# Town of Tecumseh Coastal Flood Risk Assessment

Prepared for:

Town of Tecumseh

December 23, 2022

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ONE WORLD

In association with:

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*Tecumseh Shoreline Looking West, September 28, 2020*

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# EXECUTIVE SUMMARY

The Town of Tecumseh is located on the south shore of Lake St. Clair, east of the inlet to the Detroit River. Over time the Town has developed on low-lying lands adjacent to the lake and consequently has high exposure to coastal and rainfall flooding events. A previous study by Dillon Consulting (Storm Drainage Master Plan) investigated the risk and vulnerabilities associated with rainfall flooding and the existing storm water and sanitary sewer systems. The current investigation by Zuzek Inc., SJL Engineering Inc., Foresight Management Consulting, and Dillon Consulting addresses flooding associated with coastal storms that inundates the waterfront properties and is capable propagating over Riverside Drive and flooding the interior lands of the Town.

A detailed field data collection campaign was completed to support the analytical work and numerical modelling of coastal flooding relating to lake storms and the joint occurrence of lake storms and rainfall events. Evaluated scenarios included both extreme events based on historical data, and events that included the projected impacts of climate change on lake levels and wave exposure. The risk to existing buildings and road infrastructure was evaluated for all simulated scenarios, including potential economic damages to buildings and contents. Flood mitigation strategies were developed and shared with the public at three meetings in 2000 and 2021. The key technical findings, feedback from the public, and recommendations for next steps are summarized as follows:

Key technical findings – the main findings from the study include:

- Low-lying waterfront lots, low-crested shore protection, and low-lying roads and interior land all contribute to high coastal flood vulnerability in Tecumseh. The potential economic damages to buildings and contents for the 100-year coastal flood range from $24-$37 million based on assessed property values (an under-estimate based on current market values) and flood-damage relationships for flooding above first floor elevations. Standing water could reach the exterior basement foundation walls of over 800 buildings. The potential for damages from basement flooding during a coastal storm were not evaluated due to a lack of information on lowest openings for windows and doors, but would be significant.
- When higher lake levels due to climate change were considered for the 100-year coastal storm, the potential economic damages to buildings and contents increased dramatically to $124 to $188 million. The flood waters would reach over 2,200 exterior basement foundations, but basement damages and storm sewer surcharging could not be estimated for this study.
- Several shore protection upgrade scenarios were developed to reduce the rate of wave overtopping along the shoreline during a coastal flood and the resultant interior flooding. The number of shoreline properties implicated ranges from 30 to 210, and the cost of the shore protection upgrades range from $1 to $13 million. All the scenarios featured a positive benefit-cost ratio, with some being as high as 10 (i.e., avoided damages were 10 times the capital cost of upgrades). Generally, as the amount of money invested in shore protection upgrades increase, so to does the avoided economic damages due to flooding.

- There is a very high risk of sanitary sewer surcharging during a coastal flood north of County Road 22, which could lead to extensive basement flooding. Numerous programs are ongoing to reduce this threat. These efforts should continue.
- Due to the depth of flooding on Tecumseh roads, emergency ingress and egress will be challenged during a severe coastal flood. Further emergency planning with depth of flooding maps should be completed.

Feedback from Public Information Centre (PIC) Meetings - attendance at the three public meetings was 138, which was very positive given the study was completed during the COVID pandemic and all meetings were held virtually. Some key feedback from the meetings:

- Three priorities were established for evaluating flood risk reduction solutions at the first PIC and supported by the participants as follows:
  - 77% wanted long-term solutions.
  - 69% indicated cost to landowners was important.
  - 54% identified cost to the Town of Tecumseh as a priority.
- At the second PIC, the following short- and long-term solutions to coastal flooding were generated by the participants:
  - Continue upgrading the pump stations.
  - Increase the height of existing seawalls.
  - Review development policies to reduce new building on hazardous lands.
  - Construct temporary interior flood storage basins.
  - Assist landowners with a new program to prevent basement flooding.
- The preferred long-term approaches to reduce coastal flooding by the participants at PIC3 were:
  - 58% - community scale program to upgrade existing shore protection.
  - 17% - a new flood barrier constructed along Riverside Drive and Brighton Road.
  - 25% - other (less costly options and additional storm and sanitary sewer investment).

Recommendations for Next Steps – the primary recommendations from the study are summarized in Section 7.3, and include the following:

- Continue with design work and construction plans to upgrade storm sewer infrastructure and capacity (e.g., pumping stations) to address rainfall flooding.
- Continue with a multi-facetted approach to reducing the potential for basement flooding from sanitary sewer surcharging during both rainfall and coastal flooding events.
- Further engagement on the feasibility of a community standard for flood protection should be investigated with the landowners and stakeholders of Tecumseh. If there is support for a community-scale upgrade program, further steps should be pursued with landowners and stakeholders, including planning, concept development, evaluation of funding models, final design, and construction.
- The technical findings and data from the flood study should be shared with the Essex Region Conservation Authority to pursue updated flood hazard mapping for the Town of Tecumseh.

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# 1.0 INTRODUCTION

The Town of Tecumseh is located on the south shore of Lake St. Clair between the City of Windsor to the west and Municipality of Lakeshore to the east. The Town shoreline is approximately 4.6 km in length and the study area extends inland to the Canadian National (CN) Railway line, as noted in Figure 1.1

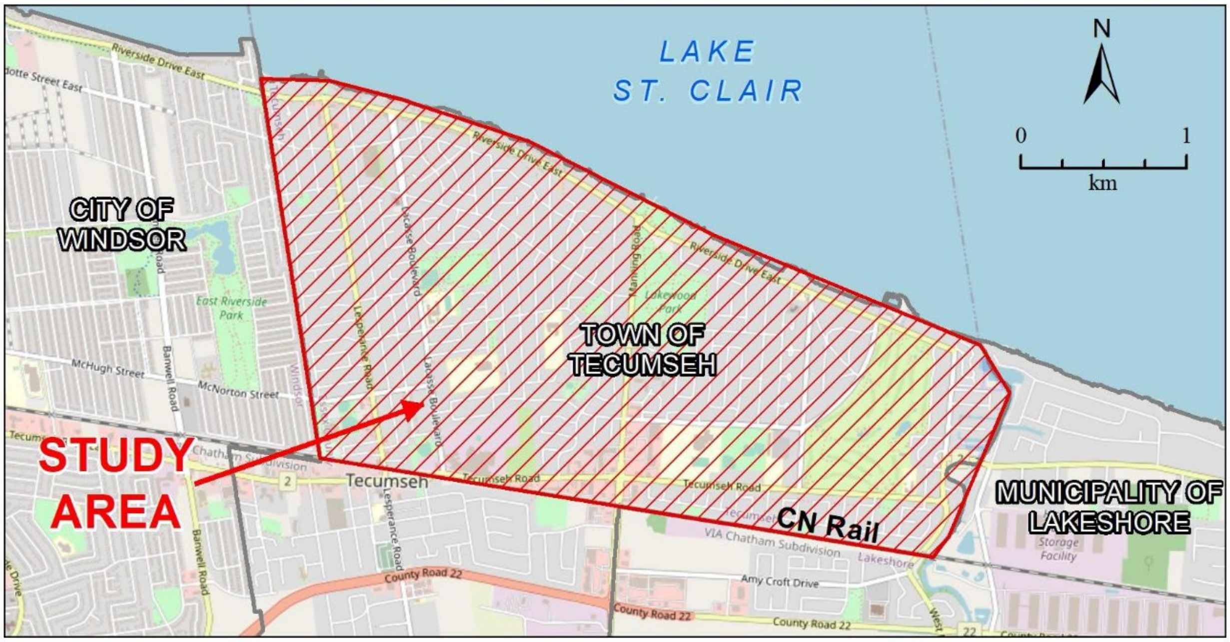



Figure 1.1 Study Area

Zuzek Inc. in association with SJL Engineering Inc., Foresight Management Consulting, and Dillon Consulting (collectively the Consulting Team) were retained by the Town of Tecumseh to complete a coastal flood risk assessment. The densely developed shoreline and low-lying interior lands are vulnerable to both coastal (lake) and rainfall flooding events. The scope of the investigation and relevant previous studies are described in the following report sections.

## 1.1 Scope of Investigation

To assess the dual threat of interior flooding during extreme rainfall events and coastal storms leading to wave overtopping events, the Consulting Team completed an innovative flood risk assessment for the Town of Tecumseh, including:

- Parcel level survey of existing shore protection structures and nearshore bathymetric conditions (depths and substrate).
- Development of a property parcel database for the entire study area (lake and interior) including assessed value, type of building (residential versus commercial), main floor elevation, and the presence of a basement.
- Statistical analysis of lake levels, storm surge, wave heights, and rainfall events, including the projected impacts of climate change.

- Assessment of coastal flooding due to wave uprush and wave overtopping at the shoreline and interior flooding due to rainfall events using a hydrologic and hydraulic modelling package known as PCSWMM 2017.

- Flood maps and economic damage calculations for 11 scenarios were generated. Economic damages to buildings and contents were estimated, and the potential for basement flooding evaluated.

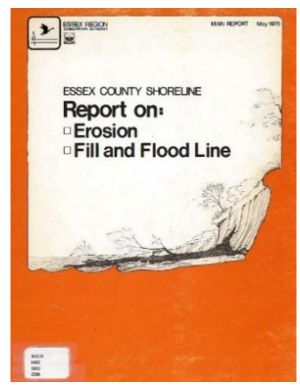
- Conceptual flood mitigation and adaptation solutions were developed for the shoreline and interior buildings in Tecumseh.

- Three Public Information Centres were held in a virtual format (due to COVID protocols), to share information from the study and solicit feedback from the community.

## 1.2 Previous Studies

Historical and recent relevant studies are introduced and summarized.

### 1.2.1 Essex County Shoreline Report on Erosion, Fill, and Flood Line (Dillon 1976)




The 1976 report investigated flooding and erosion for the Essex County shoreline, which includes portions of Lake St. Clair, the Detroit River, and Lake Erie. The document is one of the earliest shoreline management plans prepared in Ontario and includes an inventory of the shoreline, erosion and flooding maps, and design recommendations for shoreline protection. While the report is now over 40-years old, it still contains valuable information on erosion processes, waves, and flood levels. The 100-year flood level from the report is still used by the Essex Region Conservation Authority (ERCA) for the regulation of development along the Town of Tecumseh shoreline.

### 1.2.2 Tecumseh Storm Drainage Master Plan

Following an extreme rainfall event in September 2016, the Town of Tecumseh initiated the preparation of a Storm Drainage Master Plan (SDMP) to address the impacts of surface flooding within the northern and eastern regions of the Town of Tecumseh. The SDMP, led by Dillon Consulting Limited (Dillon), focused on assessing existing storm pump stations, gravity outfalls, and respective service area storm sewer and roadway overland flow systems. The ultimate storm outlet for the study area consisted of both Lake St. Clair and Pike Creek. Provided below in Figure 1.2 is the study area map of the SDMP and respective existing storm outlet service areas and outlet locations.

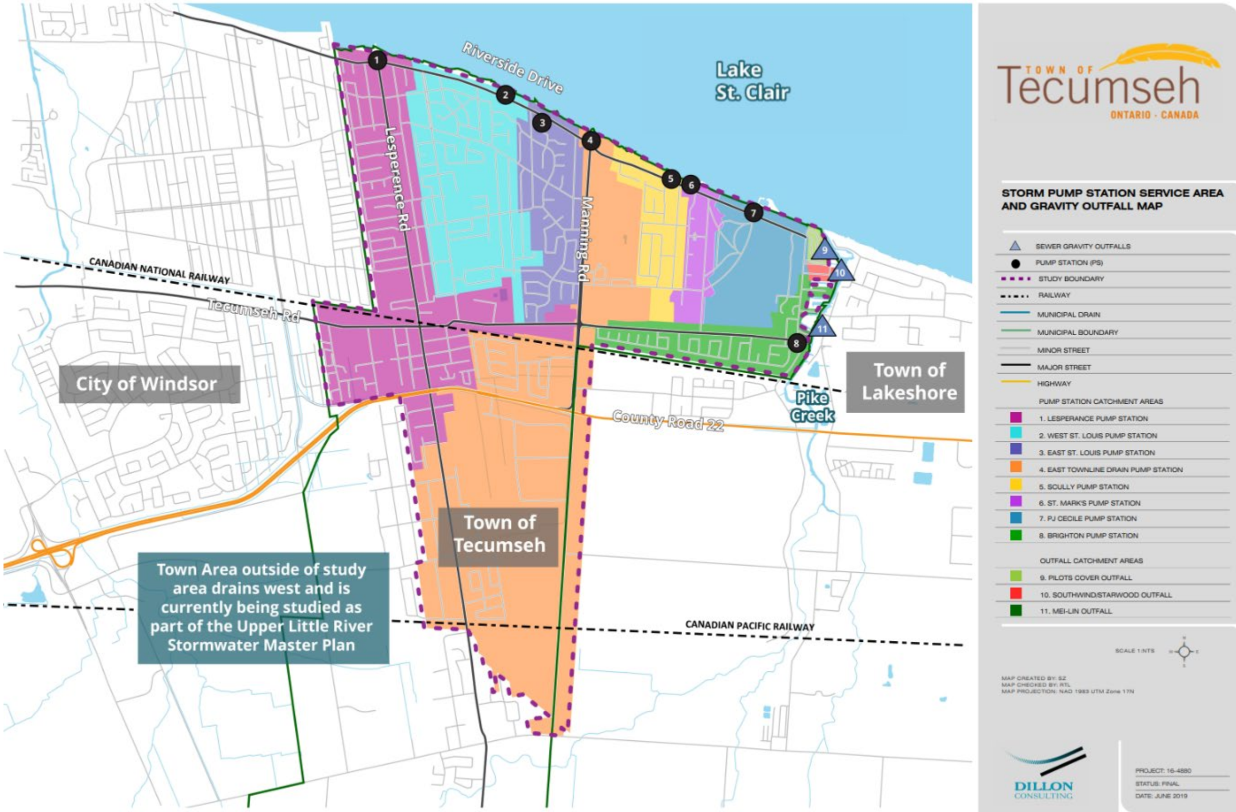



Figure 1.2 Tecumseh Storm Drainage Master Plan Study Area Map

Upon completion of the SDMP in 2019, a number of regional solutions were designed to a functional level of detail to reduce the risk of surface flooding throughout the study area. Each of these solutions were designed to follow Approach 2 of the Master Planning process and were recommended for inclusion in the Town's long term Capital Works Plan to proceed to detail design when feasible.

Recommended storm infrastructure upgrades from the SDMP study included the following:

- Trunk and local storm sewer upgrades.
- Roadway grading improvements.
- Pump station upgrades.
- Incorporation of surface and below ground stormwater storage within parkland areas and within municipal roadways.
- New pump stations.

Following the SDMP work, the present study was initiated to assess the dynamic impact of a number of joint rainfall and coastal surface flooding events using Dillon's existing SDMP model, under both existing and future conditions influenced by climate change. The simulated joint coastal-rainfall flooding scenarios included future conditions simulations accounting for upgrades to shoreline protection and the pump station and primary trunk sewer upgrades along Riverside Drive recommended from the SDMP.

## 1.3 Historical Floods and Recent High Lake Levels

Historical flooding and the recent record setting water levels on Lake St. Clair in 2019 are reviewed in the following report sections.

### 1.3.1 St. Patrick's Day Storm

On March 17, 1973 the Town of Tecumseh was hit by a major coastal flooding event known as the St. Patrick's Day Storm. The Windsor Star reported parts of Riverside Drive were flooded by 4 ft of water. Refer to the photographs in Figure 1.3 below. The north-south arteries, such as Arlington Boulevard and Manning Road, were conduits that allowed the lake flooding to propagate inland. Interior flooding extended inland more than 1 km, as evident by pictures of the flooding along Tecumseh Road south of the Beach Grove Golf & Country Club. The St. Clair Beach Police Station was also inundated.

Riverside Drive


Arlington Blvd.

Tecumseh Road

St. Clair Beach Police Station

Figure 1.3 Flooding Pictures of the St. Patrick's Day Storm (March 17, 1973)

The water level at the Belle River gauge reached 176.19 m IGLD'85 during the peak of the St. Patrick's Day storm, which is only 4 cm lower than the 100-year flood level calculated for this study (discussed later in Section 3.1.3). The mean static lake level for March 1973 was 175.83 m (i.e., not including storm surge), corresponding to a 50-year return period for the month of March. The measured storm surge peaked at 0.36 m, which is a 20-year event. The joint probability of those two extreme components of the flood occurring at the same time resulted in a storm approximately equal to the 100-year flooding event.

### 1.3.2 2019 and 2020 Record High Lake Levels

The monthly mean water levels on Lake St. Clair from 1918 to 2020 are plotted in Figure 1.4, along with the long-term average. From 2000 to 2015, water levels were at or below the long-term average. Following several years of above average net basin supplies (rainfall and snow), the lake level began to rise at an unprecedented rate.

In July 2019 Lake St. Clair established a new record high static lake level of 176.03 m IGLD'85 or 1.6 m above Chart Datum. See Figure 1.4. In total, during this wet period from 2019 to 2020 Lake St. Clair also established 8 new monthly mean records. For the remaining months (February, October, November, and December), the record highs were established in 1986.

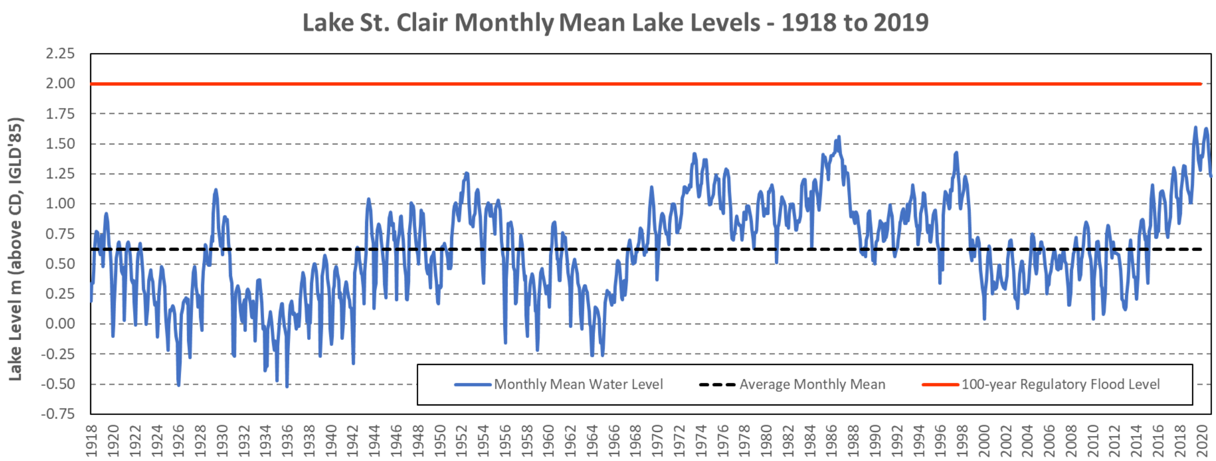



Figure 1.4 Lake St. Clair Monthly Mean Water Levels, Average, and 100-year Regulatory Flood Level

The existing 100-year regulatory flood level applied by ERCA is 176.4 m IGLD'85 or 2.0 m above Chart Datum and is also plotted on Figure 1.4. This elevation includes the influence of high static lake levels plus storm surge.

