for each building were created using the flood surfaces and the offset basis, as described in Section 4.4.1.1. The RFDAT can process flood surfaces as either geodetic elevation or flood depth. Since the TRCA provided depth grids, the ground elevation for each building was set to zero. In order to select the right flood depth for the building (from max or min), the offset basis field was used. If the offset basis was the maximum building perimeter height, then the minimum flood depth was selected for the flood tables.

The task of calculating the damages with RFDAT was originally part of the TRCA scope. However, given the amount of data processing that was required by IBI Group to complete the inventories, project timelines, and experience in using the RFDAT, IBI Group proceeded with the processing of the damage estimates. The results are detailed in the following sections.

5.1.2 Total Damage Estimates

Total flood damages for each of the return floods are estimated employing the methodologies as previously described. All of the 41 clusters have the following flood return periods available: 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year, as well as the Regional storm. Select clusters also have a 350-year storm information available. The total damages include direct damages to residential, commercial/industrial/institutional, as well as business interruption and residential displacement.

Exhibit 5.1 details the summed tangible building related damage amount for each cluster and a breakdown of damages by residential and non-residential, direct and indirect.

5.1.3 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

Tangible Building-Related Damage Totals

Total Damages

Cluster	Return Period							
	1:2	1:5	1:10	1:25	1:50	1:100	1:350	Regional
Albion Road	$0	$0	$0	$0	$107,000	$110,000	n/a	$63,121,000
Altona/Rougemount	$0	$0	$0	$0	$0	$0	n/a	$2,576,000
Avondale	$0	$5,442,000	$8,374,000	$47,803,000	$79,077,000	$100,317,000	$124,629,000	$149,998,000
Bay Ridges	$311,000	$328,000	$943,000	$2,690,000	$4,007,000	$6,186,000	n/a	$6,186,000
Bolton Core	$0	$228,000	$4,240,000	$6,959,000	$8,023,000	$9,423,000	n/a	$75,424,000
Brampton Central	$0	$0	$0	$0	$0	$0	$494,000	$71,607,000
Brickworks	$0	$500,000	$2,055,000	$5,092,000	$20,251,000	$32,310,000	$42,583,000	$50,546,000
Concord	$0	$0	$0	$278,000	$905,000	$905,000	n/a	$4,353,000
Dixie/Dundas	$0	$4,546,000	$33,620,000	$38,959,000	$42,326,000	$45,714,000	$60,021,000	$69,291,000
Dorset Park	$0	$0	$0	$1,672,000	$13,704,000	$19,399,000	n/a	$27,251,000
Dundas West	$0	$0	$0	$0	$23,000	$123,000	n/a	$28,921,000
Edgeley/Vaughan Centre	$0	$0	$0	$604,000	$2,580,000	$7,509,000	n/a	$245,177,000
Elgin Mills	$0	$207,000	$213,000	$213,000	$228,000	$228,000	n/a	$4,593,000
Hoggs Hollow	$0	$319,000	$509,000	$2,085,000	$2,670,000	$4,777,000	$6,234,000	$59,012,000
Ionview	$0	$0	$501,000	$2,130,000	$4,977,000	$6,701,000	n/a	$34,537,000
Jane/Wilson	$0	$631,000	$6,100,000	$14,370,000	$20,135,000	$34,268,000	$77,956,000	$124,254,000
Keele Industrial	$0	$0	$0	$0	$0	$0	n/a	$128,985,000
Kennedy Commons	$0	$20,000	$20,000	$769,000	$15,399,000	$26,378,000	n/a	$134,279,000
Lake Wilcox	$1,112,000	$1,488,000	$2,342,000	$3,313,000	$4,409,000	$5,439,000	$86,326,000	$99,447,000
Langstaff Business Park	$0	$0	$0	$0	$0	$9,000	n/a	$47,000
Little Etobicoke	$0	$0	$0	$0	$0	$0	$2,076,000	$5,585,000
Longbranch	$0	$5,000	$35,000	$35,000	$43,000	$52,000	$5,356,000	$10,542,000
Lower Carruthers	$187,000	$187,000	$188,000	$188,000	$188,000	$189,000	n/a	$10,766,000
Lower Don	$0	$352,000	$1,294,000	$2,606,000	$4,082,000	$26,711,000	$57,027,000	$424,569,000
Malton	$0	$740,000	$759,000	$868,000	$1,059,000	$1,124,000	n/a	$19,185,000
Maple	$1,200,000	$1,371,000	$1,515,000	$1,515,000	$2,114,000	$2,476,000	n/a	$5,530,000
Markham Industrial	$1,641,000	$5,554,000	$5,554,000	$36,087,000	$36,998,000	$57,528,000	n/a	$57,528,000
New Westminster	$0	$0	$228,000	$603,000	$1,262,000	$2,059,000	n/a	$21,329,000
Newkirk Business Park	$0	$0	$0	$1,051,000	$2,207,000	$2,623,000	n/a	$11,436,000
Old Markham Village	$0	$0	$0	$115,000	$115,000	$115,000	n/a	$2,154,000
Pickering Village	$82,000	$84,000	$10,874,000	$15,984,000	$20,452,000	$24,624,000	$31,828,000	$168,134,000
Progress Business Park	$0	$0	$12,000	$7,399,000	$23,764,000	$32,226,000	n/a	$53,980,000
Rockcliffe	$0	$1,853,000	$21,955,000	$61,888,000	$102,545,000	$173,051,000	$229,308,000	$313,239,000
South Mimico	$0	$0	$0	$0	$167,000	$412,000	n/a	$10,675,000
Stouffville Centre	$346,000	$346,000	$387,000	$447,000	$493,000	$650,000	n/a	$3,870,000
Thornhill	$1,459,000	$1,619,000	$2,022,000	$3,963,000	$4,853,000	$5,111,000	n/a	$4,866,000
Unionville	$7,000	$79,000	$209,000	$373,000	$992,000	$2,228,000	$3,309,000	$60,196,000
Vellore Woods	$0	$0	$0	$0	$0	$0	n/a	$38,424,000
West Mall	$0	$0	$0	$172,000	$368,000	$447,000	$16,778,000	$52,733,000
Willowfield	$0	$0	$0	$794,000	$1,578,000	$2,374,000	n/a	$2,374,000
Woodbridge	$0	$0	$98,000	$320,000	$1,786,000	$2,825,000	$5,196,000	$78,386,000
Total	$6,345,000	$25,899,000	$104,047,000	$261,345,000	$423,887,000	$636,621,000	n/a	$2,735,106,000

Tangible Building-Related Damage Totals

Residential Direct Damages

Cluster	Return Period							
	1:2	1:5	1:10	1:25	1:50	1:100	1:350	Regional
Albion Road	$0	$0	$0	$0	$104,000	$107,000	n/a	$54,828,000
Altona/Rougemount	$0	$0	$0	$0	$0	$0	n/a	$2,312,000
Avondale	$0	$0	$0	$0	$103,000	$332,000	$12,932,000	$18,814,000
Bay Ridges	$300,000	$317,000	$913,000	$2,604,000	$3,884,000	$5,981,000	n/a	$5,981,000
Bolton Core	$0	$220,000	$4,097,000	$6,714,000	$7,696,000	$8,754,000	n/a	$33,855,000
Brampton Central	$0	$0	$0	$0	$0	$0	$488,000	$11,703,000
Brickworks	$0	$0	$0	$0	$0	$0	$0	$0
Concord	$0	$0	$0	$274,000	$889,000	$889,000	n/a	$4,137,000
Dixie/Dundas	$0	$0	$1,116,000	$2,091,000	$3,002,000	$3,401,000	$6,014,000	$10,206,000
Dorset Park	$0	$0	$0	$1,474,000	$5,522,000	$6,984,000	n/a	$10,700,000
Dundas West	$0	$0	$0	$0	$0	$0	n/a	$25,989,000
Edgeley/Vaughan Centre	$0	$0	$0	$0	$0	$0	n/a	$0
Elgin Mills	$0	$0	$0	$0	$0	$0	n/a	$2,357,000
Hoggs Hollow	$0	$315,000	$505,000	$2,063,000	$2,642,000	$4,721,000	$6,158,000	$58,291,000
Ionview	$0	$0	$480,000	$1,918,000	$2,585,000	$3,339,000	n/a	$20,992,000
Jane/Wilson	$0	$126,000	$2,126,000	$4,447,000	$5,130,000	$7,877,000	$39,507,000	$67,173,000
Keele Industrial	$0	$0	$0	$0	$0	$0	n/a	$0
Kennedy Commons	$0	$0	$0	$0	$535,000	$1,410,000	n/a	$4,610,000
Lake Wilcox	$1,081,000	$1,451,000	$2,271,000	$3,213,000	$4,281,000	$5,284,000	$80,932,000	$92,810,000
Langstaff Business Park	$0	$0	$0	$0	$0	$0	n/a	$0
Little Etobicoke	$0	$0	$0	$0	$0	$0	$1,976,000	$5,347,000
Longbranch	$0	$0	$0	$0	$0	$0	$4,713,000	$9,367,000
Lower Carruthers	$184,000	$184,000	$184,000	$184,000	$185,000	$185,000	n/a	$10,449,000
Lower Don	$0	$0	$339,000	$671,000	$1,397,000	$9,327,000	$11,924,000	$94,386,000
Malton	$0	$716,000	$734,000	$839,000	$1,029,000	$1,092,000	n/a	$17,481,000
Maple	$1,178,000	$1,349,000	$1,493,000	$1,493,000	$2,088,000	$2,443,000	n/a	$5,440,000
Markham Industrial	$0	$0	$0	$0	$0	$587,000	n/a	$587,000
New Westminster	$0	$0	$221,000	$581,000	$1,204,000	$1,954,000	n/a	$20,510,000
Newkirk Business Park	$0	$0	$0	$993,000	$2,096,000	$2,488,000	n/a	$10,952,000
Old Markham Village	$0	$0	$0	$115,000	$115,000	$115,000	n/a	$2,088,000
Pickering Village	$79,000	$80,000	$9,620,000	$14,032,000	$17,818,000	$20,657,000	$24,859,000	$86,415,000
Progress Business Park	$0	$0	$0	$0	$0	$207,000	n/a	$2,597,000
Rockcliffe	$0	$0	$9,020,000	$20,529,000	$46,181,000	$61,471,000	$77,733,000	$118,199,000
South Mimico	$0	$0	$0	$0	$161,000	$399,000	n/a	$10,330,000
Stouffville Centre	$57,000	$143,000	$144,000	$146,000	$148,000	$258,000	n/a	$3,124,000
Thornhill	$1,431,000	$1,587,000	$1,984,000	$3,898,000	$4,759,000	$5,014,000	n/a	$4,792,000
Unionville	$0	$67,000	$195,000	$253,000	$704,000	$1,898,000	$2,787,000	$47,058,000
Vellore Woods	$0	$0	$0	$0	$0	$0	n/a	$37,374,000
West Mall	$0	$0	$0	$97,000	$239,000	$241,000	$746,000	$833,000
Willowfield	$0	$0	$0	$765,000	$1,521,000	$2,285,000	n/a	$2,285,000
Woodbridge	$0	$0	$94,000	$313,000	$1,586,000	$2,393,000	$3,516,000	$57,638,000
Grand Total	$4,310,000	$6,555,000	$35,536,000	$69,707,000	$117,604,000	$162,093,000	n/a	$972,010,000

Tangible Building-Related Damage Totals

Non-Residential Direct Damages

Cluster	Return Period							
	1:2	1:5	1:10	1:25	1:50	1:100	1:350	Regional
Albion Road	$0	$0	$0	$0	$0	$0	n/a	$2,396,000
Altona/Rougemount	$0	$0	$0	$0	$0	$0	n/a	$58,000
Avondale	$0	$3,749,000	$5,435,000	$32,186,000	$50,536,000	$61,038,000	$67,227,000	$78,868,000
Bay Ridges	$0	$0	$0	$0	$0	$0	n/a	$0
Bolton Core	$0	$0	$0	$0	$32,000	$206,000	n/a	$15,491,000
Brampton Central	$0	$0	$0	$0	$0	$0	$0	$23,264,000
Brickworks	$0	$311,000	$1,174,000	$2,573,000	$9,929,000	$14,728,000	$18,439,000	$22,045,000
Concord	$0	$0	$0	$0	$0	$0	n/a	$85,000
Dixie/Dundas	$0	$2,974,000	$18,214,000	$19,956,000	$20,966,000	$22,385,000	$27,118,000	$28,848,000
Dorset Park	$0	$0	$0	$85,000	$3,834,000	$5,918,000	n/a	$7,829,000
Dundas West	$0	$0	$0	$0	$13,000	$66,000	n/a	$924,000
Edgeley/Vaughan Centre	$0	$0	$0	$409,000	$1,835,000	$4,909,000	n/a	$151,980,000
Elgin Mills	$0	$93,000	$96,000	$96,000	$103,000	$103,000	n/a	$979,000
Hoggs Hollow	$0	$0	$0	$0	$0	$0	$0	$17,000
Ionview	$0	$0	$0	$94,000	$1,463,000	$2,079,000	n/a	$7,237,000
Jane/Wilson	$0	$314,000	$2,095,000	$6,064,000	$9,149,000	$15,462,000	$18,655,000	$26,556,000
Keele Industrial	$0	$0	$0	$0	$0	$0	n/a	$79,752,000
Kennedy Commons	$0	$8,000	$1,000	$291,000	$7,299,000	$14,315,000	n/a	$66,274,000
Lake Wilcox	$0	$0	$0	$0	$0	$0	$1,577,000	$1,910,000
Langstaff Business Park	$0	$0	$0	$0	$0	$6,000	n/a	$32,000
Little Etobicoke	$0	$0	$0	$0	$0	$0	$0	$0
Longbranch	$0	$5,000	$35,000	$33,000	$43,000	$52,000	$80,000	$84,000
Lower Carruthers	$0	$0	$0	$0	$0	$0	n/a	$0
Lower Don	$0	$198,000	$355,000	$577,000	$781,000	$7,911,000	$18,933,000	$176,415,000
Malton	$0	$0	$0	$0	$0	$0	n/a	$164,000
Maple	$0	$0	$0	$0	$0	$0	n/a	$0
Markham Industrial	$1,131,000	$3,712,000	$3,712,000	$23,581,000	$24,160,000	$37,051,000	n/a	$37,051,000
New Westminster	$0	$0	$0	$0	$0	$0	n/a	$0
Newkirk Business Park	$0	$0	$0	$0	$0	$0	n/a	$75,000
Old Markham Village	$0	$0	$0	$0	$0	$0	n/a	$0
Pickering Village	$0	$0	$303,000	$352,000	$609,000	$1,172,000	$2,323,000	$38,064,000
Progress Business Park	$0	$0	$8,000	$4,425,000	$14,118,000	$18,665,000	n/a	$29,286,000
Rockcliffe	$0	$1,401,000	$7,721,000	$25,384,000	$30,147,000	$61,954,000	$79,661,000	$98,461,000
South Mimico	$0	$0	$0	$0	$0	$0	n/a	$0
Stouffville Centre	$196,000	$196,000	$235,000	$293,000	$338,000	$382,000	n/a	$586,000
Thornhill	$0	$0	$0	$0	$6,000	$6,000	n/a	$0
Unionville	$2,000	$3,000	$3,000	$57,000	$133,000	$133,000	$204,000	$4,099,000
Vellore Woods	$0	$0	$0	$0	$0	$0	n/a	$0
West Mall	$0	$0	$0	$38,000	$45,000	$67,000	$9,253,000	$26,163,000
Willowfield	$0	$0	$0	$1,000	$1,000	$4,000	n/a	$4,000
Woodbridge	$0	$0	$0	$0	$178,000	$338,000	$1,076,000	$9,375,000
Grand Total	$1,329,000	$12,964,000	$39,387,000	$116,495,000	$175,718,000	$268,950,000	n/a	$934,372,000