# 2.0 DATA ASSEMBLY

Section 2.0 will review the new field data collected for the risk assessment and the assembly of a detailed property parcel database.

## 2.1 Field Data Collection

The land and lake surveying methods are summarized, along with the digital oblique photographs collected for the study.

### 2.1.1 Bathymetric Survey

A bathymetry survey was performed on August 5, 2020 by staff from Zuzek Inc. The survey was conducted using a SOLIX single-beam bathymetric and sonar system with built-in navigation and recording tools. The transducer was mounted at the back of the boat with a dedicated GPS antenna located directly above the unit. Refer to Figure 2.1. The unit auto-corrects for the depth of the transducer below the lake surface. Depths were recorded every second.

Figure 2.1 SOLIX Data Collection Unit and Transducer Mount

A total of 18 bathymetric profiles were collected perpendicular to shore, with two located in the City of Windsor and one in the Town of Lakeshore. Depths fronting seawalls were also collected. See Figure 2.2 for an overview of the processed bathymetry data and colour-coded depths.


Figure 2.2 2020 SOLIX Bathymetry Survey

The depth readings were corrected using hourly water levels from the Belle River Water Level Gauge (#11965), acquired from the Government of Canada (Fisheries and Oceans) water level website. The measured water levels were averaged for the day of survey. To calculate the corrected lake bottom elevation in the IGLD'85 datum, the average water level was added to the SOLIX depth for the corresponding day. For example, for SOLIX depths collected on August 5, 2020, the average hourly water level at Belle River was 176.05 m IGLD'85. A SOLIX depth of -1.5m would translate to a corrected elevation of 174.55 m (176.05 + (-1.5)).

The hourly water level data can be found here: https://www.waterlevels.gc.ca/en/stations/11965

The SOLIX also collects 2D sonar imaging in cross-section and bottom image formats. The sonar imaging provides continuous data to help characterize the lake bottom substrate. Refer to the sample output in Figure 2.3. In the downward imaging (right), vertical seawalls were captured, along with the individual piles for the various boat docks (refer to the shadow cast by the piles). The cross-section (middle) records a sand substrate. The boat location is noted in the left panel.

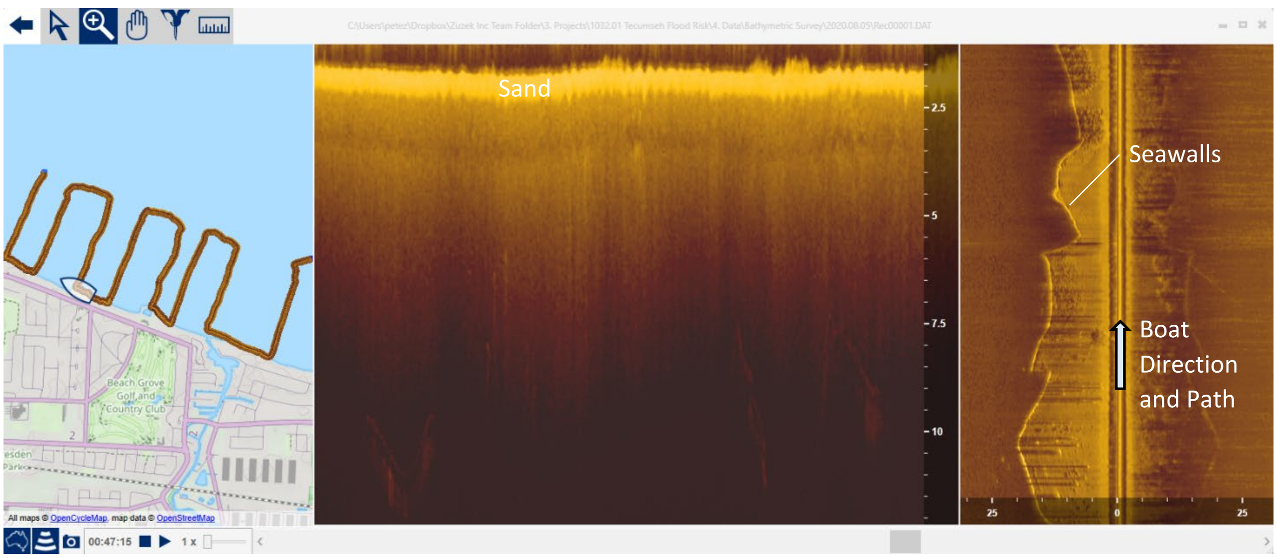



Figure 2.3 Sonar Imaging of Lake Bottom West of Beach Grove Golf and Country Club

### 2.1.2 Topographic Survey by JD Barnes

A detailed topographic survey was completed by J.D. Barnes Limited for the entire Tecumseh shoreline in September 2020. The survey crew collected crest and toe elevations of the existing shoreline protection structures, land elevations between homes to capture flood pathways, and linear features such as beach positions and waterlines. Elevations were referenced to Canadian Geodetic Vertical Datum 1928 (CGVD28) in metres. An example of the J.D. Barnes survey point density is shown in Figure 2.4 near the western boundary of the Town.

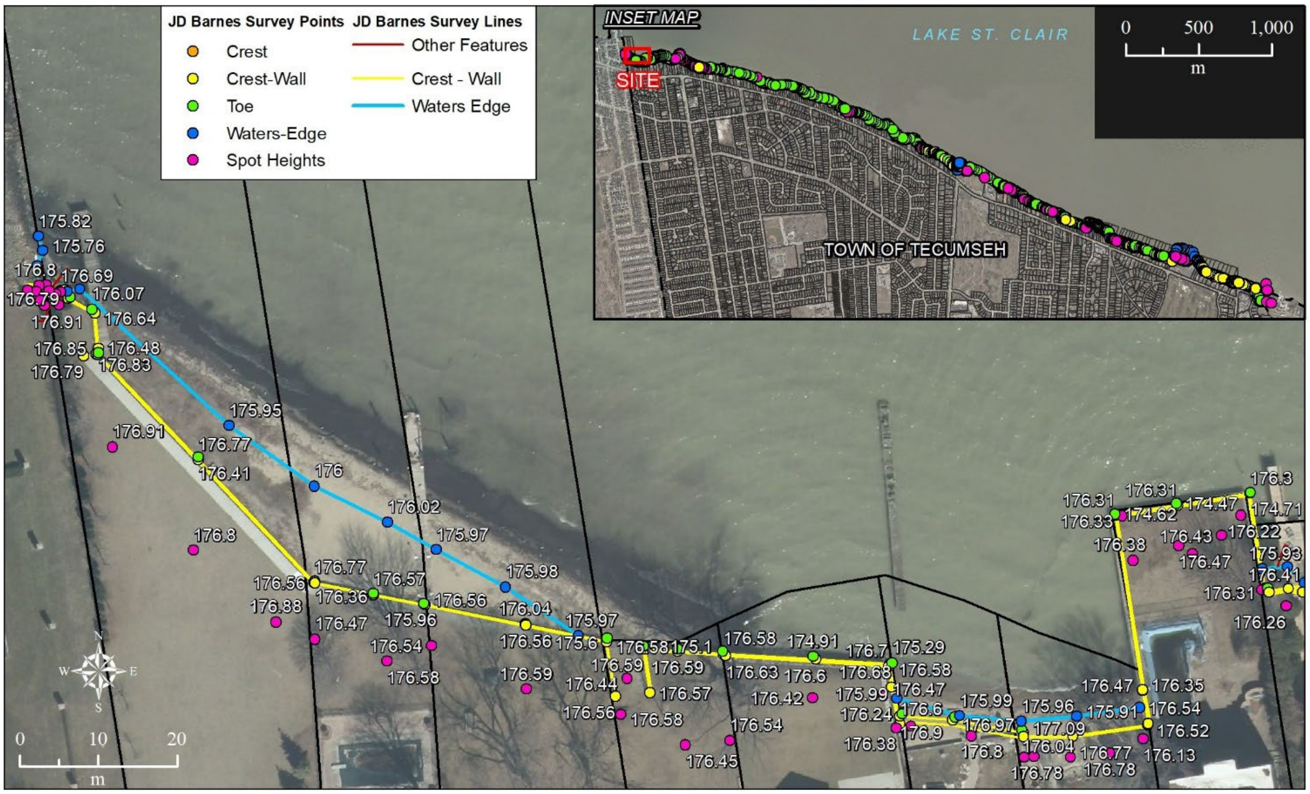



Figure 2.4 J.D. Barnes Survey Point Density

### 2.1.3 Oblique Photography

Digital oblique photographs of the entire study shoreline and Pike Creek were collected in September 2019 using a drone flying over the lake and river. A sample of the oblique photographs is provided in Figure 2.5 at the foot of Lesperance Road and Manning Road at Lakewood Park North.

Figure 2.5 Oblique Photos at the foot of Lesperance Road and Manning Road

The oblique photographs were used to develop a property parcel database and attribute existing shoreline conditions (e.g., sloping beach or shore protection, such as a vertical wall). The photographs also helped confirm the presence of flood pathways between lakefront buildings.

## 2.2 Existing Digital Information

Topographic LiDAR was collected in 2017 for the Town of Tecumseh as part of a larger data collection effort by the Ministry of Northern Development, Mines, Natural Resources and Forestry (MNDMNRF). These data were obtained from the Ontario GeoHub, an online portal for the dissemination of provincial geospatial data. The LiDAR data was downloaded as a Digital Terrain Model (DTM) in raster format. The DTM surface represents a bare-earth condition and was generated from a LiDAR point cloud. It has 0.5 m horizontal resolution and is tiled. The vertical datum is Canadian Geodetic Vertical Datum 2013 (CGVD2013) in metres.

The elevation data was used for:

- Estimating the ground elevations for the property parcel and buildings database.
- Deriving an approximate slope for the waterfront parcels.

Digital datasets were also provided by the Town of Tecumseh. For example, a digital parcel fabric comprised of polygons representing parcel boundaries with civic addresses and the current assessment value was utilized in conjunction with a buildings layer. The buildings layer (polygons) was linked to the property building database. The land elevation around buildings was attributed with the topographic LiDAR. Street centrelines (polylines) with road names and stormwater pumping station locations (points) were also provided, as well as a 2019 orthophotograph.

## 2.3 Building the Property Parcel Database

Assembling the property parcel database was a critical step for the coastal risk assessment and calculation of potential economic damages associated with future storms. The steps involved are summarized in the following report sections.

### 2.3.1 Building Attributes

A wide variety of information was collected for each building in the parcel databases, which extended from the shores of Lake St. Clair to the CN Rail Line (south limit) and from the western town limits adjacent to Windsor and Pike River in the east. Information on the following building variables was needed for the economic damage estimates discussed in Section 4.0, including:

- Estimated number of steps to the first floor of a building from the adjacent ground elevation.
- Ground elevation at the front door (which was extracted from the LiDAR terrain model).
- Number of building storeys and type.
- Presence of a basement.
- Unique parcel ID number.

The following data sources were used to populate the database for the noted attributes: Google StreetView imagery, Google Earth 3D Terrain, and street level photos obtained by Zuzek Inc.

during the November 2020 field verification survey. See Figure 2.6 for an illustration of these data sources, including Zuzek Inc. field photographs and Google StreetView images along the top row and the Google Earth 3D Terrain scenes along the bottom.

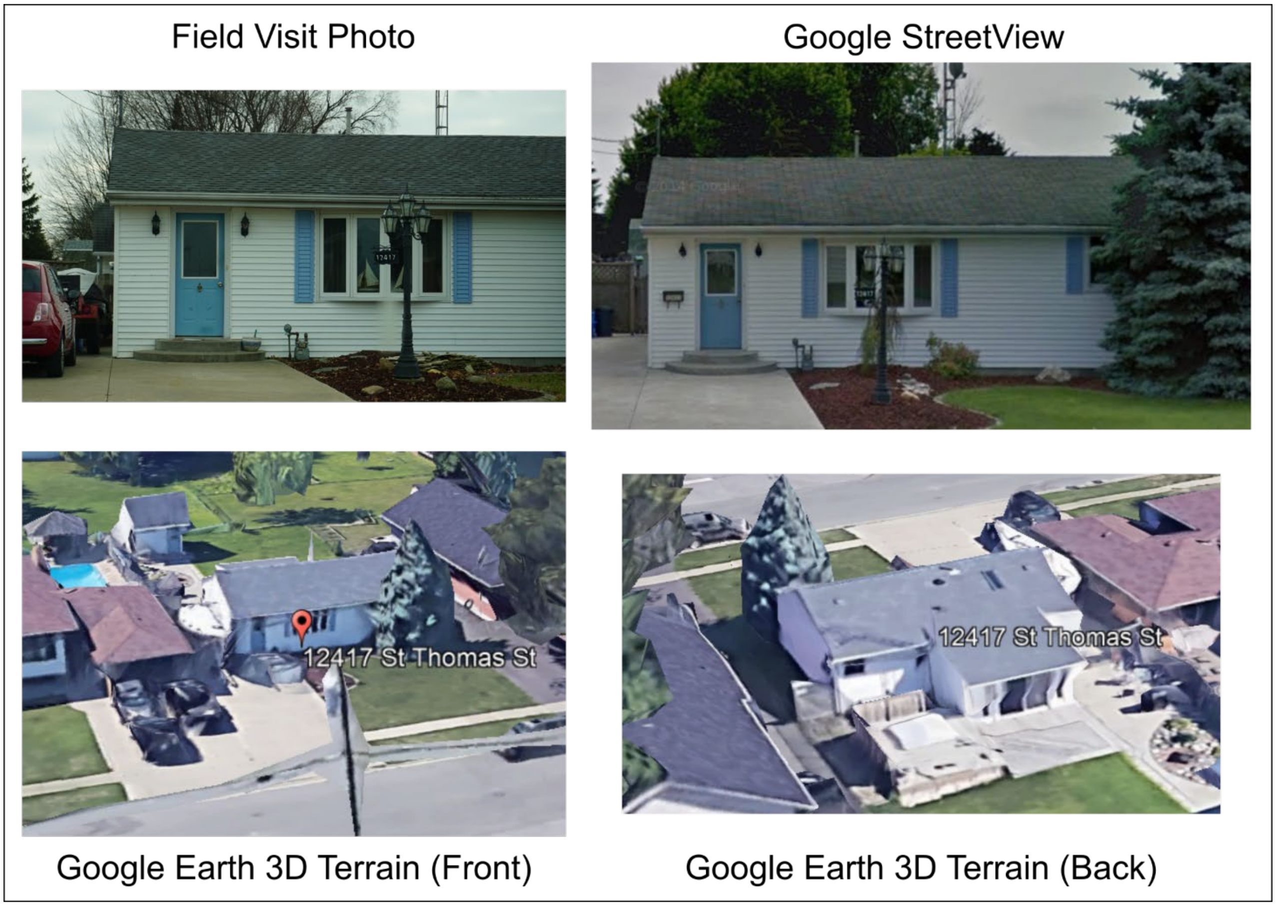



Figure 2.6 Imagery Examples from Multiple Sources

Using GIS, a point was digitized for each parcel with a building and stored as a point feature class in an Esri geodatabase. Vacant lots were not included. The point was placed at a suitable location to extract a representative ground elevation, which in turn was used to estimate the elevation of the first floor (discussed further below). Generally, this point was placed near the front steps to the house. The imagery from Figure 2.6 was consulted to determine the following building attributes:

- Building Type: The appropriate building type was selected, including Residential, Commercial, Industrial, Institutional and Recreational.

- Number of Building Storeys: The building was attributed as one storey, two stories, or greater than 2 stories.

- Presence of Basement: The presence of a basement was determined by below grade windows from the imagery sources. This field was attributed as *'Yes', 'No'* or *'Indeterminate'*. See Figure 2.7 for an example of house with basement windows.


Figure 2.7 Basement Windows below the First Floor

- Ground Elevation: A point corresponding to the ground elevation at the base of the steps to the house was extracted from the LiDAR terrain model, as noted in Figure 2.8. The total height of the steps would be added to this ground elevation to calculate the approximate elevation of the first floor.

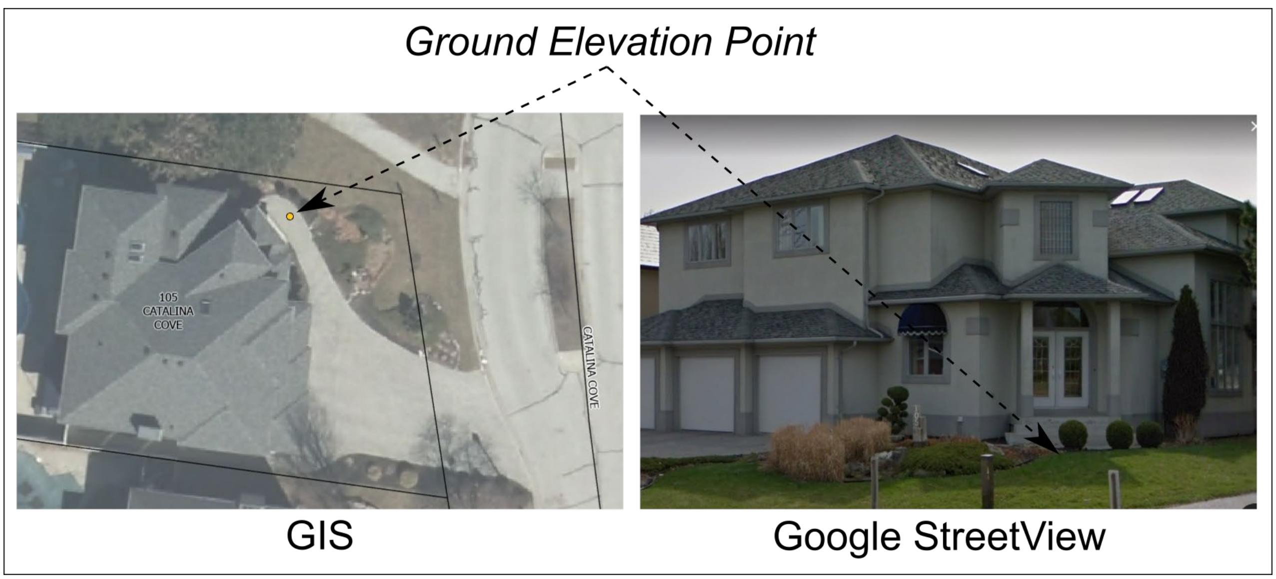



Figure 2.8 Ground Elevation Point in GIS and StreetView

- Number of Steps to the First Floor. The number of steps to the first floor was counted from the imagery. In Figure 2.9, the number of steps to the front door (first floor) was four.