Tangible Building-Related Damage Totals

Residential Displacement

Cluster	Return Period							
	1:2	1:5	1:10	1:25	1:50	1:100	1:350	Regional
Albion Road	$0	$0	$0	$0	$3,000	$4,000	n/a	$5,693,000
Altona/Rougemount	$0	$0	$0	$0	$0	$0	n/a	$114,000
Avondale	$0	$0	$0	$0	$0	$15,000	$582,000	$898,000
Bay Ridges	$11,000	$11,000	$30,000	$86,000	$123,000	$205,000	n/a	$205,000
Bolton Core	$0	$7,000	$142,000	$245,000	$271,000	$298,000	n/a	$1,266,000
Brampton Central	$0	$0	$0	$0	$0	$0	$6,000	$1,810,000
Brickworks	$0	$0	$0	$0	$0	$0	$0	$0
Concord	$0	$0	$0	$4,000	$16,000	$16,000	n/a	$94,000
Dixie/Dundas	$0	$0	$145,000	$476,000	$513,000	$639,000	$845,000	$1,209,000
Dorset Park	$0	$0	$0	$66,000	$306,000	$363,000	n/a	$690,000
Dundas West	$0	$0	$0	$0	$0	$0	n/a	$688,000
Edgeley/Vaughan Centre	$0	$0	$0	$0	$0	$0	n/a	$0
Elgin Mills	$0	$0	$0	$0	$0	$0	n/a	$393,000
Hoggs Hollow	$0	$4,000	$4,000	$22,000	$28,000	$56,000	$76,000	$674,000
Ionview	$0	$0	$21,000	$65,000	$93,000	$116,000	n/a	$2,324,000
Jane/Wilson	$0	$3,000	$200,000	$933,000	$1,062,000	$1,226,000	$2,884,000	$6,219,000
Keele Industrial	$0	$0	$0	$0	$0	$0	n/a	$34,000
Kennedy Commons	$0	$0	$0	$0	$46,000	$120,000	n/a	$251,000
Lake Wilcox	$32,000	$37,000	$71,000	$100,000	$128,000	$154,000	$2,269,000	$2,547,000
Langstaff Business Park	$0	$0	$0	$0	$0	$0	n/a	$0
Little Etobicoke	$0	$0	$0	$0	$0	$0	$100,000	$238,000
Longbranch	$0	$0	$0	$0	$0	$0	$563,000	$1,092,000
Lower Carruthers	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	n/a	$317,000
Lower Don	$0	$0	$35,000	$62,000	$123,000	$727,000	$923,000	$6,908,000
Malton	$0	$24,000	$25,000	$29,000	$30,000	$32,000	n/a	$1,306,000
Maple	$22,000	$22,000	$22,000	$22,000	$26,000	$33,000	n/a	$90,000
Markham Industrial	$0	$0	$0	$0	$0	$19,000	n/a	$19,000
New Westminster	$0	$0	$8,000	$22,000	$58,000	$105,000	n/a	$819,000
Newkirk Business Park	$0	$0	$0	$58,000	$110,000	$135,000	n/a	$373,000
Old Markham Village	$0	$0	$0	$0	$0	$0	n/a	$66,000
Pickering Village	$3,000	$3,000	$502,000	$972,000	$1,121,000	$1,259,000	$1,482,000	$5,074,000
Progress Business Park	$0	$0	$0	$12,000	$4,000	$14,000	n/a	$138,000
Rockcliffe	$0	$0	$482,000	$1,070,000	$3,077,000	$4,229,000	$6,016,000	$9,222,000
South Mimico	$0	$0	$0	$0	$7,000	$14,000	n/a	$344,000
Stouffville Centre	$4,000	$7,000	$7,000	$8,000	$8,000	$11,000	n/a	$112,000
Thornhill	$28,000	$32,000	$38,000	$64,000	$76,000	$80,000	n/a	$74,000
Unionville	$0	$4,000	$8,000	$17,000	$45,000	$86,000	$115,000	$1,457,000
Vellore Woods	$0	$0	$0	$0	$0	$0	n/a	$1,050,000
West Mall	$0	$0	$0	$3,000	$7,000	$7,000	$25,000	$31,000
Willowfield	$0	$0	$0	$28,000	$57,000	$85,000	n/a	$85,000
Woodbridge	$0	$0	$4,000	$7,000	$22,000	$34,000	$49,000	$2,341,000
Grand Total	$103,000	$157,000	$1,747,000	$4,374,000	$7,363,000	$10,085,000	n/a	$56,265,000

Tangible Building-Related Damage Totals

Business Disruption

Cluster	Return Period							
	1:2	1:5	1:10	1:25	1:50	1:100	1:350	Regional
Albion Road	$0	$0	$0	$0	$0	$0	n/a	$204,000
Altona/Rougemount	$0	$0	$0	$0	$0	$0	n/a	$91,000
Avondale	$0	$1,693,000	$2,939,000	$15,617,000	$28,438,000	$38,931,000	$43,888,000	$51,419,000
Bay Ridges	$0	$0	$0	$0	$0	$0	n/a	$0
Bolton Core	$0	$0	$0	$0	$24,000	$166,000	n/a	$24,812,000
Brampton Central	$0	$0	$0	$0	$0	$0	$0	$34,829,000
Brickworks	$0	$189,000	$881,000	$2,519,000	$10,322,000	$17,582,000	$24,143,000	$28,500,000
Concord	$0	$0	$0	$0	$0	$0	n/a	$36,000
Dixie/Dundas	$0	$1,572,000	$14,145,000	$16,436,000	$17,846,000	$19,289,000	$26,043,000	$29,027,000
Dorset Park	$0	$0	$0	$48,000	$4,041,000	$6,134,000	n/a	$8,032,000
Dundas West	$0	$0	$0	$0	$10,000	$57,000	n/a	$1,319,000
Edgeley/Vaughan Centre	$0	$0	$0	$195,000	$746,000	$2,599,000	n/a	$93,197,000
Elgin Mills	$0	$114,000	$117,000	$117,000	$125,000	$125,000	n/a	$1,258,000
Hoggs Hollow	$0	$0	$0	$0	$0	$0	$0	$30,000
Ionview	$0	$0	$0	$53,000	$835,000	$1,167,000	n/a	$3,984,000
Jane/Wilson	$0	$188,000	$1,680,000	$2,925,000	$4,794,000	$9,702,000	$16,910,000	$24,307,000
Keele Industrial	$0	$0	$0	$0	$0	$0	n/a	$49,199,000
Kennedy Commons	$0	$13,000	$2,000	$478,000	$7,520,000	$10,533,000	n/a	$63,145,000
Lake Wilcox	$0	$0	$0	$0	$0	$0	$1,548,000	$2,179,000
Langstaff Business Park	$0	$0	$0	$0	$0	$3,000	n/a	$15,000
Little Etobicoke	$0	$0	$0	$0	$0	$0	$0	$0
Longbranch	$0	$0	$0	$0	$0	$0	$0	$0
Lower Carruthers	$0	$0	$0	$0	$0	$0	n/a	$0
Lower Don	$0	$154,000	$565,000	$1,296,000	$1,780,000	$8,746,000	$25,248,000	$146,860,000
Malton	$0	$0	$0	$0	$0	$0	n/a	$234,000
Maple	$0	$0	$0	$0	$0	$0	n/a	$0
Markham Industrial	$510,000	$1,842,000	$1,842,000	$12,506,000	$12,838,000	$19,871,000	n/a	$19,871,000
New Westminster	$0	$0	$0	$0	$0	$0	n/a	$0
Newkirk Business Park	$0	$0	$0	$0	$0	$0	n/a	$36,000
Old Markham Village	$0	$0	$0	$0	$0	$0	n/a	$0
Pickering Village	$0	$0	$449,000	$629,000	$904,000	$1,536,000	$3,164,000	$38,580,000
Progress Business Park	$0	$0	$4,000	$2,963,000	$9,642,000	$13,340,000	n/a	$21,958,000
Rockcliffe	$0	$452,000	$4,731,000	$14,904,000	$23,140,000	$45,398,000	$65,899,000	$87,357,000
South Mimico	$0	$0	$0	$0	$0	$0	n/a	$0
Stouffville Centre	$0	$0	$0	$0	$0	$0	n/a	$48,000
Thornhill	$0	$0	$0	$0	$12,000	$12,000	n/a	$0
Unionville	$5,000	$5,000	$4,000	$46,000	$111,000	$111,000	$204,000	$7,582,000
Vellore Woods	$0	$0	$0	$0	$0	$0	n/a	$0
West Mall	$0	$0	$0	$34,000	$77,000	$132,000	$6,754,000	$25,707,000
Willowfield	$0	$0	$0	$0	$0	$0	n/a	$0
Woodbridge	$0	$0	$0	$0	$0	$59,000	$556,000	$9,031,000
Grand Total	$515,000	$6,222,000	$27,359,000	$70,766,000	$123,205,000	$195,493,000	n/a	$772,847,000

for the same timeframe. The AAD is obtained by calculating the area under the damage-probability curve, which depicts total damage versus the probability of occurrence. Annualized values for this project were calculated using a straight-line interpolation between events with a trapezoid area formula.

Exhibit 5.2 illustrates the charts of damages vs probability and the corresponding total AAD for all clusters. The AAD, broken down by category is illustrated in **Exhibit 5.3**. These charts for each cluster are found on the FVA Fact Sheets in **Appendix H**.

Exhibit 5.2: Total Damages vs Probability

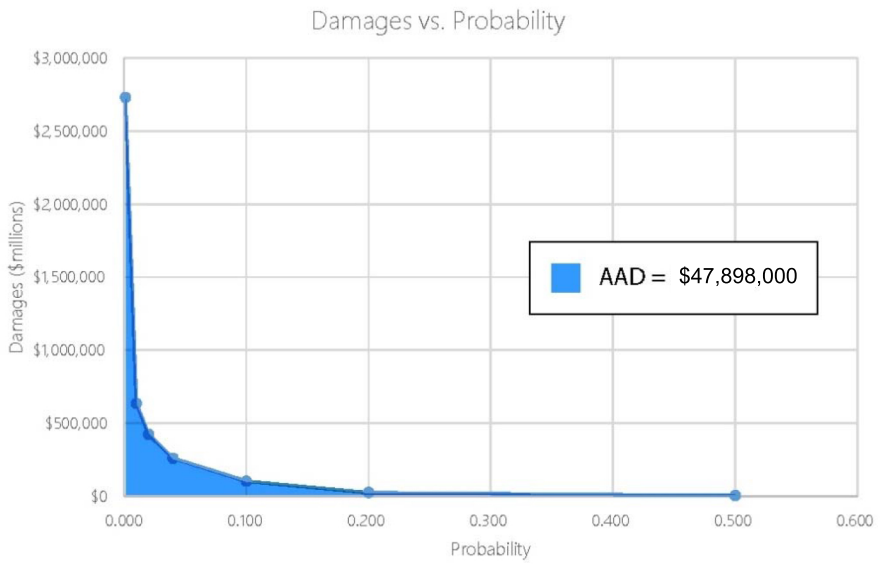
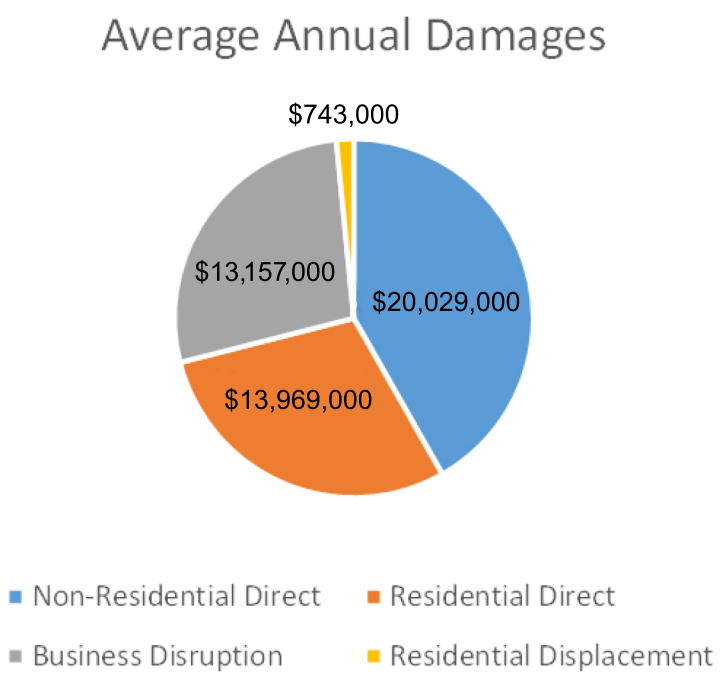


Exhibit 5.3: Average Annual Damages by Category



The Regional storm does not have a specific probability assigned due in part to the limited historical data record in relation to how truly extreme the storm was. Additionally, determining a consistent probability is problematic due to the wide-spread nature of the rainfall associated with this storm. For example, a flood-frequency analysis of the peak flow resulting from Hurricane Hazel would typically yield a lower flood-frequency at the mouth of a large watershed than that of a location in the upper reaches of the watershed. A typical Intensity-Duration-Frequency (IDF) curve approach also falls short in characterizing the return-period of the storm, because the importance of the spatial extent of the storm is neglected. To estimate a probability for the Regional storm (solely for the purposes of the average-annual damage calculation performed in this study), a flood frequency analysis was conducted at the Water Survey of Canada's West Humber at Highway No.7 (02HC031) stream gauge. The modeled peak-flow resulting from Hurricane Hazel at the West Humber at Highway 7 was then plotted on the resulting Log-Pearson Type III distribution to select a return-period. This location was selected for a number of reasons, including the following: size of contributing sub-watershed, which represented a balance between small and large within the context of TRCA's watersheds; sub-watershed land-use characteristics, which represented a balance between rural and urbanized; long period of record at the gauge; and the absence of large dams upstream which could introduce additional uncertainty into the results. Note that this probability assignment to the Regional storm was solely conducted for the purpose of damage estimates as part of this study, and TRCA maintains that there is no return period assigned to Hurricane Hazel. The AAD was calculated as the area under the damage-probability curve between the 1:2-year and the Regional storm event. In other words, no damages were assumed below the 1:2 probability and no projection was inferred beyond the Regional storm. The AAD for each cluster, by category is illustrated in **Exhibit 5.4**.

5.1.4 Scoring

To convert the AAD values into a score within the overall risk ranking matrix, the AAD for each cluster was converted into a relative score and then multiplied by the weighting for each of the four variables. Initially, the relative score was obtained by dividing a cluster's AAD by the highest cluster AAD amount. However, several clusters had much higher damage amounts than the majority. The result of the relative division was that most clusters had insignificant values. Therefore, a new relative score was obtained by dividing all values by the 90th percentile value of all scores, with a maximum value of one.