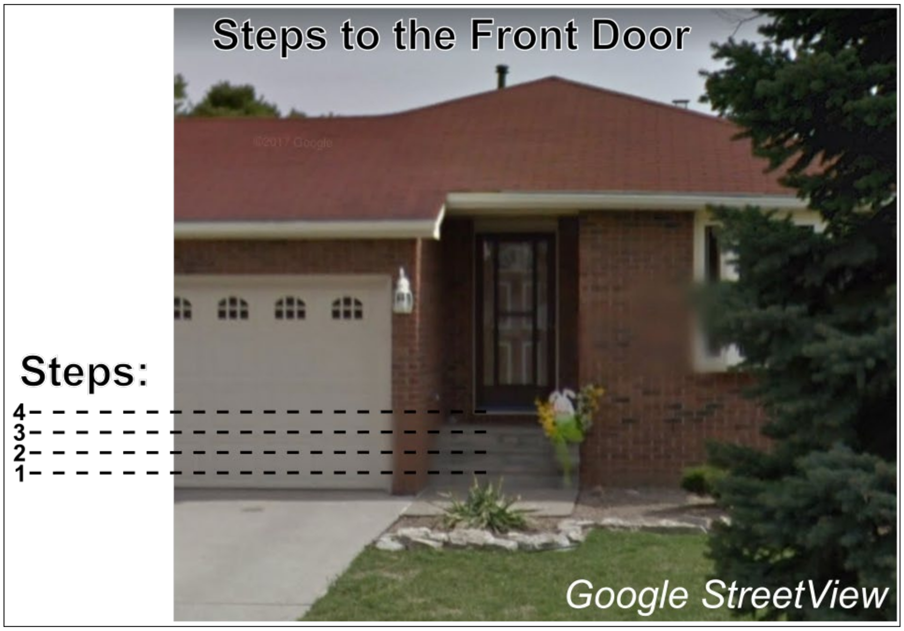



Figure 2.9  Steps to the Front Door (first floor elevation)

In November 2020, Zuzek Inc. staff visited the Town of Tecumseh to verify the step counting methodology completed with online tools.  During this time, field verification checks were completed to count the actual number of steps and compare to those identified through Google StreetView imagery.  An example of the field verification is provided in Figure 2.10, where the number of steps observed in the field (4) matched the count with the online tools (4).

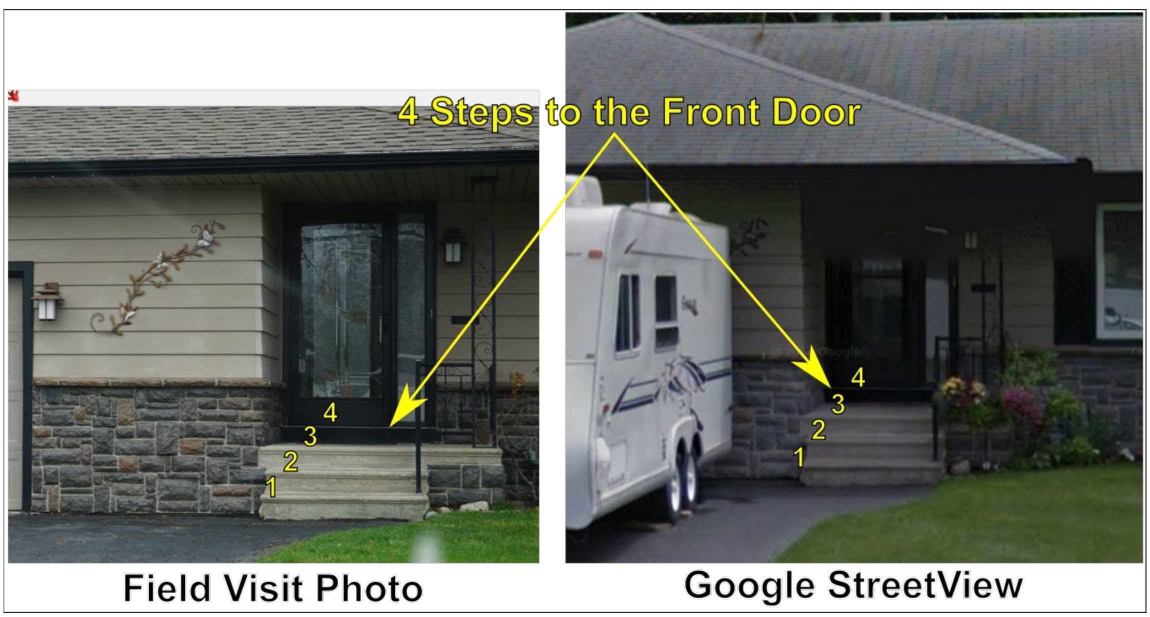



Figure 2.10  Verification of Four Steps to Front Door (Left – Field Visit, Right – StreetView Imagery)

In total, nearly 5,000 buildings were attributed in the parcel database.  An overview of the points and study area limits is presented in Figure 2.11.  A close-up view of the building database is also presented in Figure 2.12.


Figure 2.11 Property Building Database


Figure 2.12 Close-up of the Property Building Database

### 2.3.2 Parcel Attributes

Attributes of the individual property parcels were also collected for the 5,000 lots in the database. The property parcels were based on a copy of the polygon fabric provided by the Town of

Tecumseh with custom fields added. This database was compiled in a MS Excel workbook and included:

- Unique parcel ID number.
- Parcel lot length, width, and slope.
- First row parcel impacted by wave action versus interior parcel.
- For first row parcels, the presence or absence of existing shore protection, spatial extent, and crest and toe elevations.
- For first row parcels, the waters edge condition for wave uprush and overtopping calculations (e.g., sloping shoreline versus vertical structure).
- Designation of a potential flood pathway for the 100-year flood level (176.23 m, IGLD'85) and 100-year climate change coastal flood level (176.61 m, IGLD'85).

Shoreline protection types were assessed from the 2019 oblique photos, 2019 orthophotographs, and the 2020 JD Barnes survey. In the database, each parcel was attributed as either 'vertical' (indicating vertical shore protection) or 'sloping' (indicating a beach front with no shore protection, or gentle sloping rock structure). See Figure 2.13 for an example of each dataset.

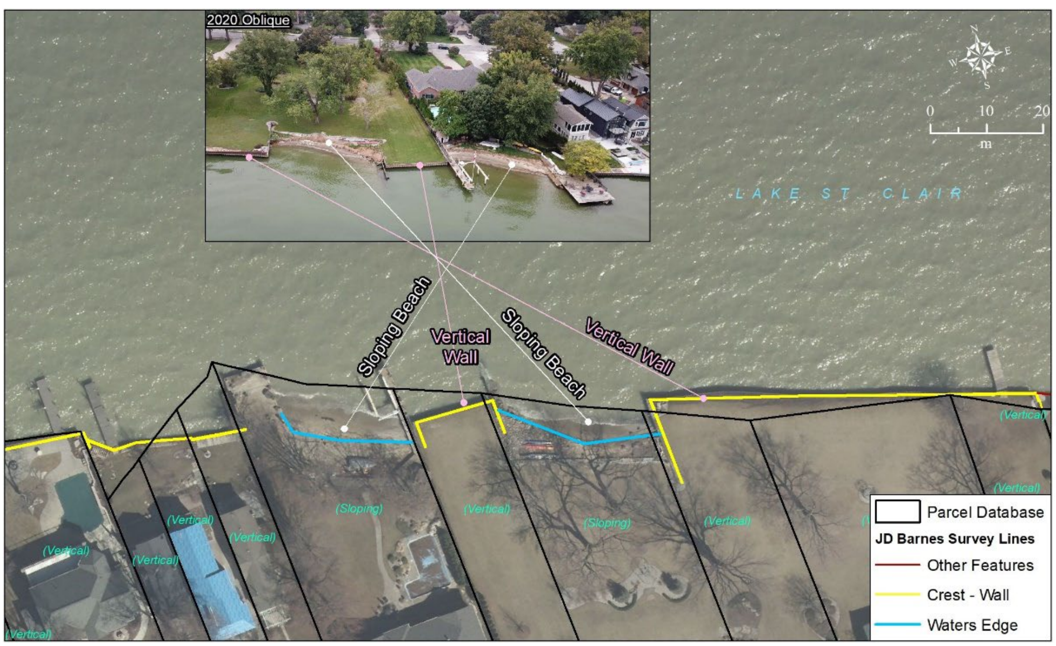



Figure 2.13 Example of Vertical Shore Protection and Sloping Beach (no protection)

Parcel dimensions such as length and width were measured in the GIS (Figure 2.14). Due to the fact that lot dimensions are not always uniform and often extend into Lake St. Clair, the length was measured as the southern lot boundary (near Riverside Dr.) to the water's edge observed in the 2019 orthophotograph. The width was measured along a line equivalent to the waters edge or the existing shore protection. If no protection was present, the width was measured along the back of the beach (e.g., crest of beach).

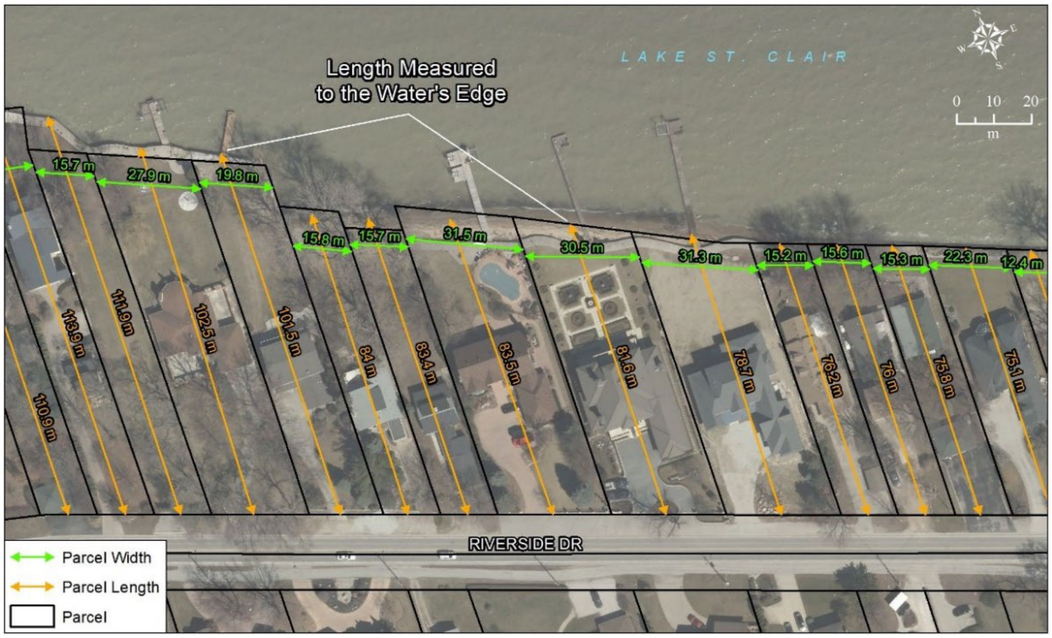



Figure 2.14 Parcel Dimensions (Length and Width)

The slope of the parcel was obtained from the 2017 topographic LiDAR digital terrain model. It was measured along a line starting in the backyard between the house and waters edge and ending at the southern lot limit near Riverside Drive (Figure 2.15). The slope was calculated using the elevations from the start and end points and is meant to represent an approximate slope from the lake to the road.

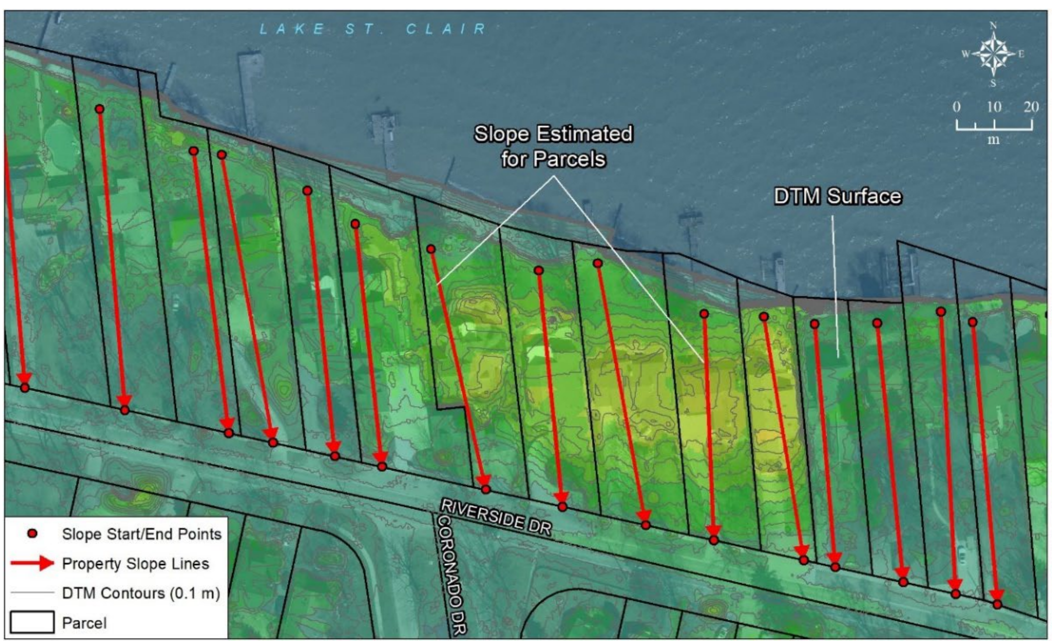



Figure 2.15 Parcel Slopes

Beach slopes were also measured for parcels with a sandy beach (see Figure 2.16), since shoreline slope is a key input variable in wave uprush calculations and overtopping calculations. Slopes were calculated using a back of beach/spot height elevation and waterline elevation as surveyed by JD Barnes in September 2020.

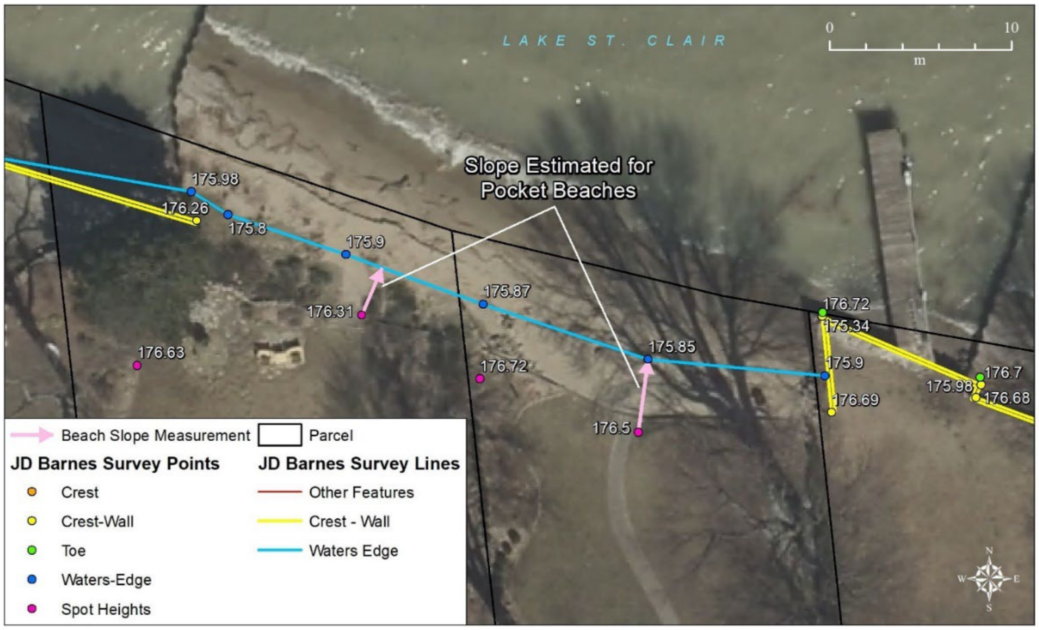



Figure 2.16 Sandy Beach Slope Calculation Example (pink arrows)

Using the JD Barnes survey, points were attributed as either 'Crest', 'Toe', or 'Water's Edge' and assigned a unique parcel identifier (Figure 2.17). In Excel, for a given parcel, the average elevation was calculated for each variable (e.g., crest , toe, and water's edge). This information was used for the flooding assessment and the conceptual design of shoreline protection upgrades.