This had the effect of giving the top four clusters full score (relative score of one) and a clearer distribution of the remaining scores. This method was chosen because it maintains both the ranking of the scores and the magnitude of the difference between the damage amounts.

The relative score (from zero to one) was then multiplied by the variable weight to obtain each cluster's weighted score for the category.

5.2 Community Impacts

5.2.1 Count of Affected Facilities

GIS shapefiles were used to obtain a count of the affected facilities for each flood event. The inundation polygons provided by TRCA required the cluster name and flood event attributes in order to create the necessary data. They were also joined by return period. The available facility data was in point file format. The count of each facility within the inundation polygons was sampled and added to its attributes.

Of the available facilities data that could be assessed, very few were located in the flood vulnerable areas. This is good news from a risk management perspective and provides evidence of appropriate application of land-use management to reduce flood risks, but provides little reward for the effort to collect and process the data. **Exhibit 5.5** details the number of facilities impacted by type and flood event. Hospitals were also examined but none were found to lie within any of the cluster boundaries.

Average Annual Damages by Cluster and Category

Cluster	Category				Total
	Non-Residential Direct	Residential Direct	Business Disruption	Residential Displacement	
Albion Road	$10,783	$249,295	$916	$25,706	$286,700
Altona/Rougemount	$263	$10,405	$411	$514	$11,593
Avondale	$4,128,973	$80,062	$2,203,880	$3,583	$6,416,498
Bay Ridges	$0	$427,636	$0	$14,306	$441,942
Bolton Core	$72,135	$991,401	$113,591	$35,200	$1,212,328
Brampton Central	$21,602	$13,061	$32,342	$1,710	$68,715
Brickworks	$637,606	$0	$649,775	$0	$1,287,381
Concord	$385	$51,131	$161	$948	$52,626
Dixie/Dundas	$3,505,383	$283,627	$2,680,595	$48,728	$6,518,333
Dorset Park	$152,348	$256,280	$156,955	$13,787	$579,370
Dundas West	$4,989	$116,952	$6,621	$3,096	$131,658
Edgeley/Vaughan Centre	$774,418	$0	$463,069	$0	$1,237,487
Elgin Mills	$36,982	$10,606	$45,598	$1,770	$94,956
Hoggs Hollow	$16	$347,791	$28	$3,893	$351,728
Ionview	$78,034	$280,100	$43,658	$17,228	$419,019
Jane/Wilson	$851,223	$757,837	$542,672	$99,213	$2,250,945
Keele Industrial	$358,883	$0	$221,397	$154	$580,433
Kennedy Commons	$556,993	$42,170	$518,842	$2,949	$1,120,954
Lake Wilcox	$8,870	$1,322,390	$8,989	$37,565	$1,377,813
Langstaff Business Park	$199	$0	$95	$0	$294
Little Etobicoke	$0	$13,855	$0	$672	$14,527
Longbranch	$6,558	$29,905	$0	$3,547	$40,011
Lower Carruthers	$0	$137,969	$0	$3,145	$141,114
Lower Don	$419,592	$296,180	$479,493	$23,903	$1,219,167
Malton	$739	$339,914	$1,052	$14,639	$356,344
Maple	$0	$704,826	$0	$11,383	$716,209
Markham Industrial	$4,026,971	$8,215	$2,096,387	$265	$6,131,839
New Westminster	$0	$169,805	$0	$7,048	$176,853
Newkirk Business Park	$336	$144,082	$161	$6,945	$151,524
Old Markham Village	$0	$16,797	$0	$297	$17,094
Pickering Village	$103,289	$1,995,115	$137,890	$119,227	$2,355,521
Progress Business Park	$698,528	$13,656	$488,992	$1,284	$1,202,459
Rockcliffe	$3,346,379	$3,221,950	$2,178,973	$199,419	$8,946,721
South Mimico	$0	$52,684	$0	$1,783	$54,467
Stouffville Centre	$127,300	$73,128	$365	$3,697	$204,491
Thornhill	$137	$987,419	$286	$18,465	$1,006,308
Unionville	$11,344	$122,250	$14,461	$5,283	$153,338
Vellore Woods	$0	$168,183	$0	$4,724	$172,907
West Mall	$68,702	$13,645	$57,903	$452	$140,702
Willowfield	$96	$85,400	$33	$3,171	$88,700
Woodbridge	$19,117	$133,712	$11,393	$3,574	$167,797
Total	$20,029,000	$13,969,000	$13,157,000	$743,000	$47,898,000

Exhibit 5.5: Impacted Facilities by Type and Flood Event

Type	Return Period						
	2	5	10	25	50	100	Regional
Emergency Services	0	0	2	2	1	3	11
Recreation Facilities	0	0	0	0	0	0	2
Places of Worship	1	2	4	7	7	7	32
Schools	0	0	0	2	2	2	12
Community Centres	0	0	0	0	0	0	3

5.2.2 Average Annual Impacted Facilities

If a facility were affected by a 1:10-year event, this would have a greater impact on the community than if it were only affected by 1:100-year event. Therefore, a method of weighting the impact based on probability is required. Just as tangible damage amounts can be annualized with probabilities, so too can any quantifiable metric. Therefore, all impact categories have been annualized in the same manner, providing a score that reflects the probability of each event.

5.2.3 Scoring

The annualized number of impacted facilities for each cluster was converted into a relative score and then multiplied by the weighting for each of the four variables. The relative score was obtained by dividing a cluster's annualized amount by the highest cluster's amount. Unlike the building damages, the facility numbers did not have outliers skewing the relative scores and they were directly multiplied by the variable's weighting to obtain the ranking score.

5.3 Social Vulnerability

The social vulnerability variables relate to households and population. As such, they are related to numbers of residential units as well as the demographic profiles of each cluster. Therefore, it is a combination of number of affected households or people and the relative demographic index. In other words, a cluster with a relatively low risk demographic may achieve a higher score than a high risk demographic due to the number of people affected. To obtain such a score, a relative cluster demographic index was used for each variable.

One variable in this category, the number of care facilities, was not demographically derived. This variable was treated in the same manner as the facilities in the Community Impacts category, described above in Section 5.2.

5.3.1 Average Annual Impacted Population

The number of people affected by an event is a product of the number of residential units. In the absence of building-specific population data, the census average residents per dwelling units for multifamily and single-family homes was used. The population affected for each event was annualized with the same method as building damages to provide a probability weighted value.

5.3.2 Demographic Indexing

TRCA provided the required demographic variables with an index value for each, benchmarked against the TRCA Jurisdiction according to the Environics database (benchmark = 100). This value was used as the population impact multiplier.

The average annual impacted population and demographic indexing is detailed in **Exhibit 5.6**.

Average Annual Impacted Population and Demographic Indexing

Cluster	Average Annual Affected Population	Household income under $20000 Index	Families With Children Index	Over 65 Years Index	Home Owners Index
Albion Road	12.53	119	112	98	97
Altona/Rougemount	0.39	110	116	57	140
Avondale	8.10	77	100	107	47
Bay Ridges	10.88	97	84	263	137
Bolton Core	46.48	97	103	117	117
Brampton Central	2.19	113	74	202	76
Brickworks	0.00	0	62	180	79
Concord	0.89	38	89	82	113
Dixie/Dundas	137.59	134	97	130	74
Dorset Park	14.00	108	117	86	93
Dundas West	1.67	63	96	132	70
Edgeley/Vaughan Centre	0.00	0	96	76	113
Elgin Mills	0.38	29	88	161	38
Hoggs Hollow	3.23	82	97	117	150
Ionview	29.18	168	113	80	15
Jane/Wilson	138.82	221	116	99	34
Keele Industrial	0.05	0	0	0	0
Kennedy Commons	7.77	142	99	146	131
Lake Wilcox	27.44	31	103	103	126
Langstaff Business Park	0.00	0	0	0	0
Little Etobicoke	0.51	19	88	201	160
Longbranch	1.53	170	79	89	54
Lower Carruthers	2.51	24	112	49	153
Lower Don	18.23	180	82	84	84
Malton	11.30	86	116	63	64
Maple	11.52	45	115	56	160
Markham Industrial	0.20	0	0	0	160
New Westminster	5.45	41	104	99	149
Newkirk Business Park	10.61	137	103	94	75
Old Markham Village	3.95	54	58	289	46
Pickering Village	103.08	45	97	123	134
Progress Business Park	69.70	138	91	104	109
Rockcliffe	150.07	195	106	99	80
South Mimico	0.90	100	0	0	0
Stouffville Centre	2.77	81	91	275	96
Thornhill	14.65	101	96	95	135
Unionville	4.67	83	71	270	143
Vellore Woods	3.41	32	122	46	155
West Mall	0.31	0	107	51	0
Willowfield	2.93	201	103	115	147
Woodbridge	13.15	81	110	105	139

5.3.3 Scoring

The number of impacted people for each event was multiplied by the demographic index to produce a demographically weighted population score. As with building damages, the clusters' affected populations varied greatly, with several having far more than the majority. Therefore, the same method of using the 90th percentile as the denominator to obtain a relative score was used. This number was then multiplied by the variable weighting to obtain the cluster scores.

5.4 Infrastructure

The primary analysis for this category related to roads. The other variables were GO Stations and Utilities. Go Stations were sampled in the same manner as community facilities and only one station was impacted. Utility data was not available in a way that assumptions about service impacts could be made. However, due to the importance of utility risk, the variable was retained for future use and all clusters given the same score of 50% of possible points.

5.4.1 Road Inundation

TRCA provided shapefiles (polylines) for road segments within each cluster with flood attributes. Because of the linear nature of road segments, the inundation data was provided as a minimum, maximum, and mean depth. There are two metrics of interest: overall inundation levels and impassible segments.

A measure of overall inundation for each segment and each flood event was obtained by multiplying the segment length by the mean depth. A road segment was deemed impassible if it had a max depth greater than 0.3 metres or a max velocity 4.5 m/s or greater.

5.4.2 Road Classification Multiplier

The impact of an impassible or otherwise inundated road segment is assumed to be related to the regular volume of traffic that would be affected. The road shapefile included the segment's road classification. This allows for a weighting of scores based on the class of impacted segment. The Ontario Road Network classification does not detail traffic counts for each class. However, municipalities such as Toronto have similar classes and associated volumes. Accordingly, a multiplier for each class was determined, based on the relative volume of traffic. These multipliers are detailed in **Exhibit 5.7**.

Exhibit 5.7: Road Class Multipliers

Road Class	Multiplier
Laneway	1.0
Service Road	1.0
Ramp	1.0
Strata	1.5
Local Road	2.5
Collector	8.0
Arterial	15.0
Freeway	40.0

5.4.3 Average Annual Road Inundation and Impassible Segments

The inundation values and counts of impassible segments for each event were all annualized using the same trapezoid area formula as the other categories. This accounts for weighting of flood probability.

5.4.4 Scoring

The score for the roads variable is a 50/50 combination of the overall inundation and impassible segments. As with building and population scores, the relative scoring was based on a denominator of the 90th percentile to account for outlier clusters with greater lengths of road than the majority.

5.5 Preparedness and Resiliency

The preparedness and resiliency variables were not calculated for this study.

5.6 Summary of Annualized Metrics

A summary of the annualized metrics for each cluster is provided in **Exhibit 5.8**

Summary of Average Annual Metrics by Cluster

Cluster	AA Damages	AAD Non-Residential	AAD Residential	AAD Non-Residential Direct	AAD Residential Direct	AAD Non-Residential Interruption	AAD Residential Displacement	AA Population	AA Commercial/Industrial m2	AA Institutional m2	AA Employees	AA Mean Road Depth*Length	AA Impassible Road Segments	AA Emergency Services	AA Recreation Facilities	AA Places of Worship	AA Schools	AA Community Centres	AA Go Stations	AA Long Term Care
Albion Road	$286,700	$11,700	$275,001	$10,783	$249,295	$916	$25,706	12.527	0.000	21.653	0.000	3,599.367	16.136	0.000	0.000	0.018	0.005	0.000	0.000	0.000
Altona/Rougemount	$11,593	$674	$10,919	$263	$10,405	$411	$514	0.386	35.677	0.000	0.573	192.580	0.935	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Avondale	$6,416,498	$6,332,853	$83,645	$4,128,973	$80,062	$2,203,880	$3,583	8.104	18,176.885	152.853	286.778	1,938.408	7.579	0.009	0.000	0.642	0.009	0.009	0.005	0.005
Bay Ridges	$441,942	$0	$441,942	$0	$427,636	$0	$14,306	10.881	0.000	0.000	0.000	1,185.643	6.314	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bolton Core	$1,212,328	$185,727	$1,026,601	$72,135	$991,401	$113,591	$35,200	46.483	100.687	21.234	2.692	4,310.840	12.513	0.009	0.000	0.000	0.000	0.000	0.000	0.000
Brampton Central	$68,715	$53,944	$14,771	$21,602	$13,061	$32,342	$1,710	2.188	95.495	14.745	1.612	117.860	4.459	0.000	0.005	0.005	0.000	0.000	0.000	0.000
Brickworks	$1,287,381	$1,287,381	$0	$637,606	$0	$649,775	$0	0.000	5,395.815	1.636	166.201	17,751.947	66.718	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Concord	$52,626	$546	$52,080	$385	$51,131	$161	$948	0.887	3.513	0.000	0.094	411.800	2.145	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dixie/Dundas	$6,518,333	$6,185,978	$332,355	$3,505,383	$283,627	$2,680,595	$48,728	137.588	22,537.328	0.000	426.502	9,093.547	17.741	0.000	0.000	0.014	0.000	0.000	0.000	0.000
Dorset Park	$579,370	$309,303	$270,067	$152,348	$256,280	$156,955	$13,787	14.005	1,968.429	40.329	35.691	515.908	4.353	0.029	0.000	0.005	0.005	0.000	0.000	0.000
Dundas West	$131,658	$11,610	$120,048	$4,989	$116,952	$6,621	$3,096	1.671	33.012	0.779	0.759	475.296	7.969	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Edgeley/Vaughan Centre	$1,237,487	$1,237,487	$0	$774,418	$0	$463,069	$0	0.000	1,985.543	60.017	28.392	781.416	3.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Elgin Mills	$94,938	$82,580	$12,376	$36,982	$10,606	$45,598	$1,770	0.378	3,598.000	9.000	53.000	140.153	0.856	0.000	0.000	0.000	0.005	0.000	0.000	0.000
Hoggs Hollow	$351,728	$44	$351,684	$16	$347,791	$28	$3,893	3.228	1.087	0.000	0.016	5.189	0.081	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Ionview	$419,019	$121,691	$297,328	$78,034	$280,100	$43,658	$17,228	29.177	373.032	0.550	6.084	228.100	1.433	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jane/Wilson	$2,250,945	$1,393,895	$857,050	$851,223	$757,837	$542,672	$99,213	138.821	1,658.766	1,391.407	41.028	56,026.868	31.535	0.273	0.000	0.227	0.014	0.000	0.000	0.000
Keele Industrial	$580,433	$580,279	$154	$358,883	$0	$221,397	$154	0.049	532.739	0.000	9.089	131.662	0.158	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Kennedy Commons	$1,120,954	$1,075,835	$45,119	$556,993	$42,170	$518,842	$2,949	7.766	5,014.832	5.389	95.813	495.949	2.052	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Lake Wilcox	$1,377,813	$17,858	$1,359,954	$8,870	$1,322,390	$8,989	$37,565	27.436	21.957	4.722	0.449	1,692.482	14.780	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Langstaff Business Park	$294	$294	$0	$199	$0	$95	$0	0.000	103.933	0.000	1.485	3.567	0.112	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Little Etobicoke	$14,527	$0	$14,527	$0	$13,855	$0	$672	0.509	0.000	0.000	0.000	142.091	7.600	0.000	0.000	0.000	0.000	0.000	0.000	0.005
Longbranch	$40,011	$6,558	$33,452	$6,558	$29,905	$0	$3,547	1.535	0.000	47.409	0.000	269.829	2.220	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lower Carruthers	$141,114	$0	$141,114	$0	$137,969	$0	$3,145	2.506	0.000	0.000	0.000	591.223	4.262	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lower Don	$1,219,167	$899,084	$320,083	$419,592	$296,180	$479,493	$23,903	18.233	3,764.686	19.894	71.999	5,935.093	35.425	0.005	0.000	0.000	0.000	0.000	0.000	0.000
Malton	$356,344	$1,791	$354,553	$739	$339,914	$1,052	$14,639	11.297	27.444	3.446	0.679	774.564	6.312	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Maple	$716,209	$0	$716,209	$0	$704,826	$0	$11,383	11.522	0.000	0.000	0.000	91.636	3.279	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Markham Industrial	$6,131,839	$6,123,359	$8,480	$4,026,971	$8,215	$2,096,387	$265	0.196	44,889.637	132.886	652.203	6,532.231	37.800	0.000	0.000	0.349	0.000	0.000	0.000	0.000
New Westminster	$176,853	$0	$176,853	$0	$169,805	$0	$7,048	5.449	0.000	0.000	0.000	86.703	0.580	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Newkirk Business Park	$151,524	$497	$151,027	$336	$144,082	$161	$6,945	10.611	5.764	0.000	0.082	241.770	3.193	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Old Markham Village	$17,094	$0	$17,094	$0	$16,797	$0	$297	3.953	0.000	0.000	0.000	305.852	4.470	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pickering Village	$2,355,521	$241,180	$2,114,342	$103,289	$1,995,115	$137,890	$119,227	103.079	348.872	0.000	6.328	526.760	7.493	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Progress Business Park	$1,202,459	$1,187,519	$14,939	$698,528	$13,656	$488,992	$1,284	69.699	5,200.457	145.298	100.638	782.592	4.470	0.000	0.000	0.023	0.005	0.000	0.000	0.000
Rockcliffe	$8,946,721	$5,525,352	$3,421,369	$3,346,379	$3,221,950	$2,178,973	$199,419	150.065	6,256.111	3,766.516	98.100	46,337.594	32.705	0.005	0.000	0.149	0.143	0.000	0.000	0.000
South Mimico	$54,467	$0	$54,467	$0	$52,684	$0	$1,783	0.904	0.000	0.000	0.000	8.446	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stouffville Centre	$204,491	$127,666	$76,825	$127,300	$73,128	$365	$3,697	2.769	92.714	444.745	1.423	125.402	1.375	0.000	0.000	0.000	0.000	0.005	0.000	0.000
Thornhill	$1,006,308	$424	$1,005,885	$137	$987,419	$286	$18,465	14.650	2.603	0.000	0.053	426.068	9.891	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Unionville	$153,338	$25,805	$127,534	$11,344	$122,250	$14,461	$5,283	4.666	870.609	4.749	19.193	24,432.372	43.287	0.000	0.000	0.014	0.000	0.000	0.000	0.000
Vellore Woods	$172,907	$0	$172,907	$0	$168,183	$0	$4,724	3.415	0.000	0.000	0.000	15.248	0.101	0.000	0.000	0.000	0.000	0.000	0.000	0.000
West Mall	$140,702	$126,605	$14,096	$68,702	$13,645	$57,903	$452	0.315	258.416	0.000	5.359	25.508	0.165	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Willowfield	$88,700	$129	$88,571	$96	$85,400	$33	$3,171	2.926	0.000	19.897	0.000	133.336	7.681	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Woodbridge	$167,797	$30,511	$137,286	$19,117	$133,712	$11,393	$3,574	13.153	18.858	33.578	0.459	5,080.173	16.921	0.005	0.005	0.009	0.000	0.000	0.000	0.000
Total	$47,898,846	$33,186,158	$14,712,706	$20,029,172	$13,969,433	$13,156,986	$743,273	873.026	123,372.901	6,342.732	2,112.773	191,963.072	430.138	0.333	0.009	1.466	0.183	0.014	0.005	0.009

6 Summary of Ranking Results

A summary table of the cluster scores and ranking for each category is provided in **Exhibit 6.1**

Summary of Cluster Scores and Ranking by Category

Cluster	Building Associated		Community Impacts		Social Vulnerability		Infrastructure		Total	Rank
	Score	Rank	Score	Rank	Score	Rank	Score	Rank		
Rockcliffe	50.00	1	2.50	3	18.00	1	11.50	1	82.00	1
Jane/Wilson	44.86	2	2.90	2	17.60	5	11.36	4	76.72	2
Dixie/Dundas	39.31	3	0.04	13	18.00	1	9.67	8	67.02	3
Pickering Village	28.94	4	0.00	19	17.73	4	4.65	16	51.32	4
Bolton Core	27.39	5	0.07	11	15.12	6	6.93	11	49.51	5
Avondale	27.17	6	4.19	1	4.08	15	10.28	6	45.73	6
Progress Business Park	20.38	12	0.13	9	18.00	1	4.39	20	42.91	7
Lower Don	25.64	7	0.03	15	6.43	9	10.11	7	42.21	8
Lake Wilcox	25.29	8	0.00	19	6.95	8	6.05	12	38.30	9
Markham Industrial	25.20	9	1.09	6	0.02	37	10.37	5	36.67	10
Brickworks	21.24	10	0.00	19	0.00	38	11.50	1	32.74	11
Thornhill	19.92	13	0.00	19	4.67	10	4.90	13	29.49	12
Kennedy Commons	19.23	14	0.01	16	3.07	17	3.97	27	26.28	13
Edgeley/Vaughan Centre	20.77	11	0.00	19	0.00	38	4.21	23	24.98	14
Ionview	10.89	17	0.00	19	9.45	7	3.78	31	24.11	15
Albion Road	10.83	18	0.12	10	4.14	14	7.06	10	22.15	16
Dorset Park	12.66	16	0.29	8	4.38	12	4.26	22	21.60	17
Maple	13.74	15	0.00	19	3.04	18	3.94	29	20.71	18
Bay Ridges	10.30	19	0.00	19	4.59	11	4.79	14	19.69	19
Woodbridge	3.49	28	2.06	4	4.19	13	7.80	9	17.55	20
Unionville	3.69	27	0.04	13	1.89	21	11.50	1	17.12	21
Malton	9.09	21	0.00	19	2.91	19	4.61	17	16.62	22
Keele Industrial	9.77	20	0.01	16	0.00	38	3.58	36	13.36	23
Newkirk Business Park	4.05	25	0.00	19	3.47	16	4.00	26	11.51	24
Hoggs Hollow	6.32	22	0.01	16	1.04	26	3.51	40	10.89	25
Stouffville Centre	4.34	24	1.00	7	1.10	25	3.72	32	10.17	26
New Westminster	4.46	23	0.00	19	1.49	22	3.61	35	9.56	27
Brampton Central	1.53	34	2.01	5	0.78	29	4.10	25	8.42	28
Vellore Woods	3.81	26	0.00	19	0.84	28	3.52	38	8.17	29
Willowfield	2.14	32	0.00	19	1.31	23	4.50	18	7.95	30
Dundas West	2.79	30	0.00	19	0.45	32	4.68	15	7.92	31
Lower Carruthers	2.93	29	0.00	19	0.58	30	4.28	21	7.79	32
Little Etobicoke	0.39	38	0.00	19	2.16	20	4.49	19	7.04	33
West Mall	2.43	31	0.00	19	0.04	36	3.53	37	6.00	34
Longbranch	1.51	35	0.00	19	0.50	31	3.89	30	5.91	35
Elgin Mills	1.99	33	0.06	12	0.09	27	3.67	34	5.80	36
Old Markham Village	0.33	39	0.00	19	1.29	24	4.18	24	5.80	37
Concord	1.04	37	0.00	19	0.20	33	3.94	28	5.18	38
South Mimico	1.28	36	0.00	19	0.09	35	3.51	41	4.88	39
Altona/Rougemount	0.31	40	0.00	19	0.12	34	3.70	33	4.13	40
Langstaff Business Park	0.00	41	0.00	19	0.00	38	3.52	39	3.52	41

7 Bibliography

AMEC Environment & Infrastructure. (2012). *Toronto and Region Conservation Authority Flood Protection and Remedial Capital Works Program Draft Report.* Burlington: TRCA.

Buss, L. S. (2010). Nonstructural flood damage reduction within the US Army Corps of Engineers. *Journal of Contemporary Water Research and Education, 130*(1), 5.

Compass Resource Management Ltd., Ebbwater Consulting, Northwest Hydraulic Consultants and Urban Systems. (2015). *City of Vancouver Coastal Flood Risk Assessment Phase II Final Report.* Vancouver: City of Vancouver.

Decent, D., & Feltmate, D. (2018). *After the Flood: The Impact of Climate Change on Mental Health and Lost Time from Work.* Waterloo: University of Waterloo, Intact Centre on Climate Adaptation, Manulife.

Department for Environment, Food and Rural Affairs. (2004). *The Appraisal of Human-related Intangible Impacts of Flooding.* Flood and Coastal Defence R&D Programma. London: Defra; Environment Agency.

FEMA. (2015). Hazus-MH Technical Manual. Washington, D.C., USA: Department of Homeland Security.

IBI Group. (2015). *Provincial Flood Damage Assessment Report.* Calgary: Government of Alberta.

IBI Group. (2017). *Draft Canadian Guidelines and Database of Flood Vulnerability Functions.* Ottawa: Natural Resources Canada.

IBI Group and Golder Associates. (2015). *Provincial Flood Damage Assessment Study.* Calgary: Government of Alberta, Environment and Sustainable Resource Development.

Insurance Bureau of Canada. (2018). *2018 Facts of the Property and Casualty Insurance Industry in Canada.* Insurance Bureau of Canada.

Joseph, R., Proverbs, D., & Lamond, J. (2015). Assessing the value of intangible benefits of property level flood risk adaptation (PLFRA) measures. *Nat Hazards*.

Messner, F., Penning-Rowsel, E., Green, C., Meyer, V., Tunstall, S., & van der Veen, A. (2007). *FLOODsite Report T09-06-01: Evaluating flood damages: guidance and recommendations on principles and methods.* Helmholtz: Helmholtz Centre for Environmental Research (UFZ).

Minano, A., & Peddle, S. (2018). *Using Flood Maps for Community Flood Risk Communication.* Partners for Action. Waterloo: Natural Resources Canada (NRCan-30006050733).

Moudrak, N., Hutter, M. A., & Feltmate, B. (2017). *When the Big Storms Hit: The Role of Wetlands to Limit Urban and Rural Flood Damage.* Waterloo: Intact Centre on Climate Adaptation, University of Waterloo.

Murdock, H. J. (2017). Resilience of Critical Infrastructure to Flooding: Quantifying the resilience of critical infrastructure of flooding in Toronto, Canada. Toronto.

Ontario Ministry of Natural Resources. (2002). *Technical Guide: River & Stream Systems: Flooding Hazard Limit.* Peterborough: Ontario Ministry of Natural Resources.

Tapsell, S. M., Tunstall, S. M., & Priest, S. J. (2009). *Developing a conceptual model of flood impacts upon human health.* London: Middlesex University.

Toronto and Region Conservation Authority. (2014). *The Living City Policies.* Toronto.

Toronto and Region Conservation Authority. (2018). *About TRCA*. Retrieved from Toronto and Region Conservation Authority: https://trca.ca/about/

Toronto and Region Conservation Authority. (2018). *Flood Plain Map*. Retrieved from Toronto and Region Conservation Authority: https://trca.ca/conservation/flood-risk-management/flood-plain-map-viewer/

Treasury Board of Canada Secretariat. (2007). *Canadian Cost-Benefit Analysis Gudie: Regulatory Proposals.* Government of Canada.

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Appendix A – Literature Review

After the Flood: The Impact of Climate Change on Mental Health and Lost Time from Work (2018) – Dana Decent and Dr. Blair Feltmate

This study examined the health effects on flooded and non-flooded residents three years after flooding in Burlington, Ontario, where severe precipitation cause atypical flooding in August of 2014.

The study found that flooded household members experienced significantly higher worry and stress (47% of those surveyed) within the first 30 days of experiencing a flood compared to those who were not flooded (11% of those surveyed). Furthermore, three years after flooding occurred, almost half of the respondents that experienced flooding still became worried when it rained compared to only 3% of those from the non-flooded households. These results indicate that flooding in homes bears risks beyond just those related to property damage, but also to the long term mental and physical health of flooded residents (Decent & Feltmate, 2018). Three factors contributed to elevated levels of worry and stress in the first 30 days following the flood: difficulty liaising with insurance providers; worsening or existing health issues; and water height in the basement

This study was also the first in Canada to quantify the number of days that household members were forced to take off of work due to flooding. 56% of the flooded households surveyed in Burlington (of those that had at least one working member) took an average of seven days off work. This number was 10 times the average number of days taken off work for non-flooded Ontario households (Decent & Feltmate, 2018). Additionally, the study proposes that when these workers return to work they will still be worried and distracted due to lingering financial impacts and stress from the flood event.

This report supported much of the previous research that IBI Group has done with regards to intangible damages and more importantly brought it into a Canadian context.

Toronto and Region Conservation Authority Flood Protection and Remedial Capital Works Program (Draft Report) (2013) - AMEC Environment & Infrastructure

AMEC used a Microsoft Access spatial database compiled by the TRCA to manage the Flood Vulnerable Areas and Flood Vulnerable Roads. Site Evaluation Factors were initially divided into, economic, social, and environmental categories, where each factor was measurable, and some factors were adjusted by the storm frequency to account for flooding impacts across the full flow regime.

Economic factors include the average annual damages as estimated through the Rapid Flood Damage Assessment Model.

Social factors include the following:

- Importance of area to viability of community: A flood event impacts communities in different ways depending on the land uses and the importance the community places in various key locations and area functions. Is it a tourist destination, historical or cultural area, central business district?
- Lead time for flood warning: This represents the time (hours) from when a storm commences to when a flood site begins to experience flooding. It is a measure of the amount of time available to adequately communicate a flood warning to the public and the time available for municipalities to implement an emergency response.
- Threat to Life: An indicator that measures the number of people potentially endangered by flooding conditions, determined using various flooding depths and

velocities based on MNR protocols, based on children and adults. A number of methods have been used to calculate threat to life in various literature. Due to the number of uncertainties and variables, the AMEC team decided that the threat to life factor inherently comes into play for all depths and velocities. Therefore, the number of people at risk was determined using land use, occupancy rates, and flood conditions.