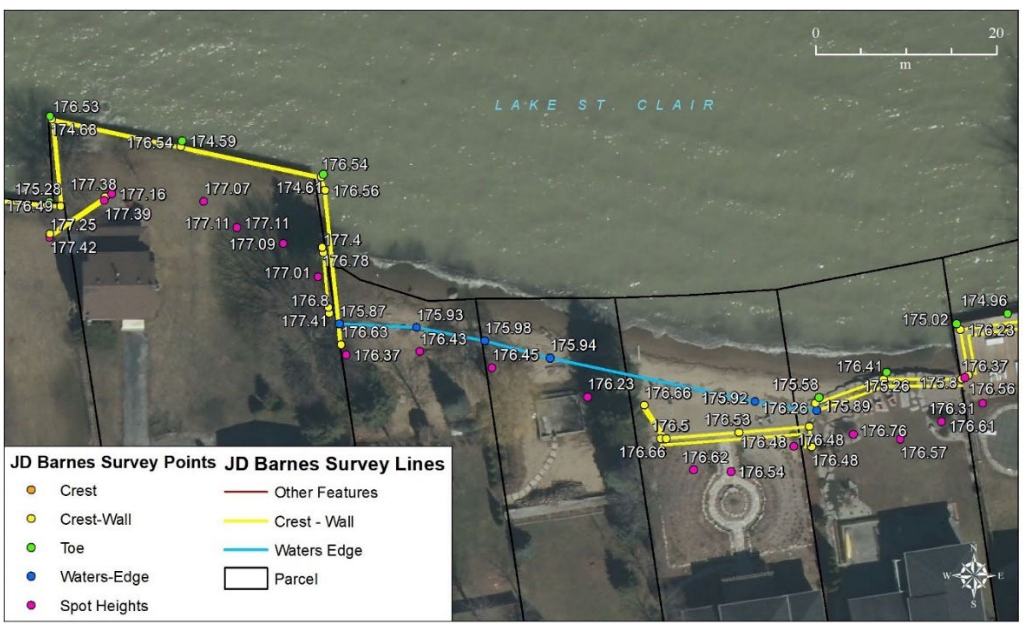
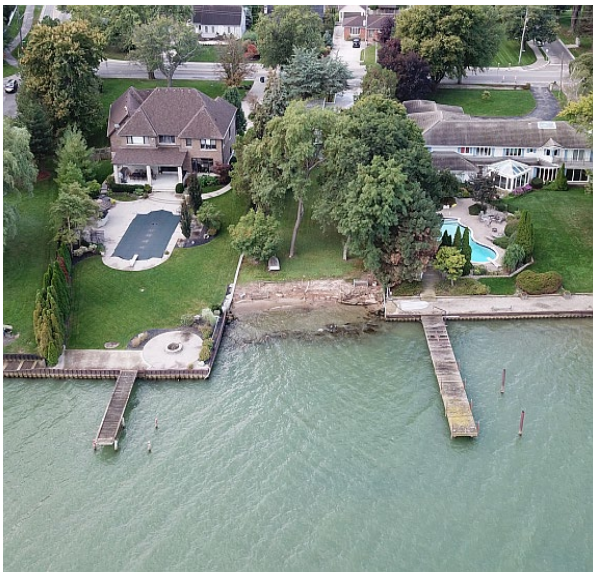


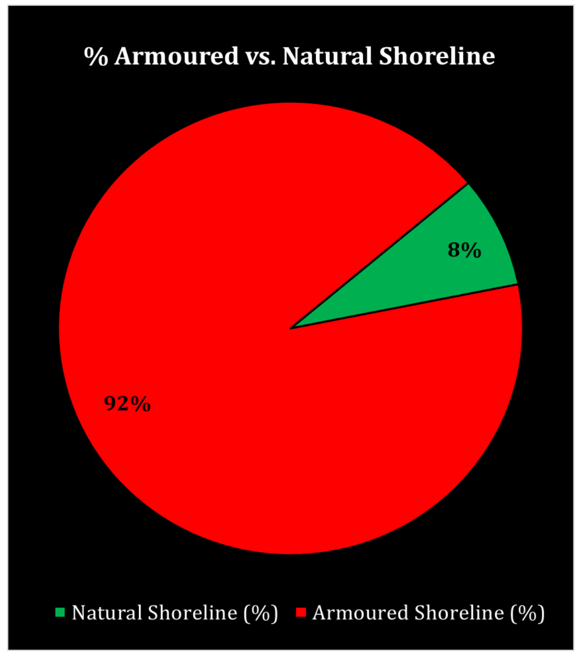

Figure 2.17 Crest, Toe, and Water's Edge Elevations from JD Barnes Survey

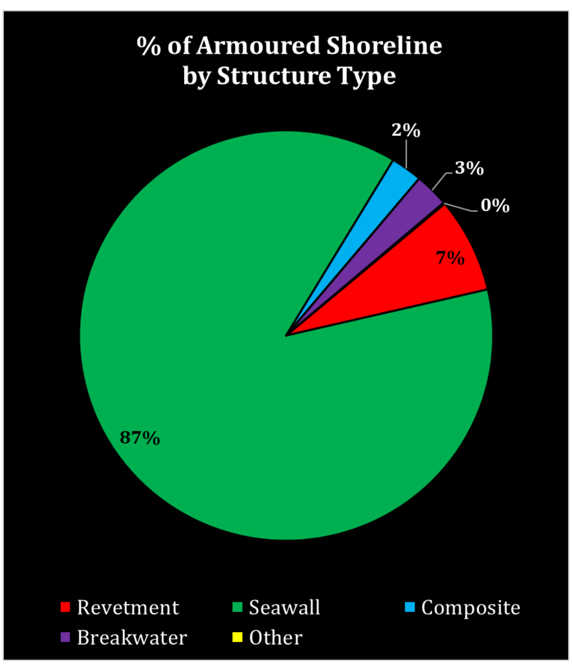
### 2.3.3 Shore Protection Details

The final component of the parcel database attributed for the waterfront properties is the type and quality of existing shoreline protection. Using the oblique digital photographs, a shoreline protection database was assembled, revealing that 92% of the Tecumseh shoreline is armoured, with only 8% remaining in a natural state. Of the protected shoreline, 87% features vertical seawalls, while 7% features sloped stone structures (e.g., revetments). It was further estimated that 91% of the documented shoreline protection infrastructure is privately owned. Refer to Figure 2.18 for details.



*Natural sand beach shoreline between two lots protected with vertical steel sheet pile walls.



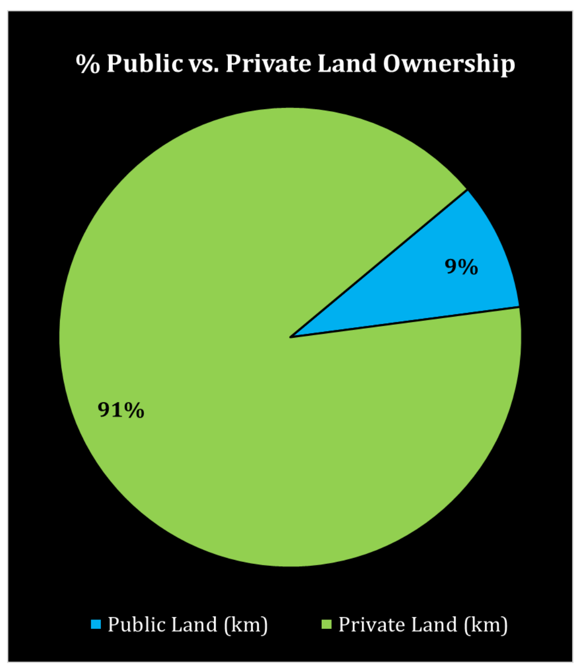




Figure 2.18 Shore Protection Details for the Tecumseh Shoreline

The overall structural condition of each parcel level shore protection structure was also assessed, and the results are summarized in Figure 2.19. Where steel sheet pile walls were identified, 98% appeared to be in good or excellent condition. However, the overall crest elevation, not considered a structural component, was often too low as determined during the flooding assessment presented in Section 4.0.

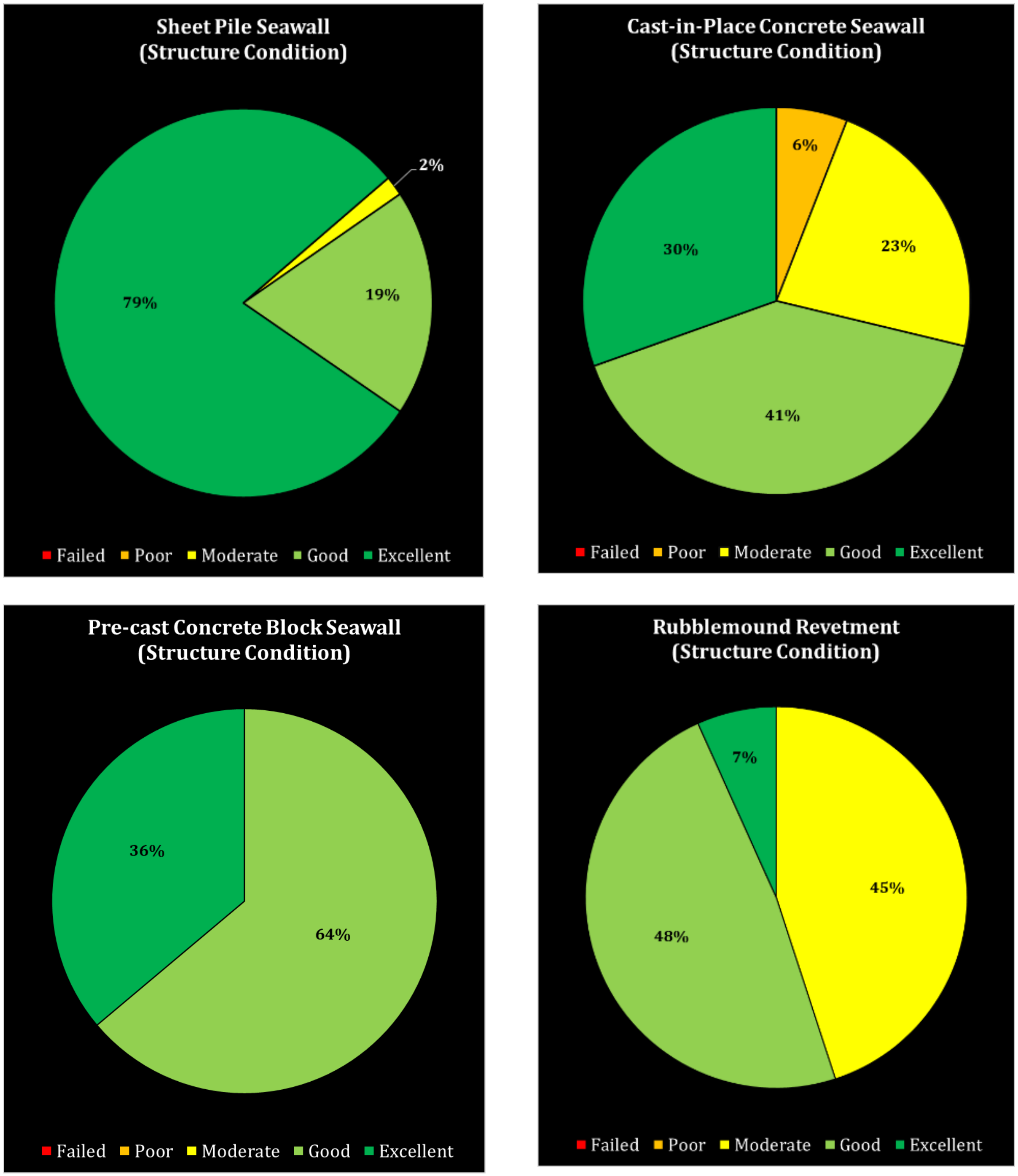



Figure 2.19 Structural Condition by Shore Protection Type

Concrete seawalls and rubblemound rock revetments featured a higher percentage of structures in moderate to poor condition.  Concrete block seawalls were not common but were generally in good condition where encountered.

Examples of low-crested shore protection and natural sandy beach shorelines are provided in Figure 2.20.  The photos were taken on August 5, 2020 during non-storm conditions.  Even relatively small storm waves would overtop the shore protection and beach, leading to interior flooding on these properties and many other similar lots.

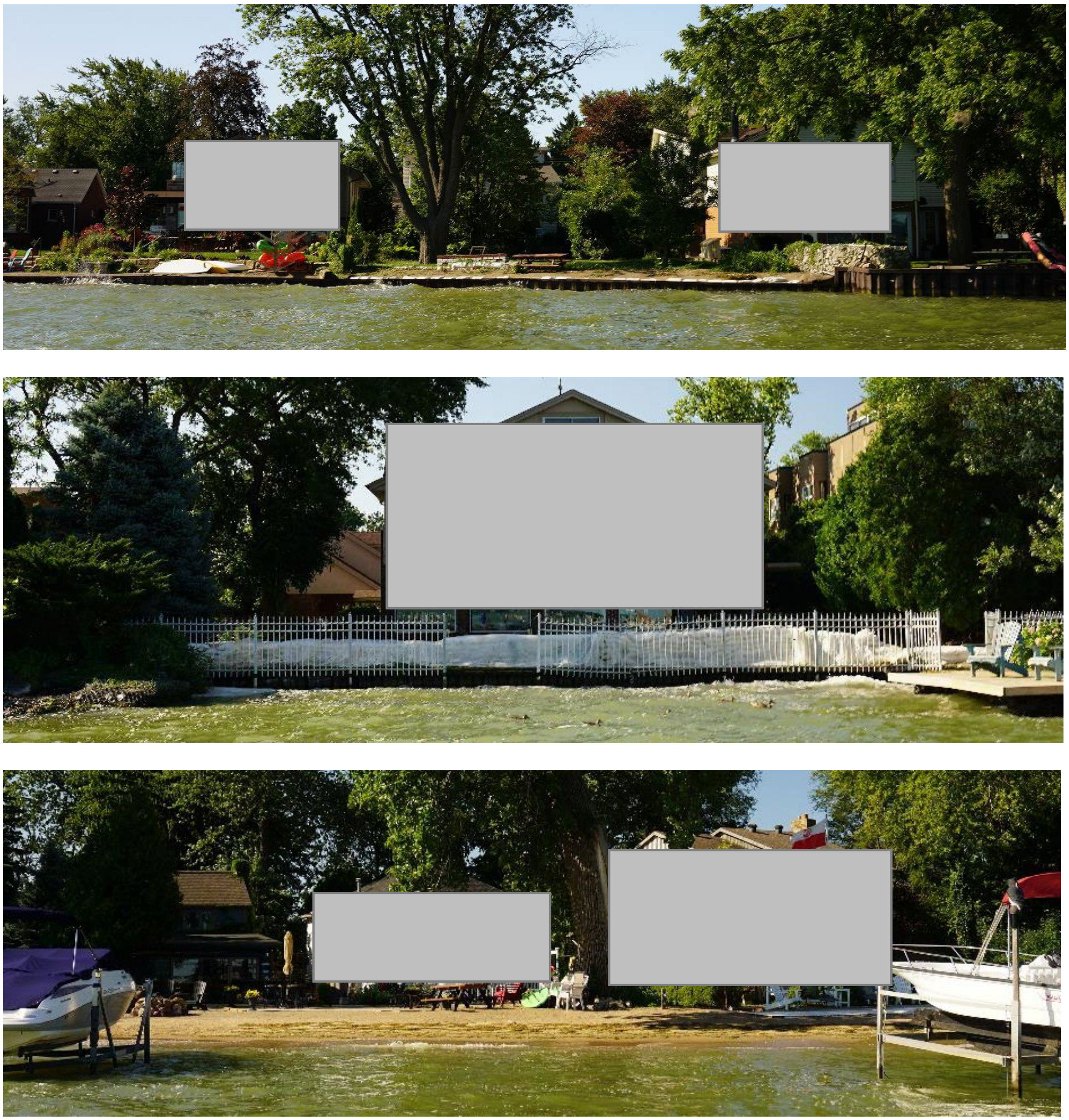


Figure 2.20  Low-crested Steel Sheet Pile Wall (top), Sandbags on Low-crested Wall (middle), and Low-crested Beach Shoreline (bottom)

# 3.0 FLOOD MODEL INPUTS AND METHODS

Section 3.0 summarizes the updated statistical analysis on model inputs, future climate change projections, the overall numerical modelling approach, and economic damage calculations.

## 3.1 Statistical Analysis of Model Inputs

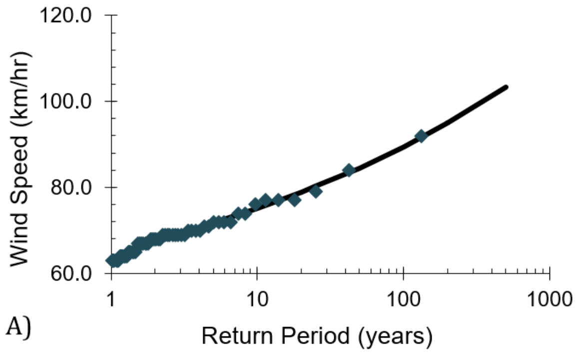
Updated statistical analysis of measured wind and water level data was completed to generate input conditions for the Tecumseh flood risk modelling.

### 3.1.1 Wind

Hourly wind data was obtained from the Government of Canada's historical climate station database. The station closest to Belle River Marina with adequate data (minimum 30 years) was Windsor Airport. Monthly data on hourly wind (speed and direction) were obtained for the period between January 1953 and September 2014 (62 years). Wind speeds in this dataset were measured 10 m above the ground for a 1-, 2- or 10-minute period ending at the time of observation. The hourly wind speed was recorded as the average over the measured interval.

Due to the geometry and spatial orientation of Lake St. Clair, northerly winds (blowing from north to south) will generate the largest waves along the Tecumseh shoreline. Consequently, an extreme value analysis was performed for northerly wind events only, identified as any wind direction ranging from west to east, or between 270 and 90 degrees. Northerly wind events were ranked by wind speed, and the top 62 events were selected for the extreme value analysis such that the number of events was equivalent to the number of years of data (n = 62). For the selection of the top-ranked events, a minimum duration of 36 hours between storms was applied to ensure independence. Wind speeds also had to exceed 35 km/hr for at least 4 consecutive hours to qualify as a significant wind event.

The ranked dataset of wind events was fitted to various cumulative probability distributions for extreme value analysis. Normality testing (Chi-squared) indicated that the data could not be described using a normal distribution. The Fisher Tippett II (Frechet) and Generalized Extreme Value (fitting via Method of L-moments, MLM) distributions generally provided the best fit, with a minimum correlation coefficient of 0.992 (Figure 3.1). Table 3.1 provides a summary of the results from the wind EVA, including an average from the two distributions that exhibited the best fit.