- Ingress/Egress: The ability of residents and emergency response workers to safely move in and out of flooded areas. The MNR developed a vehicular access flood risk factor for both private and emergency vehicles based on the depth and velocity of water.
- Roadway Class: The Ministry of Transportation provides design flood criteria for each type of road. Each road classification has been provided a weighting within the evaluation matrix according to the road importance/usage and the flood criteria established by the Ministry of Transportation.

Environmental factors were eventually removed from the evaluation because of the variability in the assessment approach and associated results for determining environmental feature significance, and because of the lack of data for each of the environmental indicators. Instead, it was thought to be more appropriate to use the environmental factors later on in the planning and design process to address individual site flood risk related to the evaluation of remedial alternatives.

The AMEC report provided good insight into potential methodologies for weighting and ranking, as well as excellent background information specific to the study area.

Applying the Flood Vulnerability Index as a knowledge base for flood risk assessment (2012) - Dissertation by Stefania-Florina Balica, UNESCO IHE Delft Institute for Water Education

This dissertation broadly defines flood vulnerability as the extent to which a system is susceptible to floods due to exposure, in conjunction with its ability (or inability) to cope, recover, or adapt. The report takes into account social, economic, environmental, and physical factors, and rolls them into one flood vulnerability factor loosely based on the following equation:

Flood Vulnerability= Exposure + Susceptibility – Resilience

In addition to a detailed report, Balica developed an online tool that allows users to calculate flood vulnerability of a system based on dozens of inputs. The tool provides definitions and metrics for each variable and gave a broad range of possible variables for use in our flood risk ranking matrix.

National Strategy for Critical Infrastructure (2009) – Department of Public Safety and Emergency Preparedness

The Department of Public Safety and Emergency Preparedness defines Critical Infrastructure (CI) as “processes, systems, facilities, technologies, networks, assets, and services that are essential to the health, safety, security, or economic well-being of Canadians and the effective functioning of government”. It can be stand-alone, or it can interconnected and interdependent with other infrastructure. In the Canadian context, the National Strategy for Critical Infrastructure categorizes CI into ten groups:

1. Energy and utilities
2. Finance
3. Food

4. Transportation
5. Government
6. Information and communication technology
7. Health
8. Water
9. Safety
10. Manufacturing

The purpose of the National Strategy is to strengthen the resiliency of these critical infrastructure groups in Canada. It provides a framework for the functions of the sector networks, including:

- Promotion of timely information sharing;
- Identification of issues of national, regional, or sectoral concern;
- Use of subject-matter expertise from critical infrastructure sectors to provide guidance on current and future challenges; and
- Development of tools and best practices for strengthening the resiliency of critical infrastructure across the full spectrum of prevention, mitigation, preparedness, response, and recovery.

The report goes on to outline three strategic objectives:

1. Build partnerships to support and enhance critical infrastructure resiliency
2. Implement an all-hazards approach to risk management
3. Advance the timely sharing and protection of information among partners and key stakeholders

One of the most important items to come out of this report was a clear definition of critical infrastructure, and the ten categories of CI specific to Canada. It was important in identifying and eliminating certain risk factors before the stakeholder engagement workshop.

"Resilience of Critical Infrastructure to Flooding: Quantifying the resilience of critical infrastructure to flooding in Toronto, Canada" – Master's thesis by Heather Murdock

The aim of this thesis was to understand how CI fan be affected by flooding in order to ensure the basic functioning of the services it provides. It also looked to find the upstream dependencies and inputs for each critical infrastructure element and understand their downstream effects in the system.

This paper was particularly important in broadening our definition of resilience as it refers to the ability of a system to respond back to a shock and return to a functioning or equilibrium state. Murdock measures this in person days, with the goal of quantifying the resilience of critical infrastructure to flooding, and how to select measures that will have the greatest positive impact on resilience. The report uses the general equation to characterize flood risk:

$$\text{Flood Risk} = \text{Flood Hazard} * \text{Exposure} * \text{Flood Vulnerability}$$

It can also be calculated as a combination of probability and consequences:

$$\text{Flood Risk} = \text{Probability} * \text{Consequence (damages)}$$

Measures can be built into the system in order to increase resiliency. There are seven measures of resilient cities. They are:

1. Flexible
2. Redundant
3. Robust or hardened
4. Resourceful
5. Reflective
6. Inclusive
7. Integrated.

Redundancy has been referred to as “spare capacity purposely created within systems so that they can accommodate disruption”, and flexibility is defined as the ability of a system to change, evolve, and adapt to changing circumstances. Hardening systems are those measures that reduce direct damages by increasing the strength or tolerance to hazards.

The author gathered data in QGIS using Open Street Map (OSM) as a base layer with points, polylines and areas from the OSM plugin. Stakeholder information and relevant reports were used to add additional information on critical infrastructure networks. The resilience of CI to flooding was assessed by identifying the overlap between flood extent and vulnerable elements of CI. At each flood return period it was determined if at that particular water depth the element of infrastructure would be functioning or not. These thresholds were previously determined in workshops and individual meetings with CI operators or through documentation. The author determined CI dependencies so that higher order failures could be included in the impact assessment. Higher order impacts are referred to as cascading effects.

Some of the dependency relations are logical, such as the dependency of traffic lights on power, however some are less intuitive. For example, the dependency of the flood forecasting system on the telecommunications network, as the sensors use the mobile network to relay water level information.

First, the direct impact of flooding on CI within the case study area is assessed. Then, if CI is flooded, the number of people it affects and for how long is quantified for each return period. The delays due to flooding of CI are calculated and disruption is measured in person x days. The method of calculation depends on the CI system. Graphs of Expected Annual Disruption (EAD_{IS}) with Exceedance probability on the x-axis and disruption on the y-axis, quantified in terms of person days. The graph is constructed for the current system so that it can be compared to the system with resilience measures afterwards.

Appendix B – Data Fields and Building Inventory

This appendix contains the data fields that were used in the building inventory database, both as intermediate fields, and fields used in the damage calculations. The following tables are included within this appendix:

Table 1: Residential Building Class descriptions
Table 2: Residential Structure Class descriptions
Table 3: Commercial Building Class descriptions
Table 4: Commercial Structure Class descriptions
Table 5: Structure Geodatabase Attributes
Table 6: Look-up table for MPAC Code to Building Class
Table 7: Fields verified using google earth

Table 1: Residential Building Class Descriptions

Class	Description (Comm-Class:column K)
AA	Home with living space defined as equal to or more than 4,000 **SqFt**
A	Home with living space defined as equal to or between 3,999 and 2,400 **SqFt**
B	Home with living space defined as equal to or between 2,399 and 1,200 **SqFt**
C	Home with living space defined equal to or less than 1,199 **SqFt**
D	Mobile Home (does NOT have a Basement)
M	4 floors or less Apartment Bldg (was MW)
N	5 floors or more Apartment Bldg (was MA)

Table 2: Residential Structure Class Descriptions

Type	Description (Struct-Type:column L)
A	Residential - 1 Storey
B	Ranch-style (not used)
C	Split Level
D	Residential -2 Storey
E	4 floors or less Apartment Bldg
F	5 floors or more Apartment Bldg
A	Mobile home (was G)

Table 3: Commercial Building Class Descriptions

Commercial	Description (Comm-Class:column K)
A1	General Office
B1	Medical
C1	Shoes
C2	Clothing
C3	Stereos/TV
C4	Paper products
C5	Hardware/Carpet
C6	Retail
C7	Misc 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
O1	Hospital

Table 4: Commercial Structure Class Descriptions

Structure	Description (Struct-Type:column L)
S1	Office /Retail
S2	Industrial/Warehouse
S3	Hotel/ Motel
S4	High Rise / Residential
S5	Institutional

Table 5: Look-up Table for MPAC Code to Building Class

MPAC Code	Description	Corresponding Flood Damage Code
100	Vacant residential land not on water	NA
101	Second tier vacant lot – refers to location not being directly on the water but one row back from the water	NA
102	Conservation Authority land	NA
103	Municipal park (excludes Provincial parks, Federal parks, campgrounds)	NA
105	Vacant commercial land	NA
106	Vacant industrial land	NA
107	Provincial park	NA
108	Federal park	NA
110	Vacant residential/recreational land on water	NA
111	Island under single ownership	NA
112	Multi-residential vacant land	NA
113	Condominium development land - residential (vacant lot)	NA
114	Condominium development land - non residential (vacant lot)	NA
115	Lands in Transition - Value based on alternate use	NA
120	Water lot (entirely under water)	NA
125	Residential development land.	NA
127	Townhouse block - freehold units	NA
130	Non-buildable land (walkways, buffer/berm, storm water management pond,etc.)	NA
134	Land designated and zoned for open space	NA
140	Common land	NA
150	Mining lands - patented	NA

MPAC Code	Description	Corresponding Flood Damage Code
151	Mining lands - unpatented	NA
155	Land associated with power dam	NA
169	Vacant land condominium (residential)-defined land that's described by a condominium plan	NA
200	Farm property without any buildings/structures	NA
201	Farm with residence - with or without secondary structures; no farm outbuildings	NA
210	Farm without residence - with secondary structures; with farm outbuildings	NA
211	Farm with residence - with or without secondary structures; with farm outbuildings	NA
220	Farm without residence - with commercial/industrial operation	NA
221	Farm with residence - with commercial/industrial operation	NA
222	Farm with a winery	NA
223	Grain/seed and feed operation	L1
224	Tobacco farm	NA
225	Ginseng farm	NA
226	Exotic farms i.e emu, ostrich, pheasant, bison, elk, deer	NA
227	Nut Orchard	NA
228	Farm with gravel pit	NA
229	Farm with campground/mobile home park	NA
230	Intensive farm operation - without residence	NA
231	Intensive farm operation - with residence	B
232	Large scale greenhouse operation	L1
233	Large scale swine operation	NA
234	Large scale poultry operation	NA
235	Government - agriculture research facility - predominately farm property	N1
236	Farm with oil/gas well(s)	NA
240	Managed forest property, vacant land not on water	NA
241	Managed forest property, vacant land on water	NA
242	Managed forest property, seasonal residence not on water	B
243	Managed forest property, seasonal residence on water	B
244	Managed forest property, residence not on water	B
245	Managed forest property, residence on water	B
260	Vacant residential/commercial/ industrial land owned by a non-farmer with a portion being farmed	NA

MPAC Code	Description	Corresponding Flood Damage Code
261	Land owned by a non-farmer improved with a non-farm residence with a portion being farmed	B
262	Land owned by a farmer improved with a non-farm residence with a portion being farmed	B
301	Single family detached (not on water)	B
302	More than one structure used for residential purposes with at least one of the structures occupied permanently	B
303	Residence with a commercial unit	B
304	Residence with a commercial/ industrial use building	B
305	Link home – are homes linked together at the footing or foundation by a wall above or below grade.	B
306	Boathouse with residence above	C
307	Community lifestyle (not a mobile home park) – Typically, a gated community. The site is typically under single ownership. Typically, people own the structure.	B
309	Freehold Townhouse/Row house – more than two units in a row with separate ownership	B
311	Semi-detached residential – two residential homes sharing a common center wall with separate ownership.	B
313	Single family detached on water – year round residence	B
314	Clergy Residence	B
322	Semi-detached residence with both units under one ownership – two residential homes sharing a common center wall.	B
332	Typically a Duplex – residential structure with two self-contained units.	B
333	Residential property with three self-contained units	B
334	Residential property with four self-contained units	B
335	Residential property with five self-contained units	M
336	Residential property with six self-contained units	M
340	Multi-residential, with 7 or more self-contained units (excludes row-housing)	M
341	Multi-residential, with 7 or more self-contained residential units, with small commercial unit(s)	M
350	Row housing, with three to six units under single ownership	B
352	Row housing, with seven or more units under single ownership	B
360	Rooming or boarding house – rental by room/bedroom tenant(s) share a kitchen, bathroom and living quarters.	B

MPAC Code	Description	Corresponding Flood Damage Code
361	Bachelorette, typically a converted house with 7 or more self-contained units	B
363	House-keeping cottages - no American plan – typically a mini resort where you rent a cabin. No package plan available. All activities, meals, etc. are extra.	B
364	House-keeping cottages - less than 50% American plan – typically a mini resort where you rent a cabin and package plans are available. Activities, meals, etc. maybe included.	B
365	Group Home as defined in Claus 240(1) of the *Municipal Act, 2001* – a residence licensed or funded under a federal or provincial statute for the accommodation of three to ten persons, exclusive of staff, living under supervision in a single housekeeping unit and who, by reason of their emotional, mental, social or physical condition or legal status, require a group living arrangement for their well being.	B
366	Student housing (off campus) – residential property licensed for rental by students.	M
368	Residential Dockominium – owners receive a deed and title to the boat slip. Ownership is in fee simple title and includes submerged land and air rights associated with the slip. Similar to condominium properties, all common elements are detailed in the declaration.	NA
369	Vacant land condominium (residential - improved) – condo plan registered against the land.	NA
370	Residential Condominium Unit	M
371	Life Lease - No Redemption. Property where occupants have either no or limited redemption amounts. Typically Zero Balance or Declining Balance Life Lease Types.	B
372	Life Lease - Return on Invest. Property where occupants can receive either a guaranteed return or a market value based return on the investment. Typically, represented by Fixed Value, Indexed-Based, or Market Value Life Lease Types.	B
373	Cooperative housing – equity – Equity Co-op corporations are owned by shareholders. The owners of shares do not receive title to a unit in the building, but acquire the exclusive use of a unit and are able to participate in the building's management.	C

MPAC Code	Description	Corresponding Flood Damage Code
374	Cooperative housing - non-equity – Non-equity Co-op corporations are not owned by individual shareholders, the shares are often owned by groups such as unions or non-profit organizations which provide housing to the people they serve. The members who occupy the co-operative building do not hold equity in the corporation. Members are charged housing costs as a result of occupying a unit.	C
375	Co-ownership – percentage interest/share in the co-operative housing.	B
376	Condominium locker unit – separately deeded.	NA
377	Condominium parking space/unit – separately deeded.	NA
378	Residential Leasehold Condominium Corporation – single ownership of the development where the units are leased.	M
379	Residential phased condominium corporation – condominium project is registered in phases.	M
380	Residential common elements condominium corporation – consists only of the common elements not units.	M
381	Mobile home – one or more mobile home on a parcel of land, which is not a mobile home park operation.	D
382	Mobile home park – more than one mobile home on a parcel of land, which is a mobile park operation.	D
383	Bed and breakfast establishment	B
385	Time-share, fee simple	NA
386	Time share, right-to-use	NA
391	Seasonal/recreational dwelling - first tier on water	B
392	Seasonal/recreational dwelling - second tier to water	B
395	Seasonal/recreational dwelling - not located on water	B
400	Small Office building (generally single tenant or owner occupied under 7,500 s.f.)	A1
401	Small Medical/dental building (generally single tenant or owner occupied under 7,500 s.f.)	O1
402	Large office building (generally multi - tenanted, over 7,500 s.f.)	A1
403	Large medical/dental building (generally multi - tenanted over 7,500 s.f.)	O1
405	Office use converted from house	A1
406	Retail use converted from house	C6
407	Retail lumber yard	C6
408	Freestanding Beer Store or LCBO - not associated with power or shopping centre	E1

MPAC Code	Description	Corresponding Flood Damage Code
409	Retail - one storey, generally over 10,000 s.f.	C6
410	Retail - one storey, generally under 10,000 s.f.	C6
411	Restaurant - conventional	I1
412	Restaurant - fast food	I1
413	Restaurant - conventional, national chain	I1
414	Restaurant - fast food, national chain	I1
415	Cinema/movie house/drive-in	M1
416	Concert hall/live theatre	M1
417	Entertainment complex - with a large cinema as anchor tenant	M1
419	Automotive service centre, highway - 400 series highways	NA
420	Automotive fuel station with or without service facilities	G1
421	Specialty automotive shop/auto repair/ collision service/car or truck wash	G1
422	Auto dealership	G1
423	Auto dealership - independent dealer or used vehicles	G1
425	Neighbourhood shopping centre - with more than two stores attached, under one ownership, with anchor - generally less than 150,000 s.f.	C7
426	Small box shopping centre less than 100,000 s.f. minimum 3 box stores with one anchor (large grocery or discount store)	C7
427	Big box shopping/power centre greater than 100,000 s.f. with 2 or more main anchors such as discount or grocery stores with a collection of box or strip stores and in a commercial concentration concept	C7
428	Regional shopping centre	C7
429	Community shopping centre	C7
430	Neighbourhood shopping centre - with more than 2 stores attached, under one ownership, without anchor - generally less than 150,000 s.f.	C7
431	Department store	C2
432	Banks and similar financial institutions, including credit unions - typically single tenanted, generally less than 7,500 s.f.	K1
433	Banks and similar financial institutions, including credit unions - typically multi tenanted, generally greater than 7,500 s.f.	K1
434	Freestanding supermarket	E1
435	Large retail building centre, generally greater than 30,000 s.f.	C5

MPAC Code	Description	Corresponding Flood Damage Code
436	Freestanding large retail store, national chain - generally greater than 30,000 s.f.	C6
438	Neighbourhood shopping centre with offices above	A1
441	Tavern/public house/small hotel	H1
444	Full service hotel	H1
445	Limited service hotel	H1
446	Apartment hotel	H1
447	Condominium Hotel Unit	H1
448	Resort Condominium	H1
450	Motel	H1
451	Seasonal motel	H1
460	Resort hotel	H1
461	Resort lodge	H1
462	Country inns & small inns	H1
463	Fishing/hunting lodges/resorts	H1
465	Child and community oriented camp/resort	H1
470	Multi-type complex - defined as a large multi-use complex consisting of retail/office and other uses (multi res/condominium/hotel)	C7
471	Retail or office with residential unit(s) above or behind - less than 10,000 s.f. gross building area (GBA), street or onsite parking, with 6 or less apartments, older downtown core	C7
472	Retail or office with residential unit(s) above or behind - greater than 10,000 s.f. GBA, street or onsite parking, with 7 or more apartments, older downtown core	C7
473	Retail with more than one non-retail use	C7
475	Commercial condominium	C7
476	Commercial condominium (live/work)	C7
477	Retail with office(s) - less than 10,000 s.f., GBA with offices above	C7
478	Retail with office(s) - greater than 10,000 s.f., GBA with offices above	C7
480	Surface parking lot - excludes parking facilities that are used in conjunction with another property	NA
481	Parking garage - excludes parking facilities that are used in conjunction with another property	NA
482	Surface parking lot - used in conjunction with another property	NA
483	Parking garage - used in conjunction with another property	NA
486	Campground	NA
487	Billboard	NA

MPAC Code	Description	Corresponding Flood Damage Code
489	Driving range/golf centre - stand alone, not part of a regulation golf course	NA
490	Golf course	NA
491	Ski resort	NA
492	Marina - located on waterfront - defined as a commercial facility for the maintenance, storage, service and/or sale of watercraft	NA
493	Marina - not located on waterfront - defined as a commercial facility for the maintenance, storage, service and/or sale of watercraft	NA
495	Communication towers - with or without secondary communication structures	N1
496	Communication buildings	N1
500	Mines - active	L1
501	Mines - inactive, including properties where closure plans invoked	L1
502	Mine tailings site associated with an active mine	L1
503	Mine tailings site not associated with an active mine	L1
504	Oil/gas wells	L1
505	Sawmill/lumber mill	L1
506	Forest products - including value added plywood/veneer plants	L1
510	Heavy manufacturing (non-automotive)	L1
511	Pulp and paper mill	C4
512	Cement/asphalt manufacturing plant	L1
513	Steel mill	L1
514	Automotive assembly plant	G1
515	Shipyard/dry-dock	L1
516	Automotive parts production plant	G1
517	Specialty steel production (mini-mills)	L1
518	Smelter/ore processing	L1
519	Foundry	L1
520	Standard industrial properties not specifically identified by other industrial Property Codes	L1
521	Distillery/brewery	L1
522	Grain elevators - Great Lakes waterway	NA
523	Grain handling - Primary elevators (including feed mills)	L1
525	Process elevators - flour mills, oilseed crushing, malt houses	L1
527	Abattoir/slaughter house/rendering plants	L1
528	Food processing plant	L1
529	Freezer plant/cold storage	L1

MPAC Code	Description	Corresponding Flood Damage Code
530	Warehousing	L1
531	Mini-warehousing	L1
532	Dry Cleaning Plant	J1
535	Research and development facilities	N1
540	Other industrial (all other types not specifically defined)	L1
541	Printing plant	C4
544	Truck terminal	G1
545	Major distribution centre	L1
550	Petro-chemical plant	L1
551	Oil refinery	L1
552	Tank farm	L1
553	Bulk oil/fuel distribution terminal	L1
555	O.P.G. Hydraulic Generating Station	L1
556	O.P.G. Nuclear Generating Station	L1
557	O.P.G. Fossil Generating Station	L1
558	Hydro One Transformer Station	L1
559	MEU Generating Station	N1
560	MEU Transformer Station	N1
561	Hydro One Right-of-Way	L1
562	Private Hydro Rights-of-Way	L1
563	Private Hydraulic Generating Station	L1
564	Private Nuclear Generating Station	L1
565	Private Generating Station (Fossil Fuels and Cogen)	L1
566	Private Transformer Station	L1
567	Wind Turbine	NA
568	Solar//Photo Voltaic Electricity Generating Facility	L1
575	Industrial condominium	L1
580	Industrial mall	L1
588	Pipelines - transmission, distribution, field & gathering and all other types including distribution connections	NA
589	Compressor station - structures and turbines used in connection with transportation and distribution of gas	NA
590	Water treatment/filtration/water towers/pumping station	N1
591	Sewage treatment/waste pumping/waste disposal	N1
592	Dump/transfer station/incineration plant/landfill	L1
593	Gravel pit, quarry, sand pit	L1
594	Peat moss operation	L1
595	Heat or steam plant	L1
596	Recycling facility	L1
597	Railway right-of-way	NA

MPAC Code	Description	Corresponding Flood Damage Code
598	Railway buildings and lands described as assessable in the *Assessment Act*	G1
599	GO transit station/rail yard	G1
601	Post secondary education - university, community college, etc.	N1
602	Multiple occupancy educational institutional residence located on or off campus	N1
605	School (elementary or secondary, including private)	N1
608	Day Care	N1
610	Other educational institution (e.g. schools for the blind, deaf, special education, training)	N1
611	Other institutional residence	N1
621	Hospital, private or public	O1
623	Continuum of care seniors facility	O1
624	Retirement/nursing home (combined)	O1
625	Nursing home	O1
626	Old age/retirement home	M
627	Other health care facility	O1
630	Federal penitentiary or correctional facility	N1
631	Provincial correctional facility	N1
632	Other correctional facility	N1
700	Place of worship - with a clergy residence	N1
701	Place of Worship - without a clergy residence	N1
702	Cemetery	NA
703	Cemetery with non-internment services	NA
704	Crematorium	NA
705	Funeral Home	C6
710	Recreational sport club - non commercial (excludes golf clubs and ski resorts)	N1
711	Bowling alley	M1
713	Casino	I1
715	Racetrack - auto	G1
716	Racetrack - horse, with slot facility	NA
717	Racetrack - horse, without slot facility	NA
718	Exhibition grounds/fair grounds	NA
720	Commercial sport complex	NA
721	Non-commercial sports complex	NA
722	Professional sports complex	NA
725	Amusement park	NA
726	Amusement park - large/regional	NA
730	Museum and/or art gallery	NA
731	Library and/or literary institutions	N1

MPAC Code	Description	Corresponding Flood Damage Code
733	Convention, conference, congress centre	N1
734	Banquet hall	I1
735	Assembly hall, community hall	N1
736	Clubs - private, fraternal	I1
737	Federal airport	G1
738	Provincial airport	G1
739	Local government airport	G1
740	Airport leasehold	G1
741	Airport Authority	G1
742	Public transportation - easements and rights	NA
743	International bridge/tunnel	NA
744	Private airport/hangar	G1
745	Recreational airport	G1
746	Subway station	G1
748	Transit garage	G1
749	Public transportation - other	G1
750	Scientific, pharmaceutical, medical research facility (structures predominantly other than office)	N1/F1
755	Lighthouses	NA
760	Military base or camp (CFB)	N1
761	Armoury	N1
762	Military education facility	N1
805	Post office or depot	C4
806	Postal mechanical sorting facility	L1
810	Fire Hall	N1
812	Ambulance Station	N1
815	Police Station	N1
822	Government - agricultural research facility - predominantly non farm property (office building, laboratories)	N1
824	Government - wharves and harbours	NA
826	Government - special educational facility	N1
828	Government - canals and locks	NA
830	Government - navigational facilities	N1
832	Government - historic site or monument	N1
840	Port authority - port activities	NA
842	Port authority - other activities	NA

Table 6: Fields Verified using Google Earth

Field	Description
Offset	the height of the main floor from grade
Offset basis	the location on the parcel from which the elevation was measured (e.g. max, min, or mean), relating to the assumed offset variations around the perimeter of the building.
Class Main	the class of building's main floor according to the depth-damage curves.
Class Upper	the class of the building's upper floors according to depth-damage curves.
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
Basement	Yes or No for the presence of a basement or underground parking
Comments	special notes relating to the building. 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 and were labeled NS (No Street View)

Appendix C – Residential Classification Scheme

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.

Residential Classification - Typical Examples

AA

AA

A

A

B

B

Residential Classification - Typical Examples

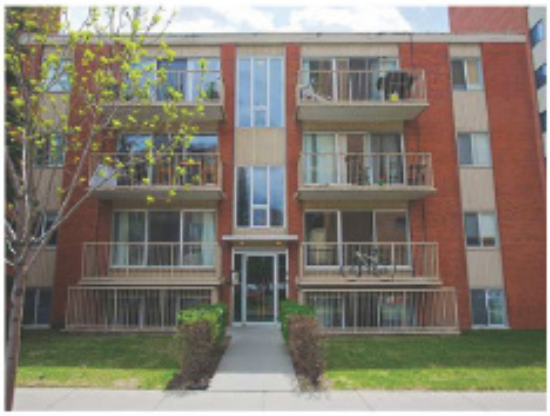
D

D

MA

MA

MW



MW

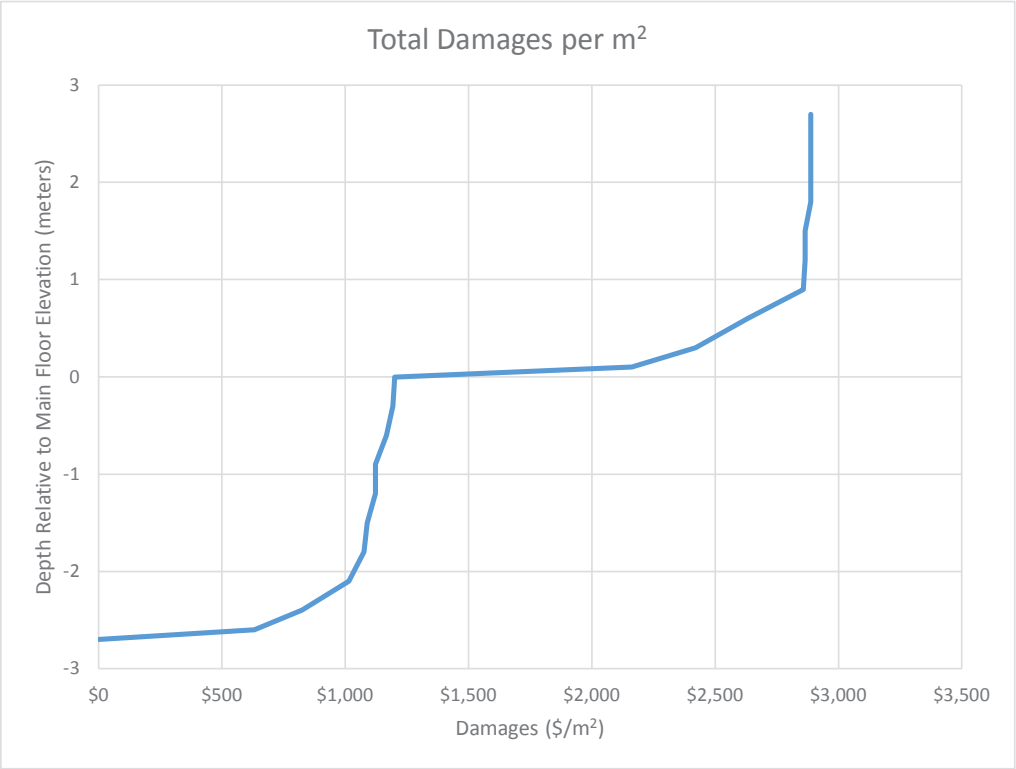
Appendix D – Depth-Damage Curves and Values