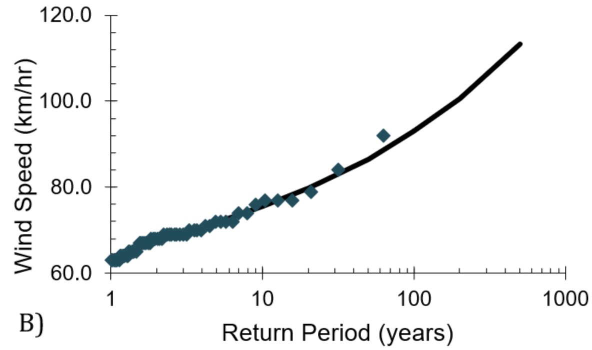




Figure 3.1 Historical wind data modeled with A) the Fisher Tippett II (Frechet) distribution and B) the Generalized Extreme Value distribution (MLM fitting)

Table 3.1 Summary of EVA Results for Sustained Wind Speeds (NW to NE directionality) – Windsor Airport

| | Peak Sustained Wind Speeds (km/hr) | | |
|---|---|---|---|
| **RP (years)** | **1. FT II (Frechet)** | **2. GEV MLM** | **Average (1/2)** |
| 1.5 | 65.92 | 66.23 | 66.07 |
| 2 | 67.44 | 67.62 | 67.53 |
| 5 | 71.78 | 71.86 | 71.82 |
| 10 | 75.18 | 75.48 | 75.33 |
| 20 | 78.91 | 79.71 | 79.31 |
| 25 | 80.20 | 81.23 | 80.72 |
| 50 | 84.53 | 86.56 | 85.54 |
| 100 | 89.41 | 92.95 | 91.18 |
| 200 | 94.92 | 100.64 | 97.78 |
| 500 | 103.35 | 113.26 | 108.30 |
| **Corr. Coeff.** | 0.9936 | 0.9915 | |

### 3.1.2 Waves

Wave growth is related to the magnitude, direction, and duration of winds blowing over a waterbody. It is possible to hindcast historical wave conditions using available wind data. Using parametric hindcasting techniques, various return period wind events can be translated to the respective return period (RP) wave height and wave period. Parametric hindcasting was used to establish wave conditions on Lake St. Clair correlating to the 1-year event up to the 500-year event for the region based on the following methodology.

The extreme value analysis results presented in Table 3.1 (column three) were used for parametric wave hindcasting, with hindcast methodology adopted from the Coastal Engineering Manual (USACE, 2012). Inputs included fetch length (open water distance on the lake), storm duration and average water depth over the area of wave generation. The fetch length was taken to be the entire length of Lake St. Clair across its north-south axis: 43 km. A storm duration of 12 hours was assumed for all hindcasted events, and a conservative lake depth of 6 m was assumed based on lake depths obtained from NOAA. Outputs from this analysis are presented in Table 3.2.

Table 3.2 Summary of results from parametric wave hindcasting – Lake St. Clair

| RP (years) | Wind Speed (km/hr) | 1977 SPM – Shallow Water | |
|---|---|---|---|
| | | Wave Height (m) | Wave Period (s) |
| 1.5 | 66.07 | 1.30 | 4.7 |
| 2 | 67.53 | 1.32 | 4.7 |
| 5 | 71.82 | 1.37 | 4.8 |
| 10 | 75.33 | 1.42 | 4.9 |
| 20 | 79.31 | 1.46 | 5.0 |
| 25 | 80.72 | 1.48 | 5.0 |
| 50 | 85.54 | 1.53 | 5.2 |
| 100 | 91.18 | 1.59 | 5.3 |
| 200 | 97.78 | 1.65 | 5.4 |
| 500 | 108.30 | 1.75 | 5.7 |

The wave conditions presented in Table 3.2 were validated against wave data archived by the Department of Fisheries and Oceans (DFO) for Lake St. Clair (buoy C45147). Wave data for Lake St. Clair was available between 2000 and 2019. The limited dataset provided minimal comparison for extreme wind/wave events, however, the magnitude and relative frequency of wave events recorded at the Lake St. Clair buoy throughout the 20-year period were in general agreement with the predicted wave heights.

The wave characteristics determined from parametric hindcasting are representative of offshore wave conditions. Nearshore wave transformations such as wave shoaling and wave breaking must be taken into consideration to determine wave conditions along the shoreline. Shuto's Non-Linear Shoaling (1974) and Goda's formulation for wave breaking (1985) were applied to transform the offshore waves to depth-limited nearshore waves at various locations along the Tecumseh shoreline using measured lakebed elevations and corresponding depths based on the 100-year flood level described in Section 3.1.3.

### 3.1.3 Historical Lake Levels and Projected Future Conditions

The long-term monthly mean water levels for lake St. Clair were plotted in Figure 1.4. For this coastal risk assessment, we relied on the 100-year combined flood level, which includes the impacts of storm surge. This flood level is derived from a combination of static water levels and storm surge having a joint probability of occurrence of 1% in any given year. The published 100-year flood level reported for Belle River in Dillon (1976) and MNRF (1989) and are presented in Table 3.3. These older reports relied on a combination of statistical analyses of historical water level data and theoretical computations to estimate the 100-year flood level at Belle River.

Table 3.3 Existing 100-year Flood Level for the Belle River Gauge (IGLD'85)

| | Dillon (1976)<br>Pike Creek to Belle River | Dillon (1976)<br>Belle River to Stoney Point | MNR (1989) |
|---|---|---|---|
| 100-year Flood Level | 176.39 m | 176.33 | 176.36 m |

Since the previous estimates by Dillon (1976) and MNRF (1989) reports, several decades of higher resolution water level data have been logged at gauges around Lake St. Clair. To provide an up-to-date and more accurate estimate of the combined flood level along the south shore of Lake St. Clair, an updated joint probability analysis of static water levels and storm surge at the Belle River Gauge was performed and is presented in the following sections.

#### *3.1.3.1 Updated Static Lake Levels*

Measured historical static water level data is archived by the Department of Fisheries and Oceans (DFO) for various gauging stations across the Great Lakes, including Lake St. Clair. Monthly mean water levels for Lake St. Clair, based on averages from a network of gauging stations, were obtained from these archives for 1918 through 2020 (103 years). The water level data was divided into 12 monthly datasets, ranked and fitted to several statistical distributions for extreme value analysis, including: (1) Weibull, (2) Fisher-Tippett, (3) Generalized Extreme Value (GEV) and (4) Generalized Pareto.

The Weibull and GEV distributions generally provided the best fit to the monthly static lake level data (Figure 3.2), with minimum correlation coefficients across all datasets of 0.996. The other extreme value distributions provided considerably lower correlation coefficients and thus were not utilized for further analyses. There was some variation in 100-year static WL estimates between the Weibull and GEV distributions, up to 5 cm depending on the month. To ensure conservatism in the analysis, the higher of the two estimates was generally taken, provided the correlation coefficients were similar.

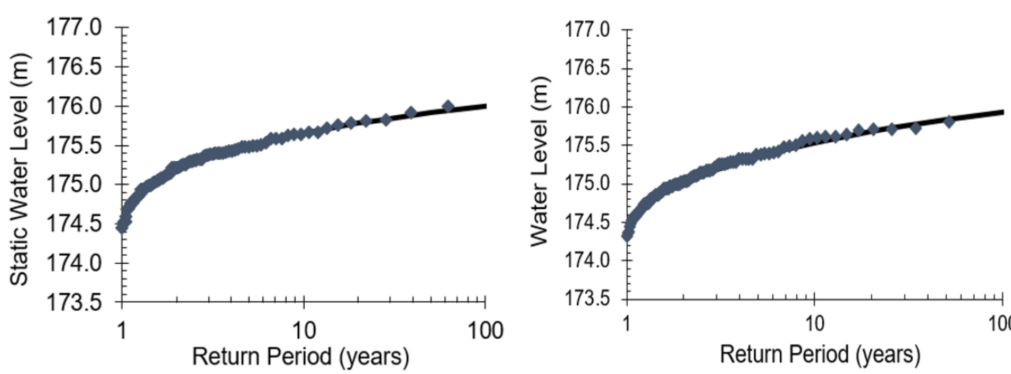



Figure 3.2 Left: Weibull Distribution for June Static WL data (Corr. Coeff. = 0.998) Right: GEV (Method of Moments) Distribution for April Static WL Data (Corr. Coeff. = 0.998)

Table 3.4 provides a summary of results from the monthly extreme value analysis of static water levels described above. The governing predicted 100-year static WL is 176.04 m IGLD'85, occurring in July. The most recent published static WL estimate for this area prior to this study was 175.95 m, based on data recorded between 1900 and 1987 (MNR, 1989). The findings from this analysis exhibit a 9 cm increase over the findings of the MNR – to be expected given the inclusion of record setting static lake levels experienced in recent years (e.g., 2019 and 2020).

Table 3.4 Predicted 100-year Monthly Static Lake Levels for Lake St. Clair (based on data from 1918-2020)

| | Monthly Lake Level in m IGLD85' (1918 - 2020) | |
|---|---|---|
| **Month** | **Max Observed WL** | **Predicted 100-year WL** |
| January | 175.80 | 175.85 |
| February | 175.80 | 175.86 |
| March | 175.83 | 175.91 |
| April | 175.91 | 175.97 |
| May | 175.98 | 175.97 |
| June | 176.02 | 176.00 |
| July | 176.04 | 176.04 |
| August | 175.97 | 175.97 |
| September | 175.88 | 175.91 |
| October | 175.96 | 175.83 |
| November | 175.82 | 175.78 |
| December | 175.80 | 175.79 |
| **Max =** | **176.04** | **176.04** |

#### *3.1.3.2 Storm Surge*

Surge occurs when there is a temporary water level rise during a storm, resulting from the combined effects of barometric pressure gradients and wind setup across a water body. On large inland lakes, wind setup is typically the primary contributor to storm surge, as the effects of pressure variations are relatively small. Wind setup occurs when wind-induced shear stress at the water-air interface pushes water in the same direction as the prevailing wind, causing a temporary rise in water levels at the downwind shore. The amplitude of a storm surge event is dependent on the local wind speed, wind direction, fetch (lake distance over which the wind is blowing), shoreline orientation, and lakebed bathymetry.

Storm surge events can be interpreted from measured water level data as long as the temporal resolution is sufficiently high to capture surge events, which typically last several hours. The Belle River water level gauge (Station ID: 11965) on Lake St. Clair is in close proximity to Tecumseh and has sufficient data resolution for a storm surge analysis. Data from the Belle River Station was sourced from the Department of Fisheries and Oceans (DFO) for the period of 1961 to 2020 (60 years). Archived data was available in varying resolution, with hourly data available between 1961 and 1988, 15-minute data available between 1989 and 2002, and 3-minute data available post-2002. Storm surge analysis was completed using hourly data; however, selected surge events were compared to higher resolution data where available to ensure maximum surge levels had been captured by the hourly data.

To isolate and quantify surge events from the water level dataset, each individual data entry was compared to background static lake levels to highlight temporary positive residuals at the gauge location (surge events). To determine the background static lake level, a 72-hour average was calculated for every data point, excluding the central 24 hours (12 hours before and after the point of interest). The 72-hour average lake levels were then subtracted from instantaneous water levels, with resultant high-magnitude, positive residuals representing potential surge events. Surge events were separated into 12 monthly datasets, each including data from the month preceding and following (i.e., the January data set included December, January, and February events) to remove any bias associated with surge events occurring at the boundaries between months. This adds an additional layer of conservatism to the surge analysis. A minimum duration of 36-hours between events was applied to ensure independence of the selected storm events.

The top 60 ranked surge events for each month were fitted to various cumulative probability distributions for extreme value analysis. The Weibull and GEV distributions generally provided consistently good fits for the surge data, with higher correlation coefficients for winter months (minimum correlation coefficient from Dec-Mar was 0.99) and lower correlation coefficients for summer months (minimum correlation coefficient from Apr-Nov was 0.94). The Pareto and Fisher-Tippett II (Frechet) distributions also provided an excellent fit for some months, with similar seasonal fit-disparity. This disparity is particularly severe in the September dataset where the highest ranked events were all of similar magnitude and the tail-end data exhibited a plateau as a result (refer to Figure 3.3). This is potentially a result of physical limitations of Lake St. Clair combined with seasonal wind limitations. The best fitting distributions were selected for each month, with the predicted seasonal 100-year surge estimates presented in Table 3.5.

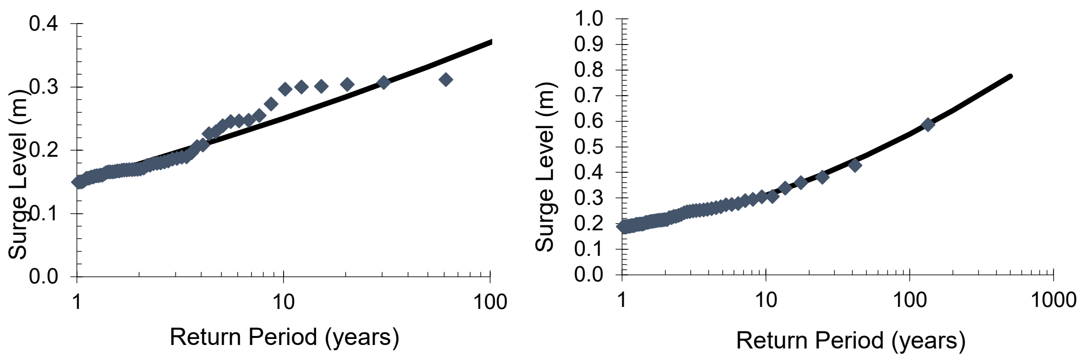



Figure 3.3 Left: Pareto (Method of Moments) distribution for September surge events (Corr. Coeff. = 0.974) Right: Weibull distribution for December surge events (Corr. Coeff. = 0.994)

Table 3.5 Seasonal, predicted 100-year storm surge magnitudes at Belle River.

| Month | Belle River Surge (1961 - 2020) Max. Observed Surge (m) | Predicted 100-year Surge (m) |
|---|---|---|
| January | 0.43 | 0.53 |
| February | 0.54 | 0.53 |
| March | 0.36 | 0.52 |
| April | 0.40 | 0.43 |
| May | 0.26 | 0.42 |
| June | 0.36 | 0.32 |
| July | 0.26 | 0.34 |
| August | 0.24 | 0.33 |
| September | 0.31 | 0.37 |
| October | 0.31 | 0.48 |
| November | 0.58 | 0.51 |
| December | 0.38 | 0.55 |
| **Maximum =** | 0.58 | **0.55** |

Based on the analysis described above, the governing 100-year surge is 0.55 m, occurring in the winter months. This estimate is considerably lower than the previous estimate of 0.81 m published by the MNRF (1989), which was based on historical data recorded between 1957 and 1986. It is likely that the 1989 estimate provided by the MNRF extrapolated too far beyond the limited 30-year dataset. The new estimate, although lower, is expected to be more accurate with 60+ years of contributing data and improved extreme value analysis techniques.

It is noted that the present analysis found the largest observed surge event at Belle River, with a magnitude of 0.58 m (occurring November 2, 1966), to have a recurrence interval of between 130 and 160 years based on the best fitting distributions for the month of November.

#### *3.1.3.3 Joint Probability (Static WL + Surge)*

A joint probability analysis (JPA) was completed for each of the 12 monthly static water level and storm surge datasets, to determine combined flood levels for each month of the year. Monthly (seasonal) static water level and storm surge distributions used in the JPA were those described in the sections above.

In the joint probability analysis, static lake level and storm surge are treated as independent variables X and Y, respectively. Once an extreme value distribution is fit to each dataset, as discussed above, multi-variate discretization is performed, and the convolution formula is used to assess the joint probability of combined water levels, Z (where Z = X + Y). The resulting joint probability equation can be expressed as:

$$P(Z) = \sum_{Rx} P(X) \cdot P(Z - X)$$

Figure 3.4 presents a sample cumulative distribution plot resulting from the joint probability analysis of combined water levels, for the month of June at the Belle River gauge. The combined flood level, Z (static water level + storm surge), can be obtained from the figure for any return period based on the respective cumulative probability. For example, a return period of 10 years indicates a cumulative probability of 0.90 for any given year (1-10/100). The corresponding z-value (combined flood level) can be read from the X-axis and is approximately +175.8 m IGLD85' for the month of June.

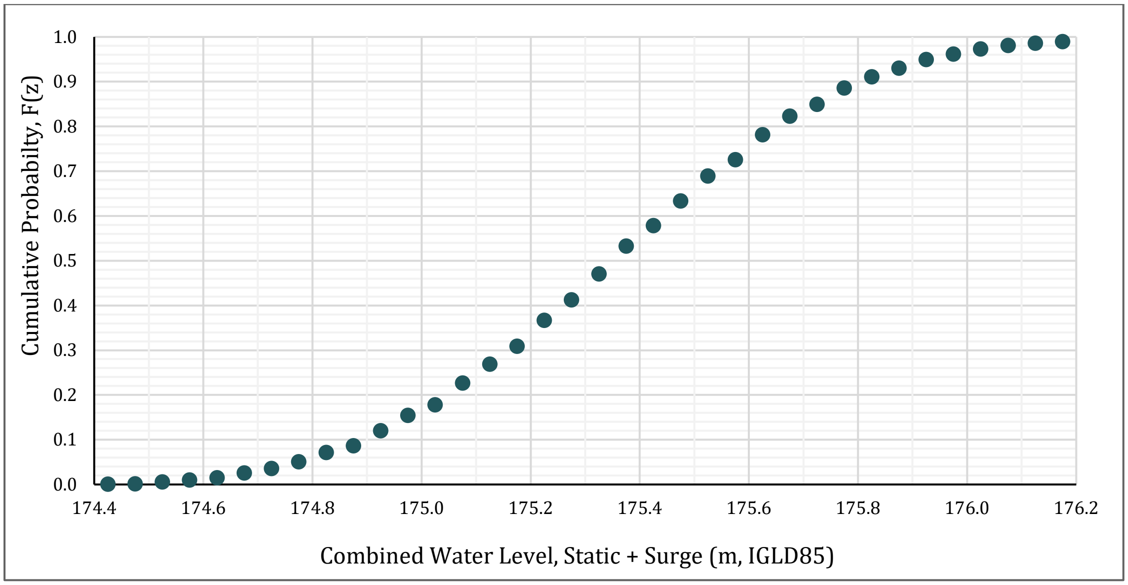



Figure 3.4 Cumulative Joint Probability Distribution Plot of Combined Lake Levels (static water level + storm surge) at Belle River for the Month of June

Table 3.6 provides summary results for the joint probability analysis of 100-year combined flood levels (static WL and storm surge) for all months at the Belle River gauge.