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

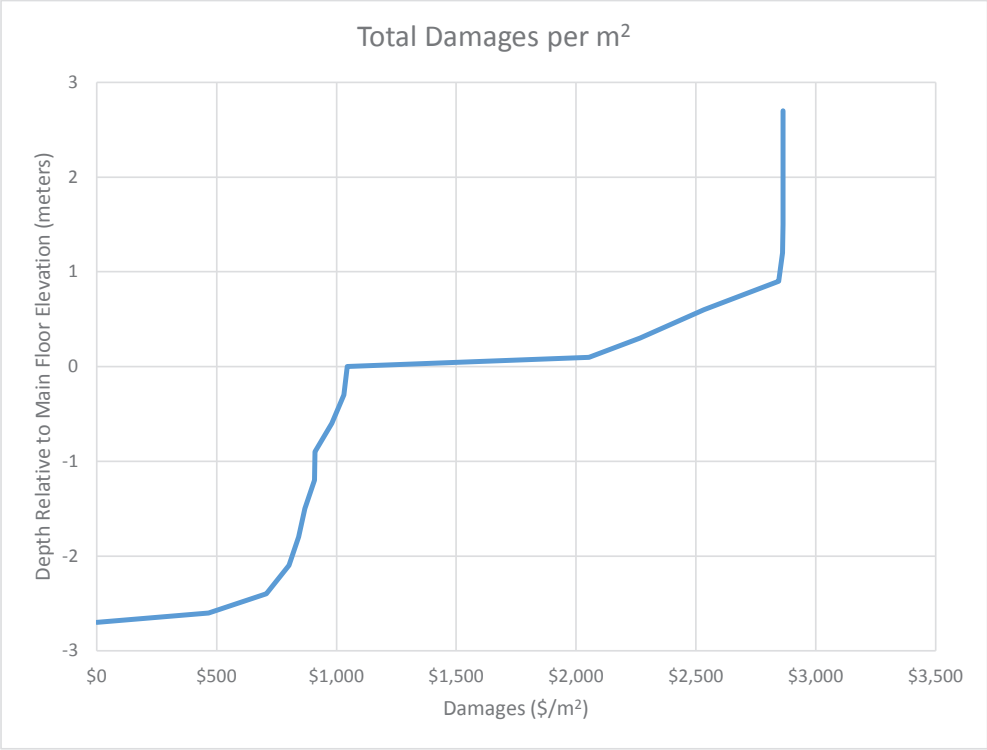


Damage Curves and Values - Class A - Residential Two-Storey

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

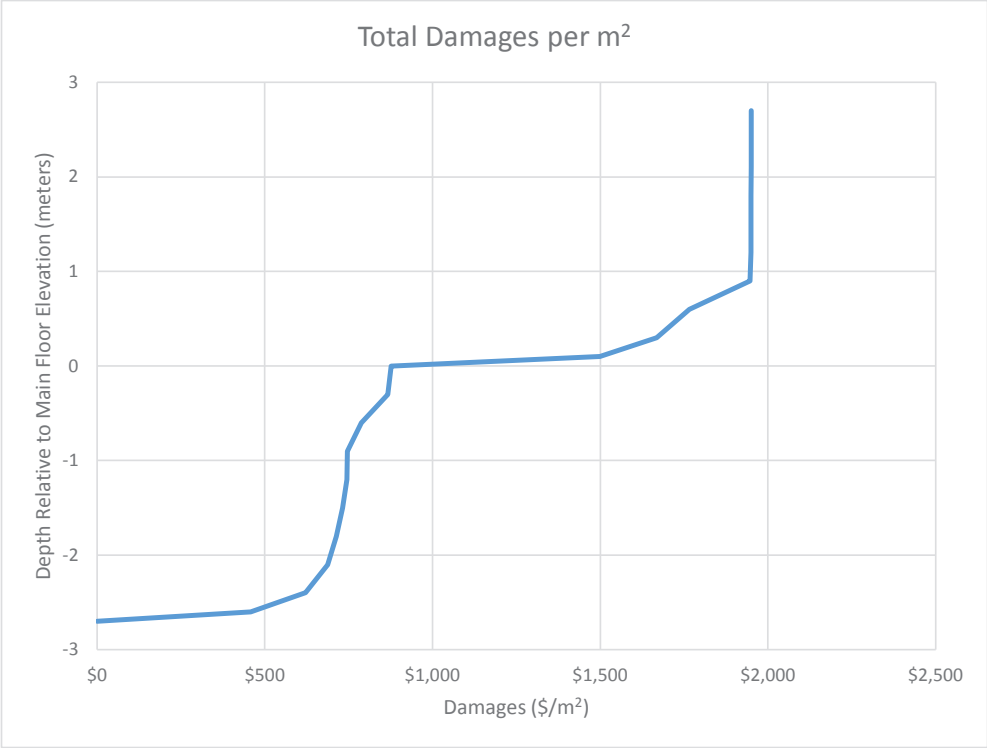


Damage Curves and Values - Class B - Residential One-Story

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

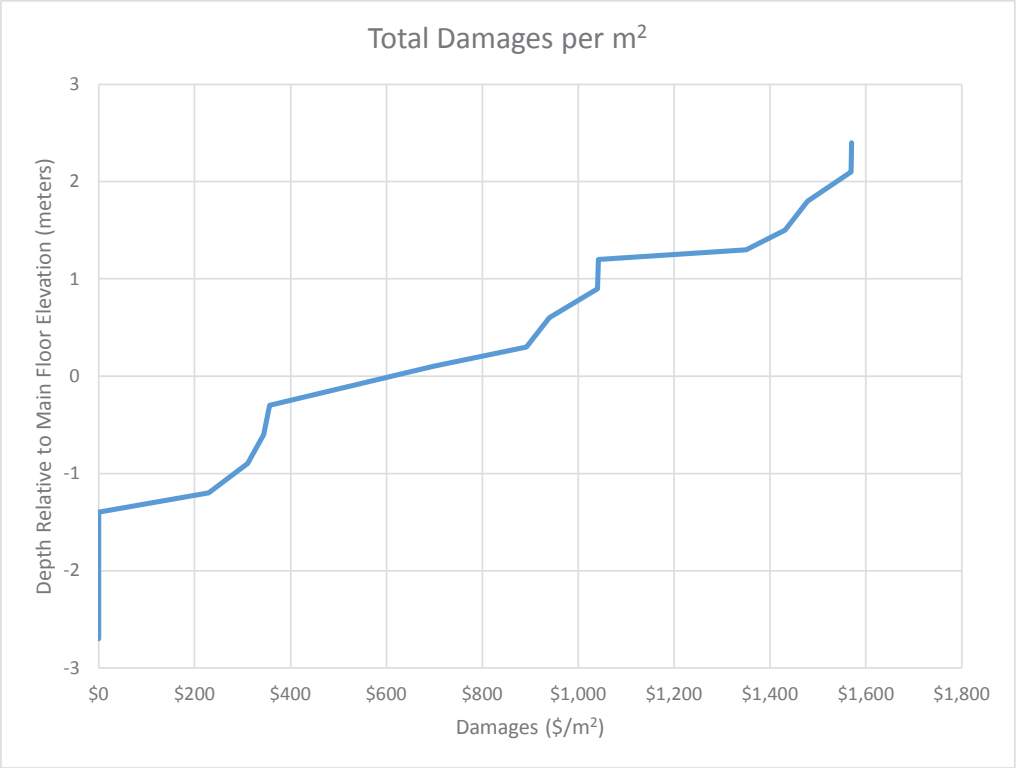


Damage Curves and Values - Class B - Residential Split Level

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

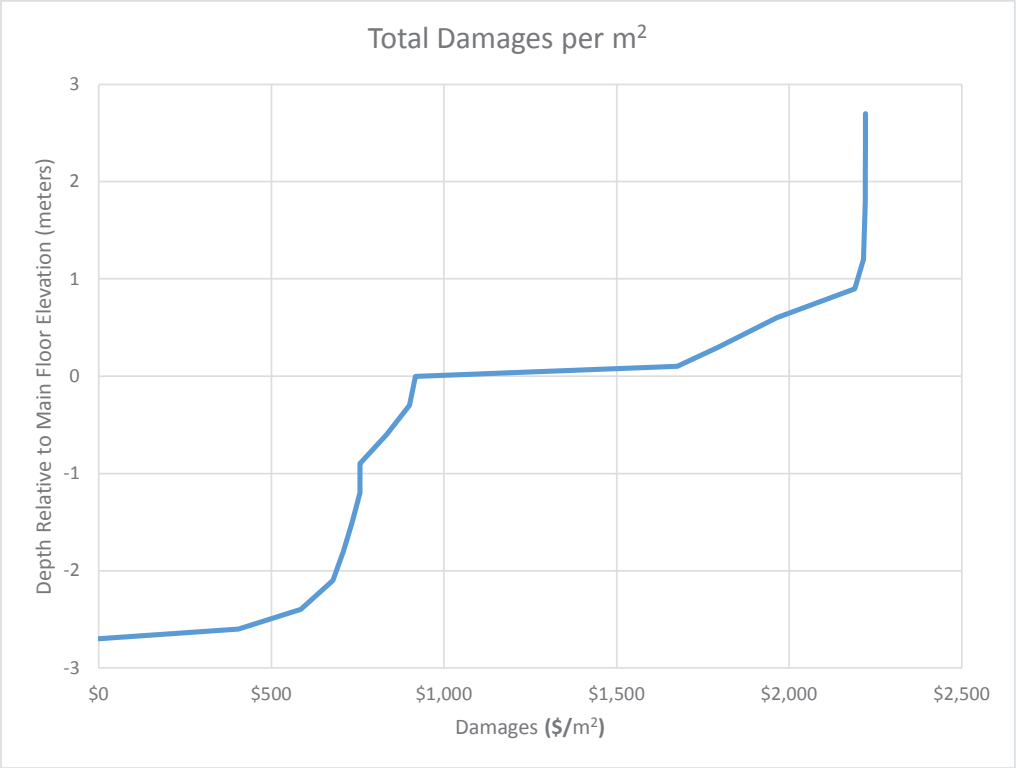


Damage Curves and Values - Class B - Residential Two-Storey

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

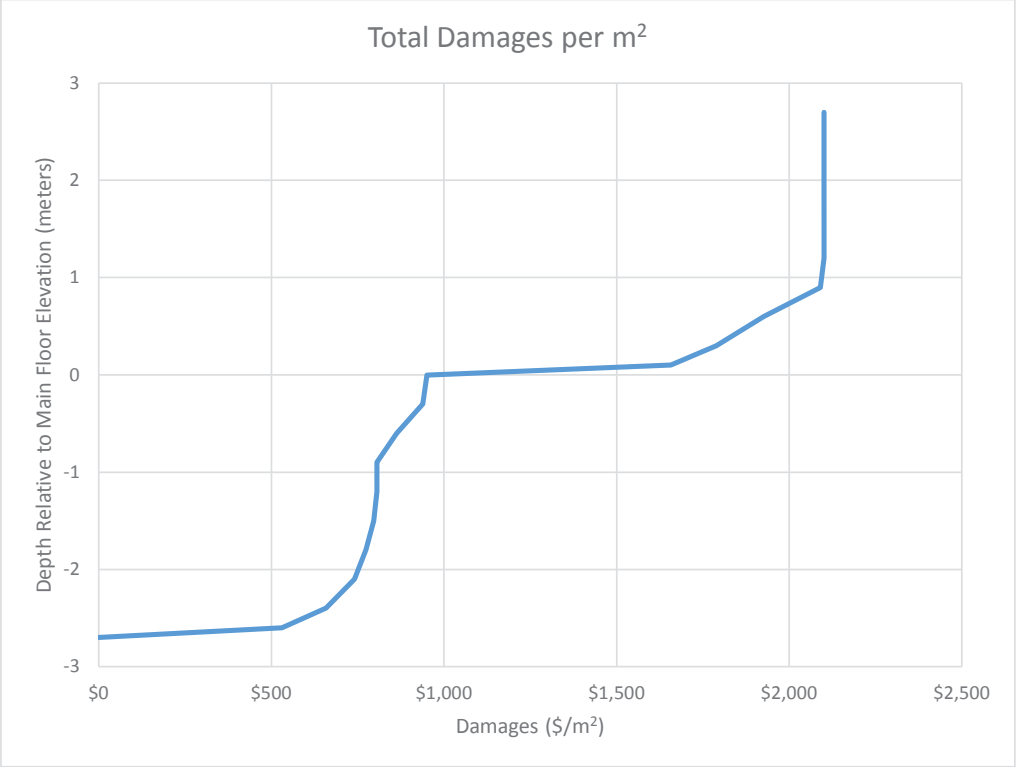


Damage Curves and Values - Class C - Residential One-Storey

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

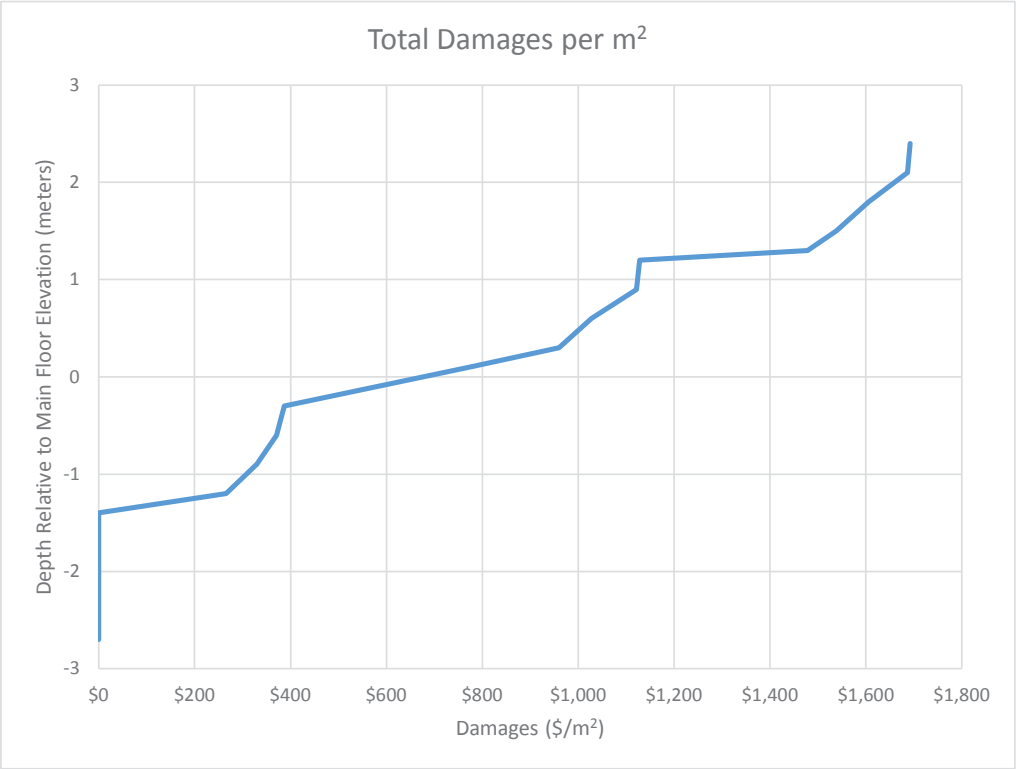


Damage Curves and Values - Class C - Residential Split Level

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

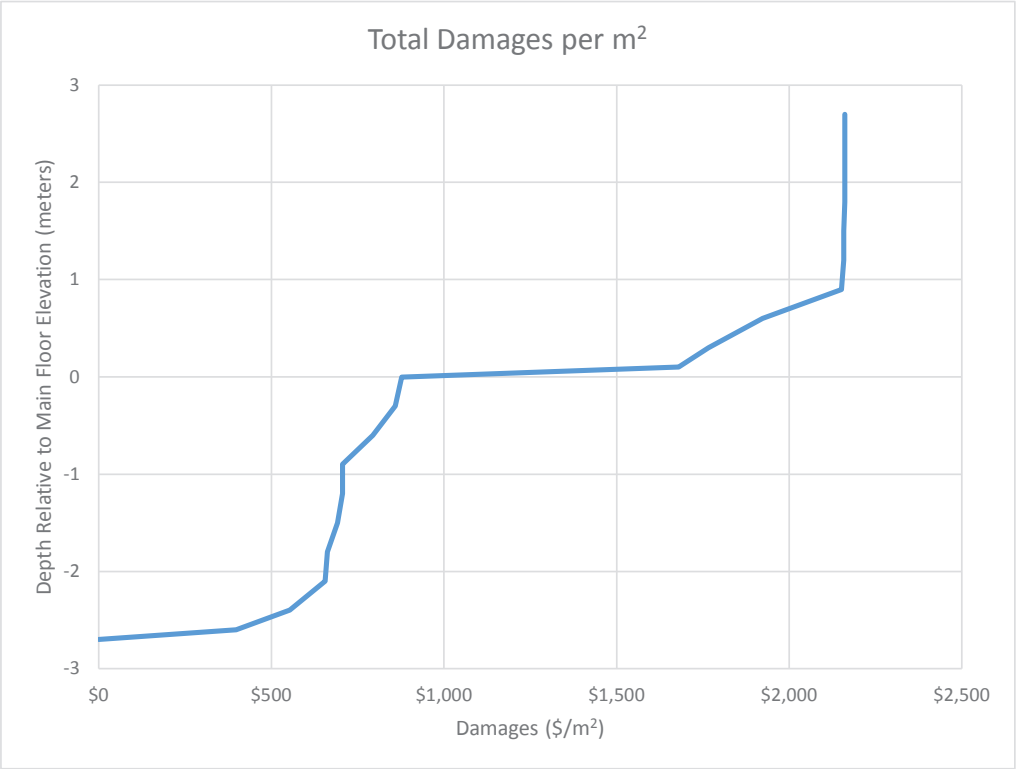


Damage Curves and Values - Class C - Residential Two-Storey

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

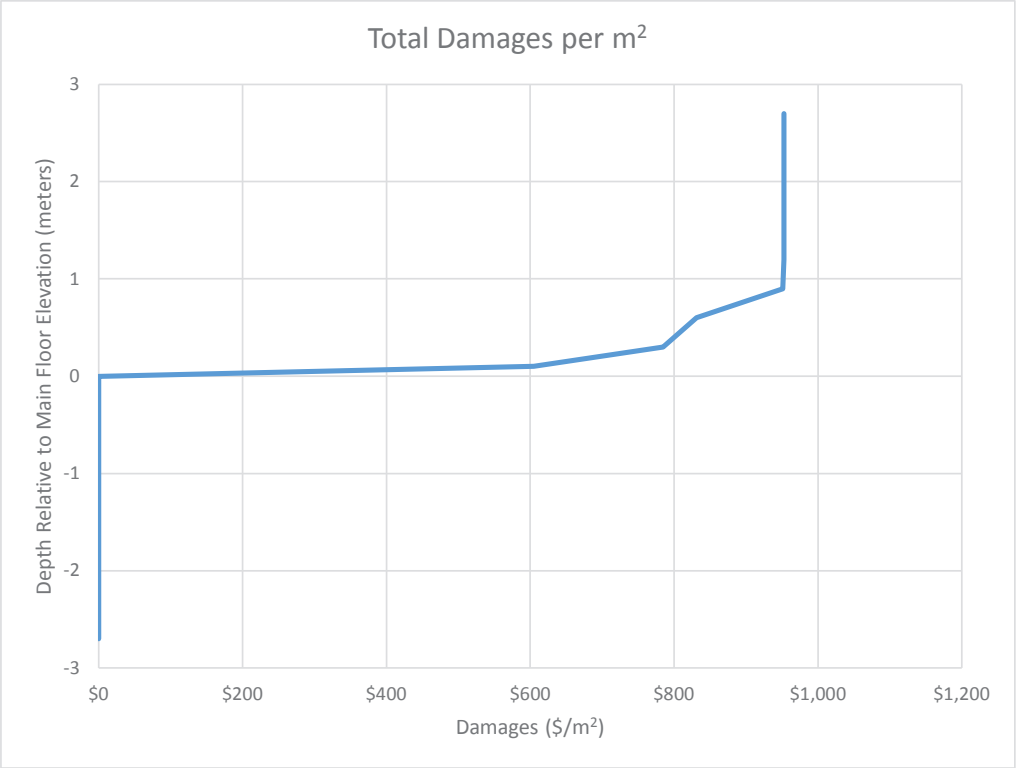