Table 3.6 Summary of Predicted Combined Lake Levels at Belle River Based on the Joint Probability Analysis of Static Water Level and Storm Surge

| | **100-year Combined Flood Level (m IGLD85')** |
|---|---|
| **Month** | **Belle River** |
| January | 176.10 |
| February | 176.11 |
| March | 176.19 |
| April | 176.24 |
| May | 176.22 |
| June | 176.21 |
| July | 176.23 |
| August | 176.18 |
| September | 176.13 |
| October | 176.11 |
| November | 176.07 |
| December | 176.08 |
| **Maximum =** | **176.24** |

Based on the results of the joint probability analysis, the governing 100-year combined flood level at Belle River is estimated to be +176.24 m IGLD'85. This value was predicted for the month of April; however, the months of April, May, June and July are very similar, suggesting the 100-year combined flood level could be realized during any of these months. The estimated

100-year level is 12 cm lower than values previously published by the MNRF (1989), and 9 to 15 cm lower than Dillon (1976). The slightly lower values are primarily due to the difference in extreme surge estimates. More confidence can be placed in the surge estimate presented herein, as the analysis is backed by 60+ years of historical data and improved surge estimation and extreme value analysis techniques. For reference, the highest recorded hourly water level throughout the entire 60+ year operation of the Bell River water level gauge is +176.19 m IGLD'85.

The eastern limit of the Tecumseh shoreline is roughly 11 km west of Belle River. The Town of Tecumseh presently uses a 100-year lake level of 176.4 m IGLD'85, which is based on Dillon (1976). Despite the updated analysis presented in this report, it is not recommended that the current regulatory flood levels in Tecumseh be reduced below 176.4 m, particularly due to the increased frequency of high lake levels across Lake St. Clair in recent years and future projections for climate change impacts. However, for the purpose of the flood modelling and risk assessment, a 100-year lake level of 176.24 m will be used.

### 3.1.4 Climate Change Lake Level Projections

In a recent report from Environment and Climate Change Canada (Seglenieks and Temgoua, 2021), projections of future lake levels were summarized for global temperature increases of 1.5 to 3.0 degrees Celsius. Data on precipitation, evaporation, and runoff for the analysis was extracted from 13 pairs of Global and Regional Climate Models from the Coupled Model Intercomparison Project Phase 5 (CMIP5). Based on the modelling results, the historical variability in measured lake levels is projected to continue (i.e., periods of highs and lows). However, due to increases in precipitation with a warming climate, both mean lake levels and extreme highs are projected to increase in the future. Refer to Figure 3.5 from Seglenieks and Temgoua (2021), which plots the projected future water levels for Lake St. Clair due to climate change. For some of the modelled scenarios, water levels are 0.5 m to over 1.0 m higher than the measured historical data on Lake St. Clair.

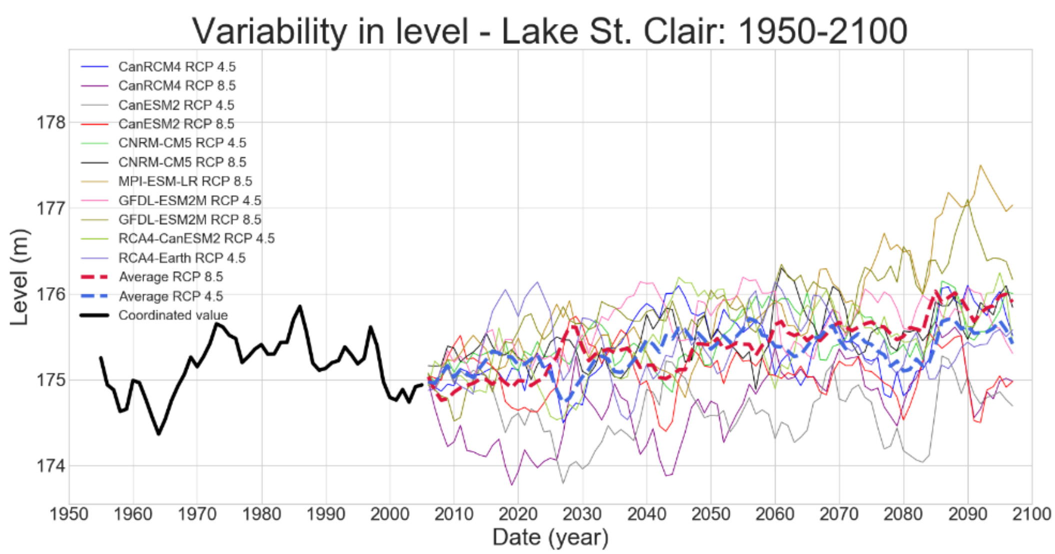



Figure 3.5 Projected Future Lake St. Clair Water Levels for Different Global Warming Trends and GCM-RCM Simulations (from Seglenieks and Temgoua, 2021)

The ECCC results on future lake levels are also summarized as probability of exceedance relative to the historical baseline condition from 1961 to 2000. The results for the 1% (100-year) and 50% exceedance (average lake levels) for increases in global mean temperatures from 1.5 and 3.0 degrees Celsius are summarized in Table 3.7. These data indicate that as temperatures in the Great Lakes Basin continue to increase in the future, average lake levels will increase slowly over time (refer to the 50% exceedance results in Table 3.7).

More importantly for this coastal flooding risk assessment, there is an increase in the projected 100-year lake levels for the various warming estimates (refer to 1% exceedance levels in Table 3.7). For other risk assessments in the Great Lakes, Zuzek Inc. is using the average increase in the 1% lake levels for 1.5 and 2.0 degrees Celsius of future warming to integrate projected climate change impacts. For Lake St. Clair, the 100-year climate change lake level would be approximately 0.38 m higher than the historical limit based on measured data.

Table 3.7 Projected Change in Future Lake Level Extremes (Seglenieks and Temgoua, 2021)

| Percent Exceedance | Projected Increase in Lake Level from Historical Baseline | | | | |
|---|---|---|---|---|---|
| | 1.5 C of Warming | 2.0 C of Warming | 2.5 C of Warming | 3.0 C of Warming | Average of 1.5 and 2.0 C |
| 1% | 0.34 m | 0.42 m | 0.60 m | 1.00 m | 0.38 m |
| 50% | -0.02 m | 0.09 m | 0.14 m | 0.23 m | ~0.04 m |

The 2018 report from the Intergovernmental Panel on Climate Change (IPCC) puts these projected increases in global warming in context by presenting a timeline of historical CO2 emission and future scenarios. There is high confidence that global mean temperatures will surpass 1.5 degrees Celsius between 2030 and 2052 if CO2 emissions continue to increase at the current rate (refer to Figure 3.6).

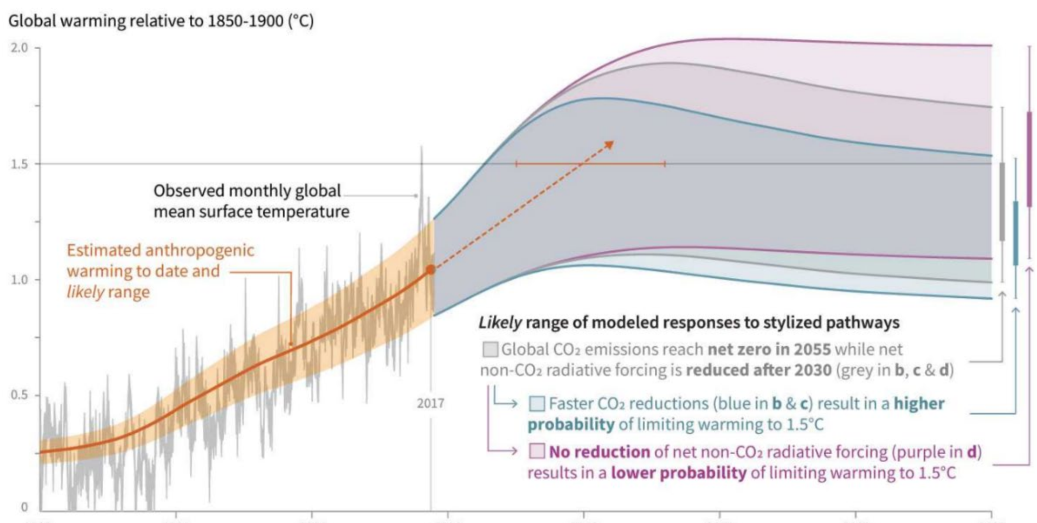



Figure 3.6 Observed Global Temperature Change and Projected Increases for Different CO2 Emission Scenarios (IPCC, 2018)

In Canada's Changing Climate report by Bush and Lemmen (2019), Chapter 4 on temperature and precipitation states that it is virtually certain Canada's climate will continue to warm in the future, with the projected increase in mean temperature in Canada being about twice the global estimate (Zhang, X. et al, 2019). The results presented specifically for Ontario project an increase in annual mean surface air temperature from 1.5 to 2.3 degrees Celsius by 2030-2050 (Zhang, X. et al, 2019) relative to 1986 to 2005.

## 3.2 Combined Coastal and Rainfall Flooding Events

Prior to selecting the appropriate storm inputs for the coastal flooding modelling scenarios, an evaluation of the Windsor Airport weather station was completed to look at the probability of combined rainfall and wave events on Lake St. Clair. Measured precipitation events from 1953 to 2020 were analyzed and plotted against wind direction at the peak of the event. Refer to the results in Figure 3.7. There is a group of precipitation events from north through to east (0 to 90 degrees) on the x-axis of Figure 3.7), then another population of storms from south (180 degrees) to north (360 degrees). For the Tecumseh analysis, the shoreline is vulnerable to storm events from the entire northwest and northeast quadrants. The analysis confirms that precipitation events do occur at the Windsor Airport when winds are from these quadrants and thus capable of generating waves that propagate onshore and potentially lead to coastal flooding.

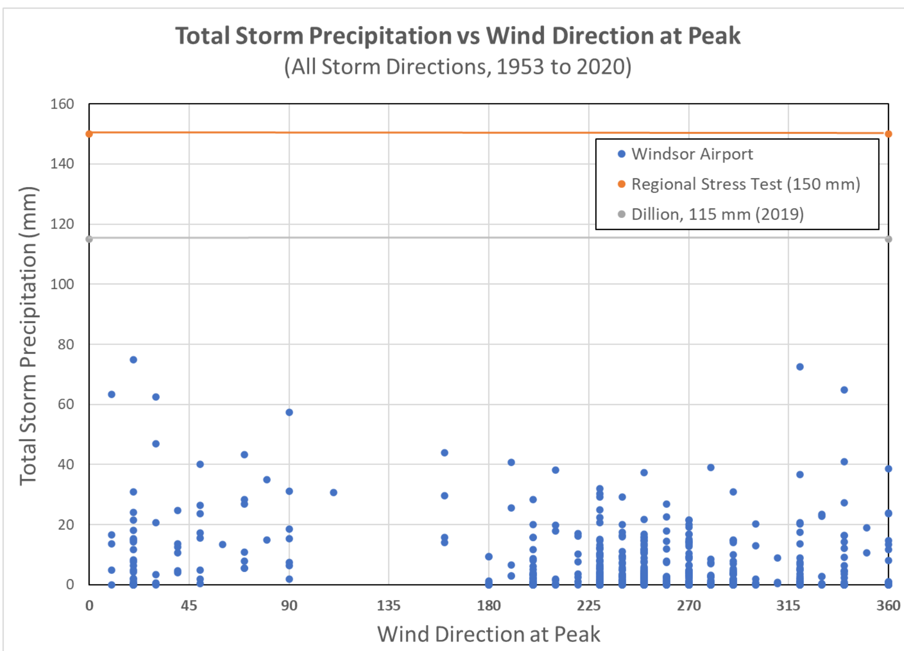



Figure 3.7 Precipitation Events by Direction at the Windsor Airport Weather Station

The precipitation events corresponding to the top 140 wind events from the northwest through to the northeast between 1953 and 2020 were isolated and plotted on Figure 3.8. Roughly 25% of the top wind events that would generate waves reaching the Tecumseh shoreline featured no precipitation. The remaining 75% of the storms featured precipitation ranging from a few millimetres (mm) to over 70 mm. These results suggested the possibility of precipitation leading to inland flooding and coastal storms leading to lake flooding could occur simultaneously and required further investigation.

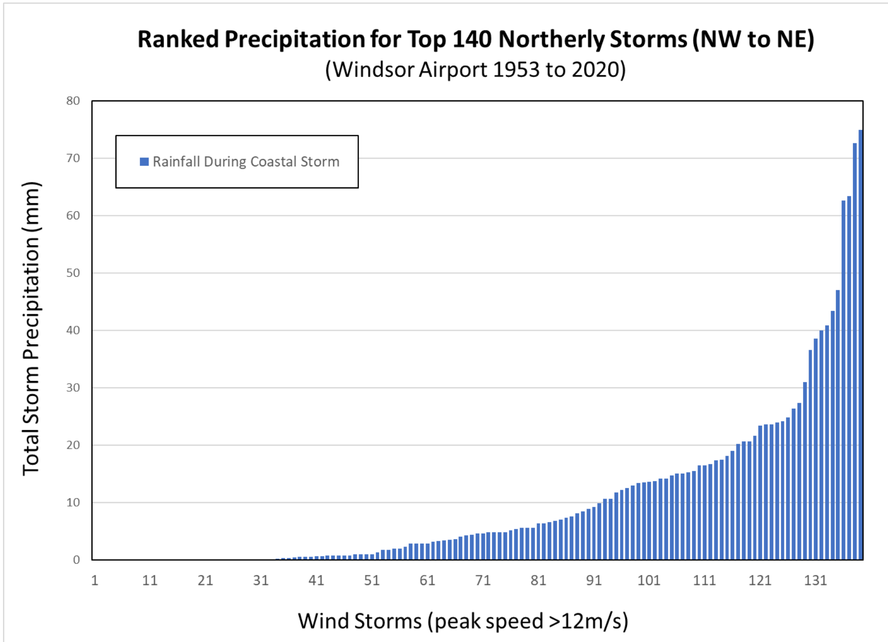



Figure 3.8 Ranked Precipitation Events during the Top 140 Northerly Wind Events (1953 to 2020)

The precipitation events that occurred during the top 140 wind events from the north are plotted against wind speed in Figure 3.9. From this graph, it is clear there is no strong correlation between wind speed and total precipitation during the top 140 events.

However, for the largest wind speed events (i.e., greater than 18 m/s), there does appear to be a decreasing trend in the amount of precipitation. Conversely, the highest precipitation totals are associated with wind speeds of approximately 13 to 17 m/s.

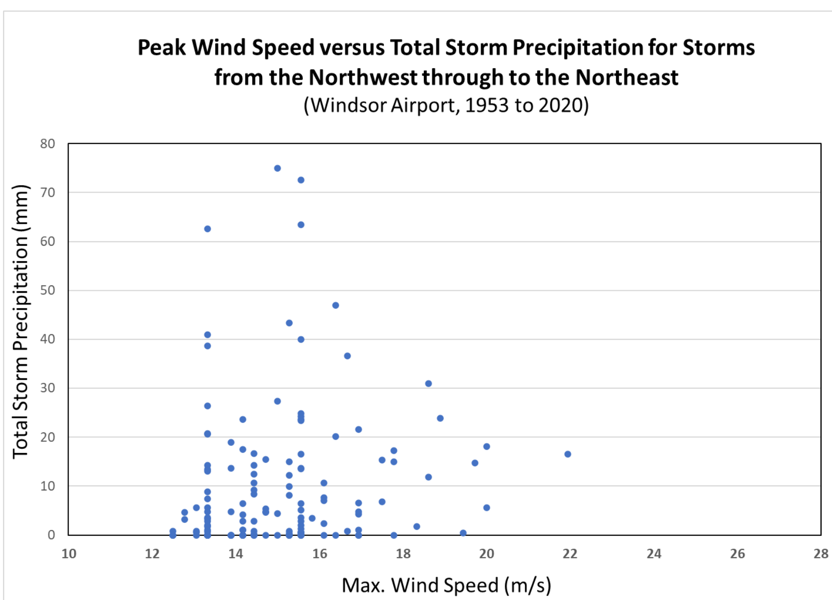



Figure 3.9 Precipitation Totals for Top 140 Northerly Wind Events by Wind Speed

Since the coastal flooding will focus on the 100-year storm, which has a 1% chance of occurrence in any given year, the EVA on the Windsor Airport winds from the north in Table 3.1 were consulted. The 100-year wind speed is 91.2 km/hr or 25.3 m/s. Since none of the measured precipitation events from Figure 3.9 featured wind speeds greater than 22 m/s, it appears the most severe storms generating waves historically have not featured major rainfall totals.

## 3.3 Storm Inputs

The rainfall and coastal storm inputs to the flood model are described in the following sections.

### 3.3.1 Synthetic Rainfall Design Storm Event Simulations

Based on design guidelines taken from the Windsor/Essex Region Stormwater Management Standards Manual (2018), a number of synthetic design rainfall events were considered for the joint rainfall and coastal flooding probability analysis. Review of historical rainfall and wind data (as a surrogate for wave height) from the Environment Canada Windsor Airport Rain Gauge determined that significant coastal storm events (low frequency) rarely coincide with high rainfall totals (refer to previous section). Coastal flooding and wave overtopping events that impact Tecumseh occur during a northerly wind condition where the majority of the regions larger rainfall events have entered the area from the southwest. It was therefore determined that there would be a low probability of a significant coastal flooding event (e.g., 100-year coastal storm) occurring at the same time as a significant rainfall event (e.g., 100-year rainfall event). Joint storms of this frequency were therefore not considered as part of this assessment.

Based on the review of potential simultaneous rainfall and coastal flooding events, the Chicago 5-year, 4-hour rainfall event was chosen as the synthetic design storm event to coincide with major coastal flooding events (100-year storm) for this model simulation exercise. This synthetic design storm event was chosen as it is shown to surcharge the majority of the existing Town storm sewer system within the model where under a larger coastal flooding event, this probability of occurrence is more likely. The region's Urban Stress Test (24 Hour Rainfall Event) synthetic design storm is considered to exceed a 100-year event and was chosen to be the most significant rainfall event assessed as part of this study. The Urban Stress Test event was therefore simulated during a more minor coastal flood condition (5-year event). Information for each simulated joint rainfall-coastal flooding scenario is further detailed in Section 4.0.

Table 3.8 summarizes the rainfall events used for the flood simulations in this study.