[1]distance between floors is variable in model, 2.7m illustrated

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



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

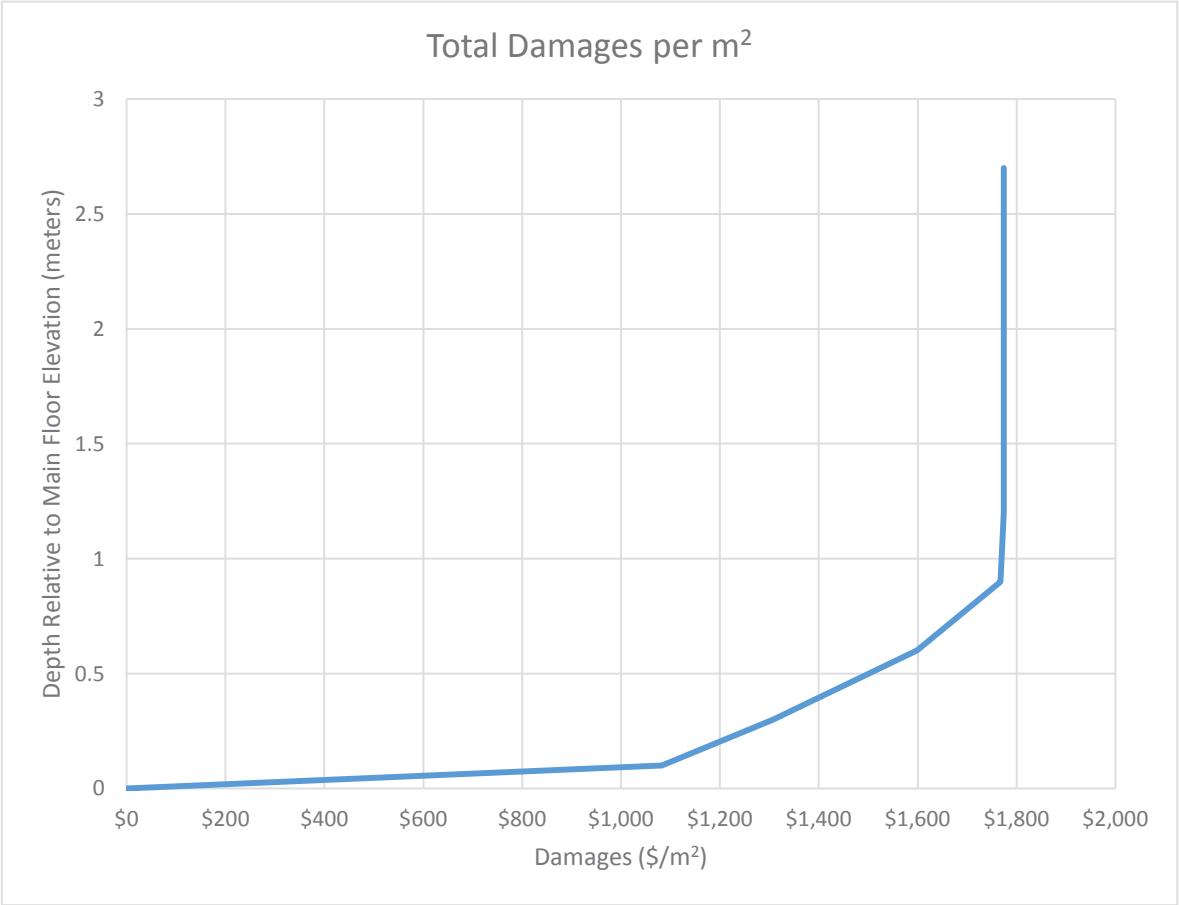
One Storey Mobile Home (No Basement)					
Depth relative to main floor	Main Floor Contents	Main Floor Structure	Basement Contents	Basement Structure	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$0	$0	$0
-2.4	$0	$0	$0	$0	$0
-2.1	$0	$0	$0	$0	$0
-1.8	$0	$0	$0	$0	$0
-1.5	$0	$0	$0	$0	$0
-1.2	$0	$0	$0	$0	$0
-0.9	$0	$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



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

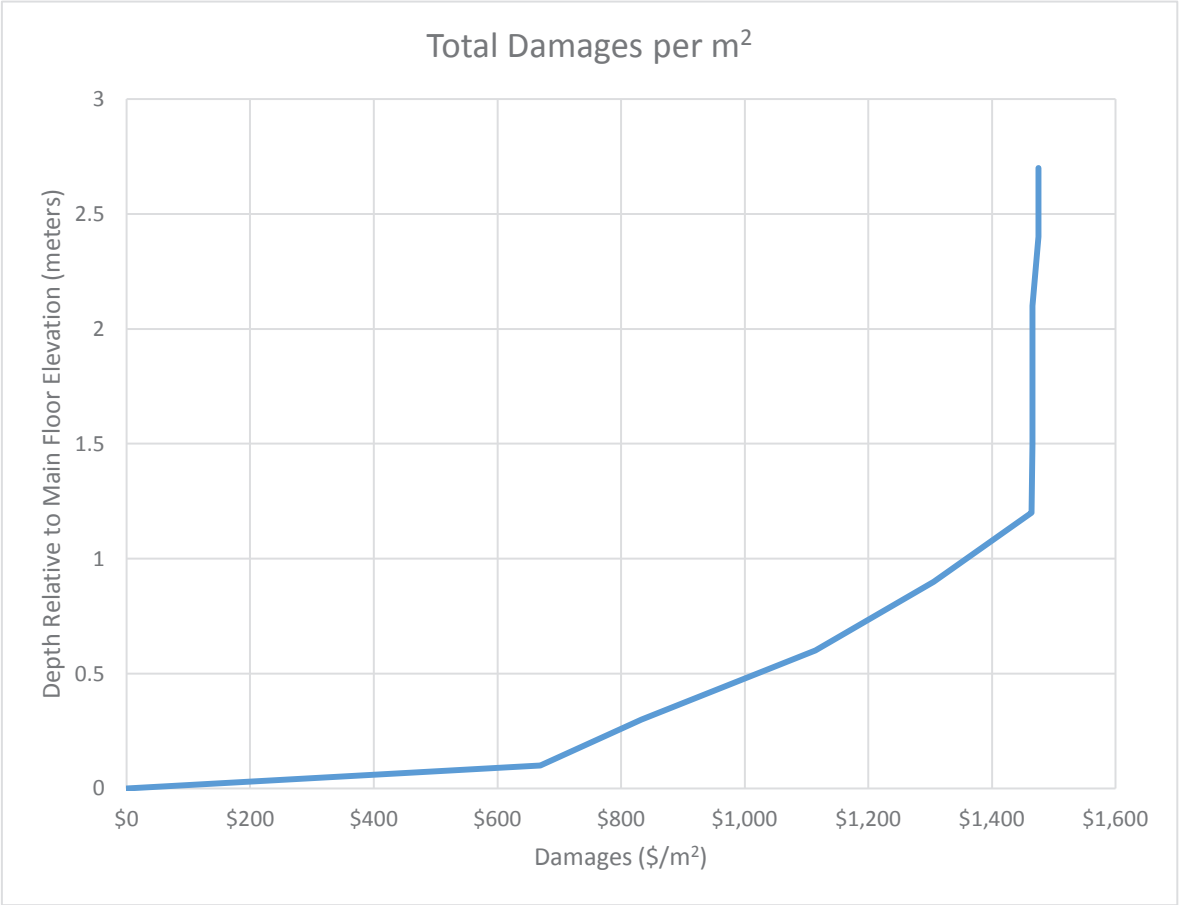
*Underground Parking damages are $215/m^2



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

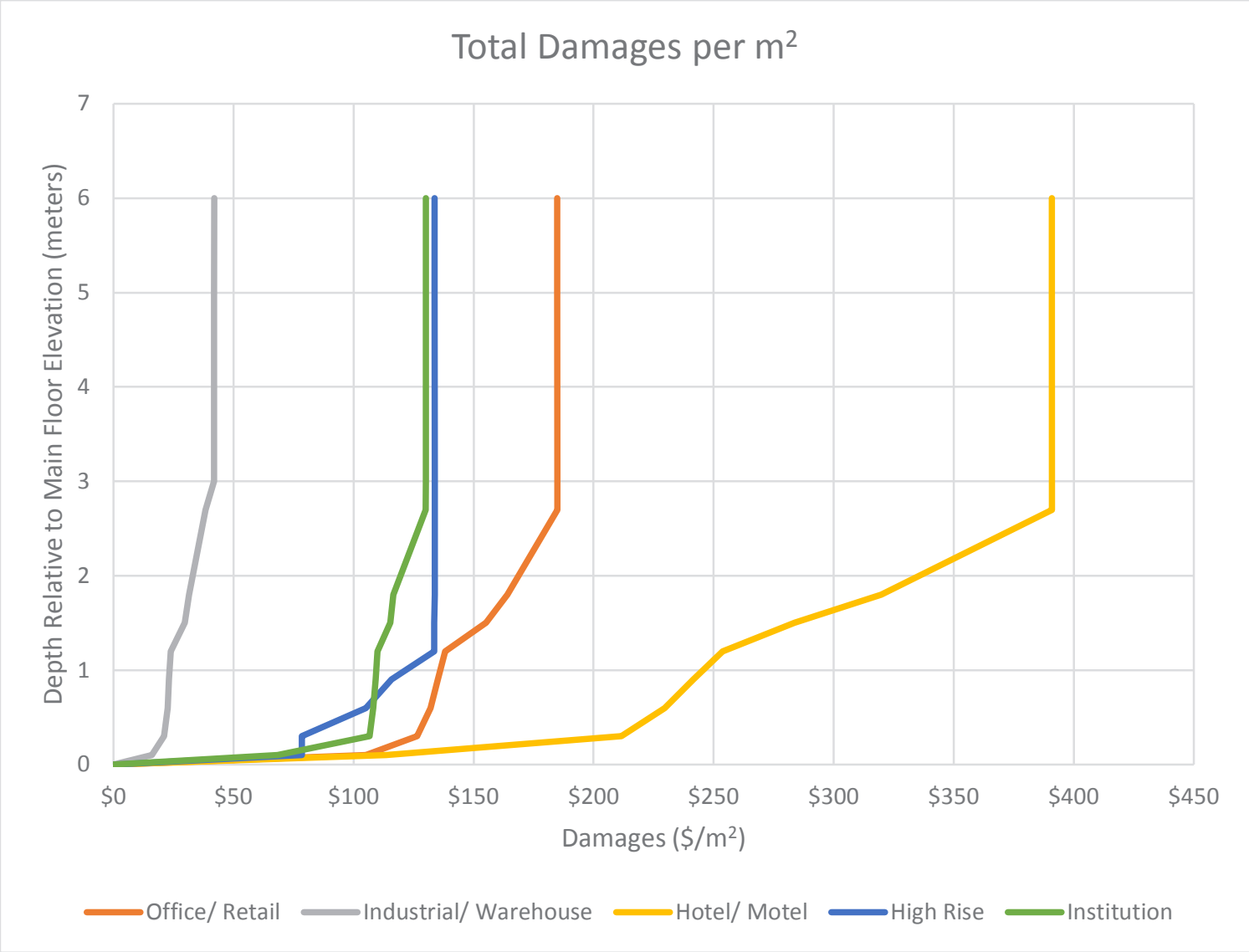


Damage Curves and Values - Non-Residential Structure

	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

Damage Curves and Values - Non-Residential Structure



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

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

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

Damage Curves and Values - Non-Residential Contents