Table 3.8 Study Rainfall Events

| Design Storm Distribution | Synthetic Storm Event | Storm Event Duration | Incremental Intensity | Total Precipitation |
|---|---|---|---|---|
| Chicago | 5-Year Storm Event | 4-Hours | 15 minute | 49.5 mm |
| Chicago | Urban Stress Test Event | 24-Hours | 15 minute | 150 mm |

### 3.3.2 Wave Uprush and Overtopping

Wave overtopping occurs along shorelines when wind generated waves strike shorelines and overtop the crest of existing structures or embankments, as seen in the top photograph of Figure 3.10. The volume of water that overtops a structure or embankment is related to the storm water level, available water depth (d), crest height of the structure or embankment, wave height and roughness of the structure or shoreline material. Conceptual diagrams of wave overtopping and runup are provided in the middle and bottom panels of Figure 3.10.

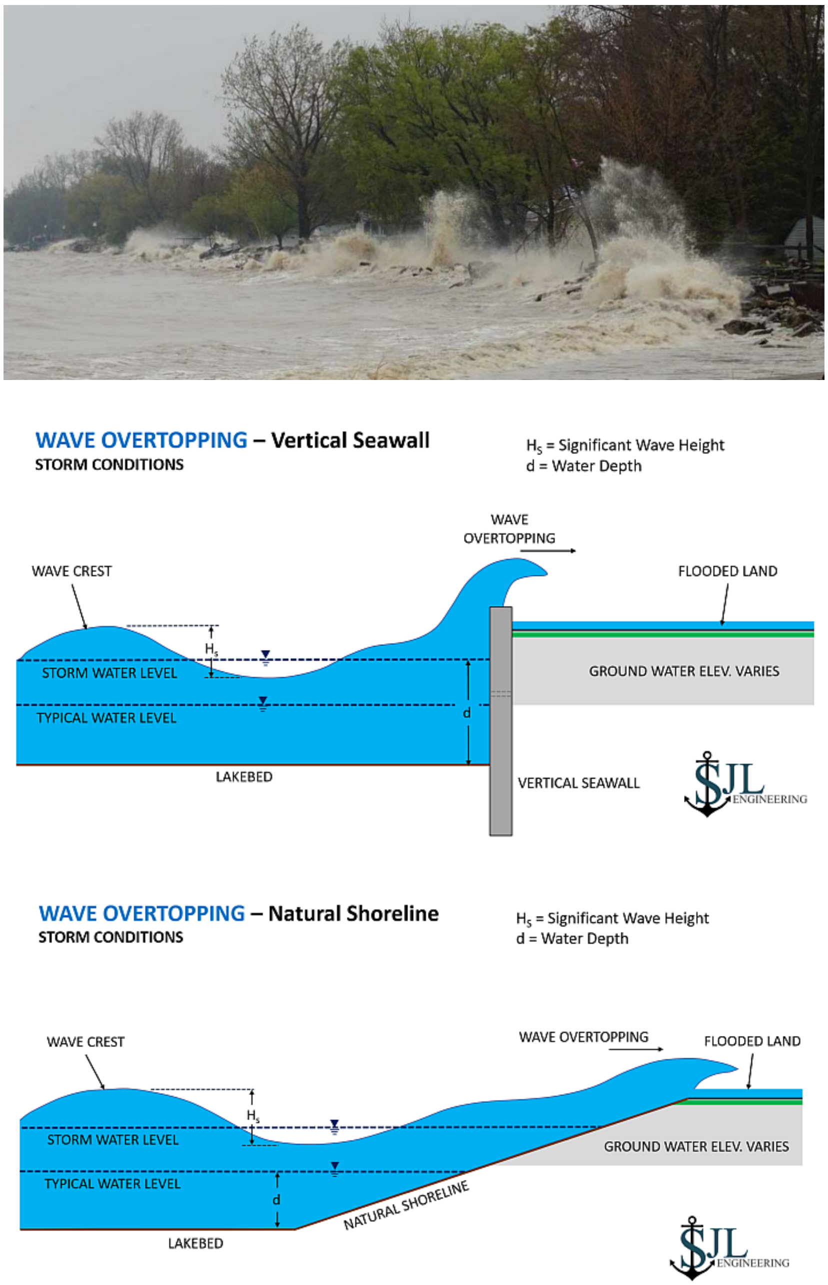



Figure 3.10 Wave Overtopping of Shore Protection Structures and Natural Shorelines

Once water overtops the seawalls, rock revetments, and beach shorelines in Tecumseh, it will propagate inland based on land elevations and grades/slopes. The GIS analysis of potential flood pathways for a typical section of the Tecumseh shoreline is presented in Figure 3.11. The parcels shaded in blue along the shoreline are below the elevation of the 100-year flood level and represent pathways for overtopped flood water to propagate inland.

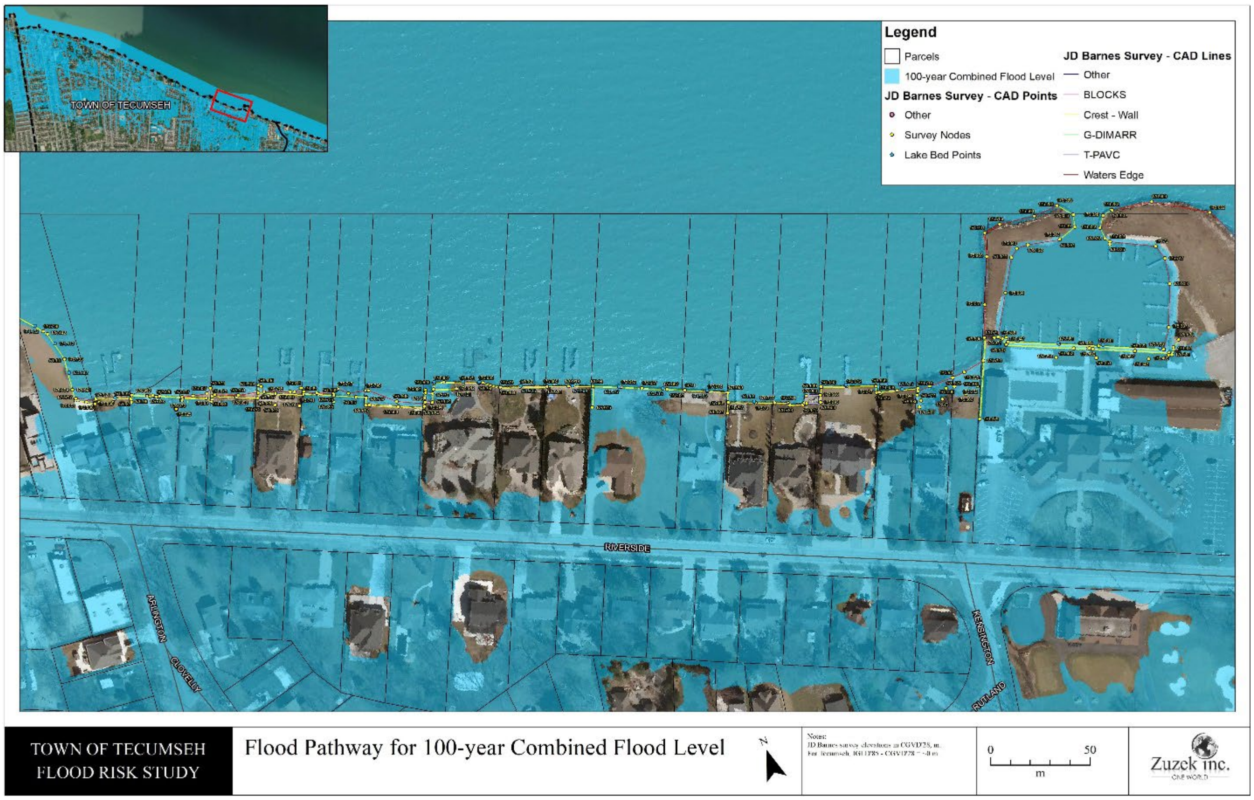



Figure 3.11 Flood Pathways for Wave Overtopping

Once the waves overtop the shoreline, water flows south between the existing development and the next potential physical barrier, Riverside Drive. However, as seen in Figure 3.12, the western and eastern portions of Riverside Driver are located below the 100-year flood level. Therefore, the coastal flood waters can propagate over the road and in an east and west direction along Riverside Drive. When the 100-year climate change lake level was considered, the entire 4.5 km length of Riverside Drive would be submerged and will not impede the inland propagation of the coastal flood.

Similarly, with the north-south orientation of Lesperance Road (see Figure 3.13), between 1.3 km and 1.6 km of the road could be completely inundated for the 100-year flood level and the 100-year climate change flood level, respectively. In other words, the road serves as a flood pathway and allows the water from a coastal storm to propagate further inland.

Brighton Road in the east features a similar scenario for the 100-year climate change flood level, with the wave overtopping inundation potentially travelling more than 1 km inland south along the road. With the 100-year flood level, the inland propagation of the coastal flood is limited to approximately 200 m, as seen in Figure 3.14.

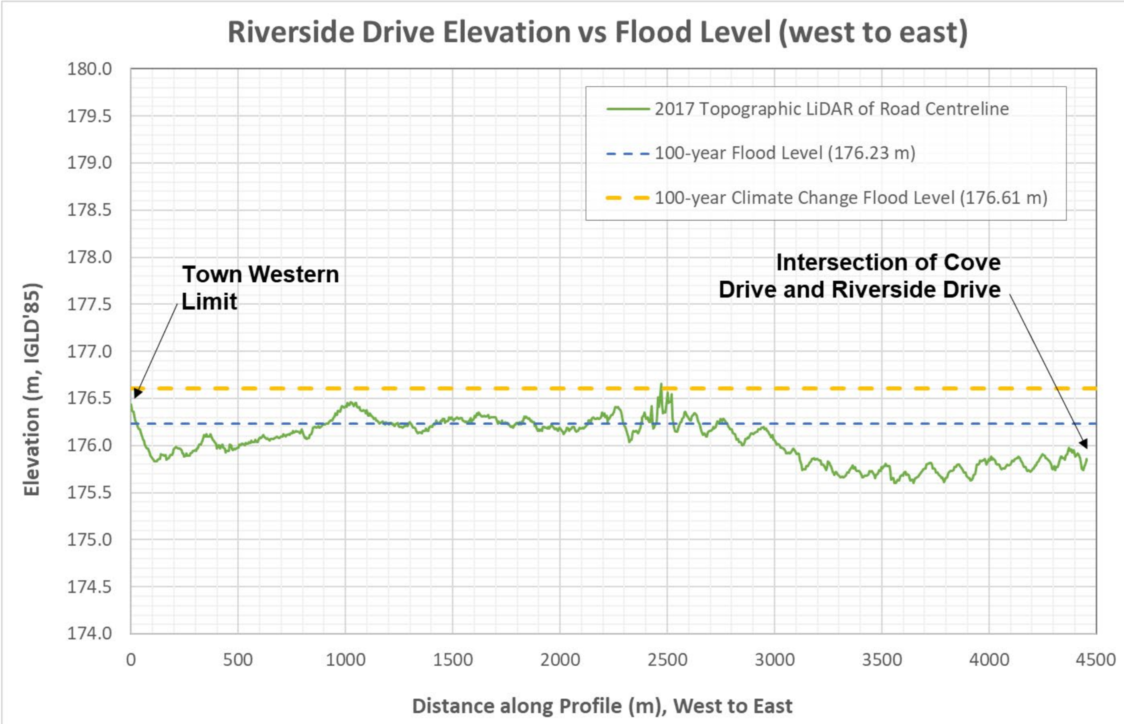



Figure 3.12 Riverside Drive Profile from West to East

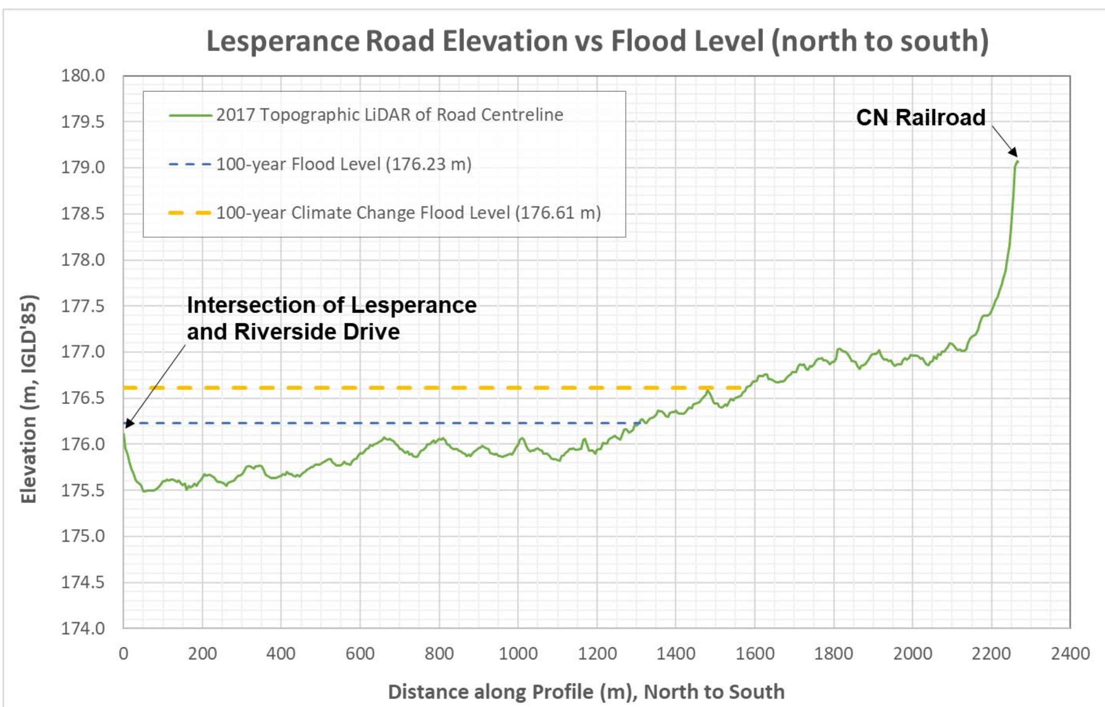



Figure 3.13 Lesperance Road Elevation versus the 100-year Flood Level and the 100-year Climate Change Flood Level

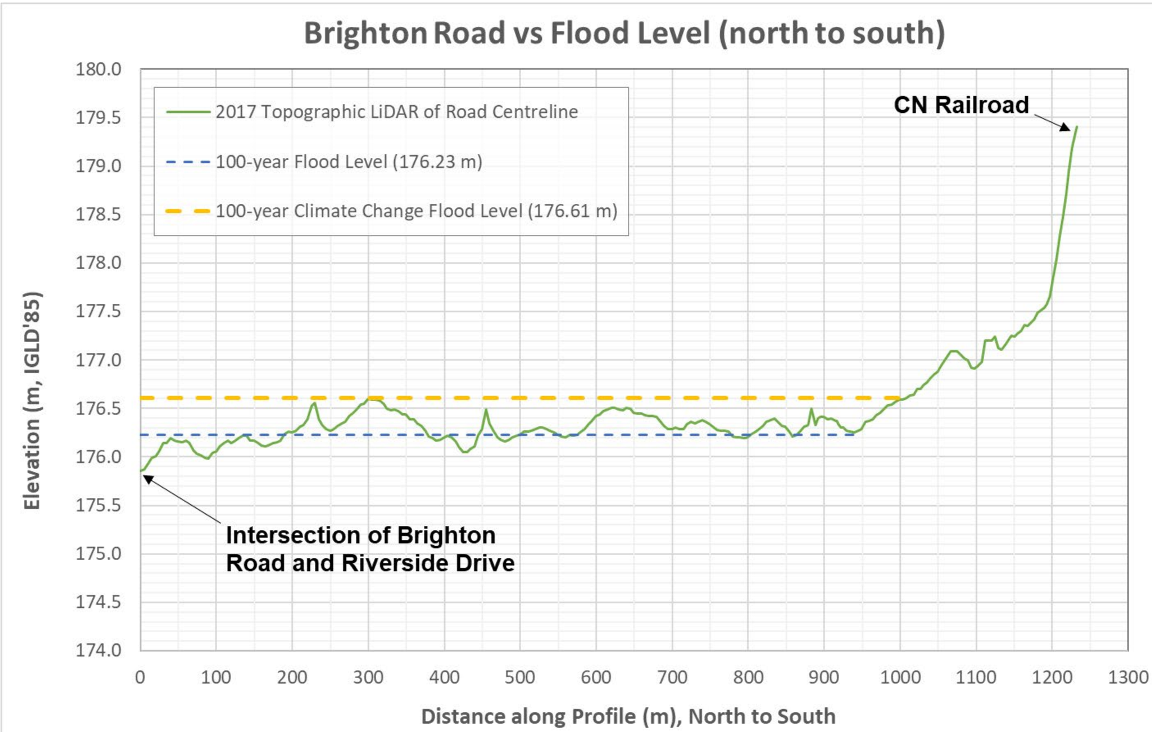



Figure 3.14 Elevation of Brighton Road and Coastal Flooding Scenarios

## 3.4 Numerical Modelling to Simulate Flooding

The numerical modelling approach developed to simulate coastal and interior flooding in Tecumseh is reviewed.

### 3.4.1 Dillon Hydrologic/Hydraulic Model

Hydrologic and hydraulic modelling for both existing and future conditions were undertaken using the previously developed Dillon model from the SDMP using the PCSWMM 2017 software. PCSWMM models stormwater, wastewater, and watershed drainage systems and includes a graphical user interface (GUI) for the United States Environment Protection Agency's Stormwater Management Model (EPA SWMM).

The model was originally developed to a catch basin and manhole level of detail and used to simulate the existing flow conditions of the minor (sewers) and major (overland) systems within the study area during large rainfall events. The minor system was modelled using a 1-Dimensional (1D) linear model network, while the major system was modelled using a 2-Dimensional (2D) approach. This integrated 1D-2D approach was used to model the ground surface in 2D free surface flow, while still using the 1D Saint Venant equations for storm sewer and municipal drain flow. The 2D characteristics of the overland flow network are defined by the underlying DEM model layer.

The components of the 1D storm drainage system include:

- Storm sewers.

- Manholes.
- Catch basins.
- Municipal Drains.
- Private Storm Connections.
- Pump Stations.
- Gravity Outfalls.

To develop a 2D surface flow mesh system within the model, a digital elevation model (DEM) of the study area was created using available LiDAR data. This form of surveying measures distance from an aerial craft to a target by illuminating the target with pulsed laser light and measuring the reflected pulses with a sensor. The 2D mesh system was used to accurately represent overland flow routing within the municipal road right-of-way and through private properties during major surface flood events. This 2D analysis allowed the Consulting Team to assess major system flooding due to both rainfall and coastal flood events and examine surface ponding depths within depressed areas, along localized roadways and within ground surfaces outside of the municipal right-of-way.

Modelling the minor and major systems required combining the results from 1D and 2D model elements. These elements are connected at key locations to allow for the transfer of flow between the two systems, in particular allowing any flow that exceeds the capacity of the minor (1D) network to flow overland to the major (2D) system. A visual representation of the LiDAR mapping used to develop the DEM and ultimately the 2D surface mesh has been provided below as a topographic elevation heat map in Figure 3.15 (the warm colours (red) are low-lying areas while the cool colours (blue) are high).

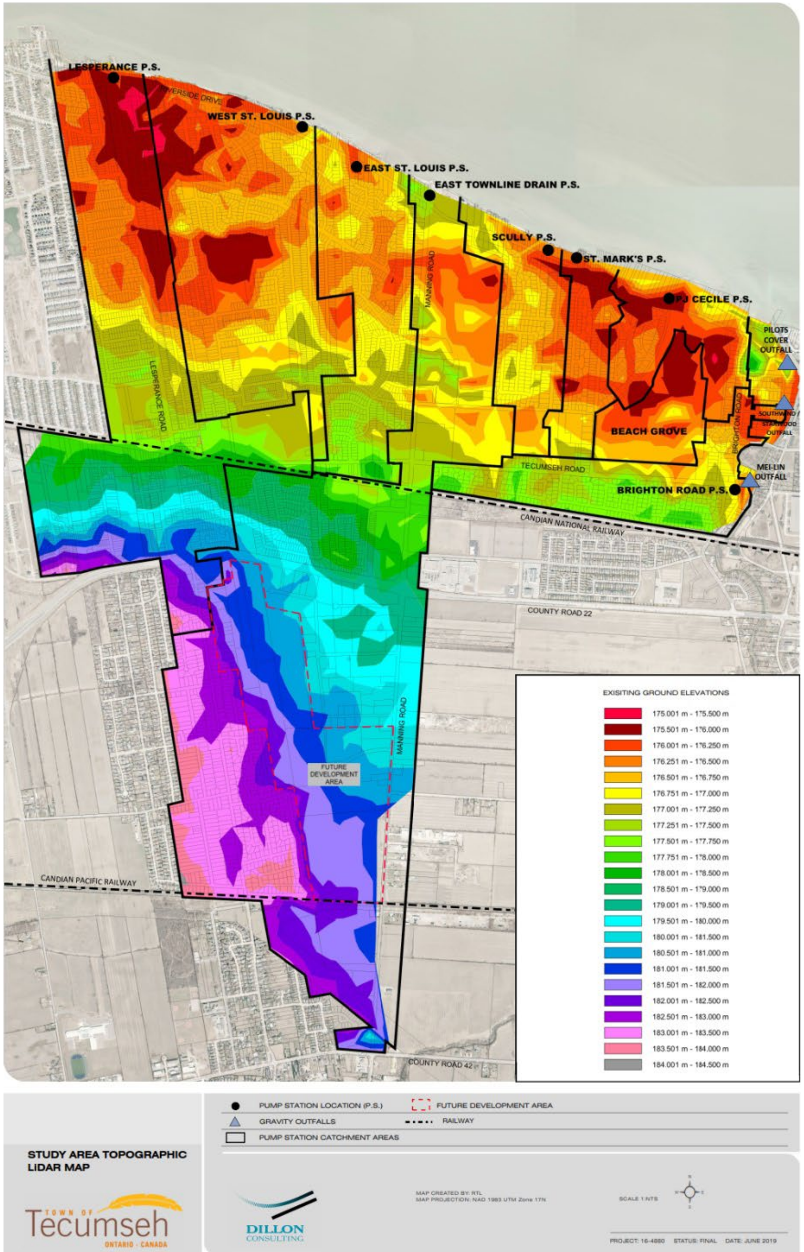



Figure 3.15 Study Area Topographic LiDAR Map

For the modelling scenarios, the recommended regional surface flooding solution SDMP pump station firm capacities were used within the model. This was completed to assess the impact of storm pump station infrastructure upgrades on the mitigation scenarios where hypothetical shoreline protection upgrades were considered to reduced flooding inputs from the lake (i.e., wave overtopping).

Provided below in Table 3.9 are the existing and proposed pump station upgrades taken from the SDMP and used in the simulations for this study. The proposed pump station firm capacity upgrades shown below were used during the future condition scenarios; simulations F through M, as discussed in Section 4.1.

Table 3.9 Modelled Pump Station Capacities

| Pump Station | Existing Condition Approx. Firm Capacity | SDMP Proposed Condition Firm Capacity |
|---|---|---|
| Lesperance | 3.143 $m^3/s$ | 9.0 $m^3/s$ |
| West St. Louis | 1.69 $m^3/s$ | 7.0 $m^3/s$ |
| East St. Louis | 3.38 $m^3/s$ | No Change |
| East Townline Drain | 7.47 $m^3/s$ | No Change |
| Scully | 0.794 $m^3/s$ | 6.0 $m^3/s$* |
| St. Marks | 0.347 $m^3/s$ | |
| PJ Cecile | 0.397 $m^3/s$ | 3.0 $m^3/s$ |
| Brighton | 2.325 $m^3/s$ | No Change |
| *Starwood/Southwind | - | 0.20 $m^3/s$ |

* Consolidated or New Pump Stations Based on Recommendations from the SDMP

### 3.4.2 Rainfall Event Simulation and Hydrologic Flow Routing

To assess the impact of rainfall events within the storm infrastructure and major overland flow system, the synthetic regional design storms identified in Section 3.2.3 were linked to each catchment area within the model. Individual catchment area runoff in the model was then dynamically simulated to enter the municipal storm sewer system. During larger storm events, once the storm sewer system reaches capacity, surcharging would occur above the obvert of the pipe, sometimes reaching the land surface and into the 2D overland mesh system. During events where the storm sewer system is surcharged to the surface, the model dynamically computes overland flow routing and surface ponding in the 2D mesh through the duration of the simulated storm and coastal flooding event. Rainfall events were simulated for over 24 hours to fully account for both the rainfall event and wave overtopping and drawdown in surface flooding.

### 3.4.3 Integrating Wave Overtopping in the Flood Predictions

Using the Topographic Survey (August 2020) by JD Barnes, 2D surface mesh points within the model were adjusted to reflect more accurate top of seawalls or natural landform elevations along the shoreline. The adjustment to the SDMP Model also included all permanent landform berms constructed in 2020 along the backs of properties in flood prone areas. The revised coastline model junctions within the 2D mesh at each property were used as wave overtopping input points along the study area shoreline.

<u>Existing Condition Scenario</u>

To simulate coastal flooding events within the joint rainfall-coastal flooding model, hourly time series coastal inflow hydrographs representing wave-overtopping rates ($m^3/hr$) were developed for 13 blocks (groups of lots) along the shoreline. The block boundaries were determined based on the existing total length of shoreline and the elevation of shoreline infrastructure. The coastal inflow hydrographs representing wave overtopping above the existing shoreline infrastructure (e.g., beaches, barriers, and seawalls) for each block were used as an input parameter in the 2D model. Each of the coastal inflow hydrographs were developed for a total duration of 22 hours, which is consistent with a large lake surge event. Of the 22 hours, 8 hours were considered peak surge/wave overtopping conditions, with a ramp period of 7 hours before and after. Figure 3.16 illustrates the 13 wave overtopping input blocks developed as part of this study for the initial determination of coastal inflow hydrographs.

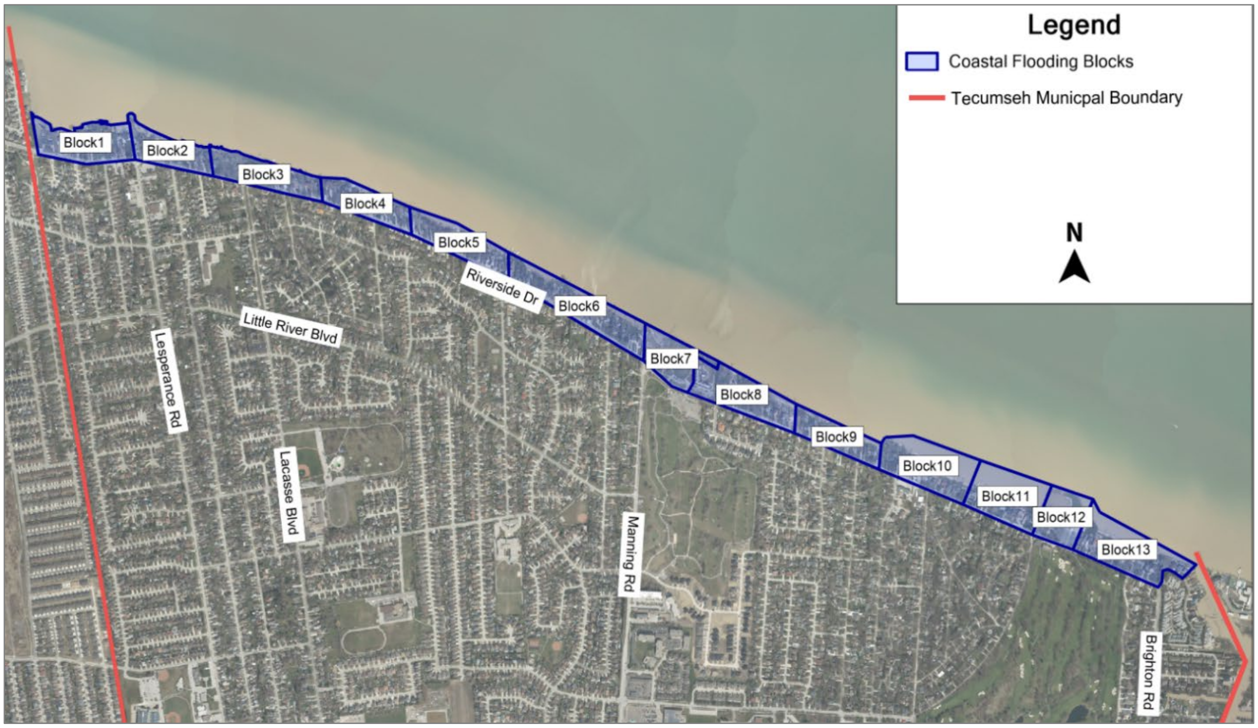



Figure 3.16 Coastal Inflow Blocks

The wave overtopping inflow hydrographs were incorporated into the drainage model at each selected property inflow point in the models 2D surface mesh. The coastal inflow point selected for each property was generally located at one of the lowest points on the site, immediately south of the shoreline infrastructure. To simulate wave overtopping for multiple properties, a scaling factor was applied to each coastal inflow point. This scaling factor represented the percentage of the total block coastal inflow hydrograph entering the 2D surface for each property. The values were determined based on the length of shoreline for the property and the type and elevation of existing shoreline infrastructure. Figure 3.17 represents a typical block with the respective scaling factor and location of inflow points located at the low points within each property in the block. The scaling factors determined at a property level are an example from the Scenario-B model set up. It is noted that the scaling factors for each property were adjusted for each scenario discussed in Section 4.1, as wave overtopping differed at a property level for different coastal flooding wave overtopping simulations.

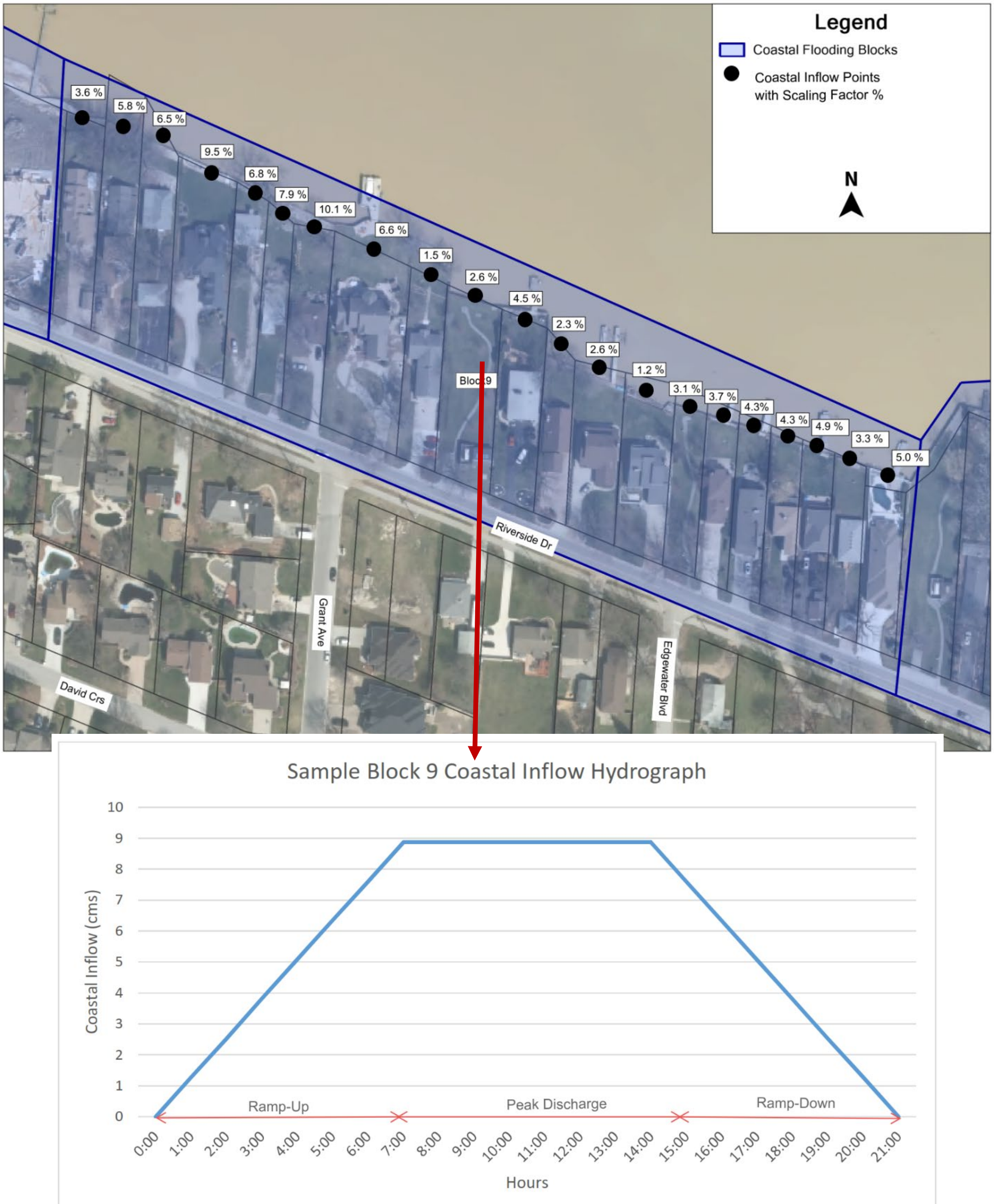



Figure 3.17 Sample Coastal Block Inflow Points and Scaling Factors

The wave overtopping inflow points at each property in the model represented a distributed coastal inflow due to high lake levels and wave action for each scenario. During each model simulation, the coastal flood waters overtopping the coastline flowed overland southerly towards Riverside Drive between buildings and toward low-lying areas. This ultimately caused surface inundation in these areas. Where storm infrastructure inlets (e.g., catch basins) exist, coastal flood water is captured by storm sewer infrastructure and ultimately discharged back into the lake through the pump stations. The 2D surface mesh junctions representing the edge of the shoreline along both Lake St. Clair and Pike Creek were assigned static water levels (WLs) representing the high WL in Lake St. Clair for the respective scenarios. As such, coastal flood waters also have the potential to flow back over the shoreline and into the lake if surface flood inundation levels along the coastline are higher than the water level in the lake.

Proposed Shore Protection Upgrades to Limit Wave Overtopping

A similar approach was followed for modelling the proposed future condition scenarios (Scenarios G, H, J and K). However, the wave overtopping inflow hydrographs during proposed conditions scenarios were limited at each shoreline property based on hypothetical upgrades to the existing shoreline protection. Wave overtopping limits of 10 and 50 L/m/s were assessed. These overtopping limits simulated the potential for standardized increases in the crest elevation of the existing shoreline protection along the coastline and a hypothetical continuous flood berm, thus limiting wave overtopping to specific flows. Since the existing condition model results determined the coastal wave overtopping during storms was the primarily governing factor for the flood inundation within the study area, no synthetic rainfall events were assessed during the investigation of remedial shoreline solutions with the model.

Proposed Flood Barrier on Riverside Drive and Brighton Road

Two additional scenarios were considered representing a hypothetical flood barrier along Riverside Drive, as discussed in Section 4.1. For this simulation, a continuous flood barrier was developed along the centerline of Riverside Drive and extending south along Brighton Road to Tecumseh Road. The flood barrier at the western edge of the municipality was extended north to prevent coastal flood waters from being conveyed overland to the City of Windsor. For the additional two simulations (Scenario L & M), no restriction in coastal inflows at the shoreline (i.e., shoreline infrastructure upgrades) were assumed.

## 3.5 Flood Vulnerability and Potential Economic Damages

There is a large body of literature that documents the linkages between flood inundation depth and economic damages to buildings, contents, and other community infrastructure. The basic premise of the relationship is the greater the depth of flooding relative to the first floor building elevation, the greater the economic damages. These methods have been applied previously in the Great Lakes to evaluate flood risk (Baird, 2005; Baird, 2012; Baird, 2015; Zuzek Inc., 2021).

### 3.5.1 Building Damages from Flood Inundation

Following our literature review, the depth-damage mathematical relationships developed for the State of Louisiana by GEC (2006) were selected for use in this study. This work was completed for the US Army Corps of Engineers and was chosen for the following reasons: 1) the depth-damage curves included relationships for freshwater and saltwater (many studies only provide information for saltwater), 2) curves were available for a wide range of buildings types (e.g., residential, commercial, single storey, two storey, etc.), 3) curves were available for short- and long-duration floods, 4) curves were provided for minimum, mostly likely, and maximum potential damages, facilitating the presentation of a range of damages, and 5) the depth-damage relationships were based on field data and expert opinion (i.e., multiple lines of evidence).

The depth-damage relationship for a one-story residential building is provided in Figure 3.18. Polynomial equations were fit to the data and used to establish potential building damages for Tecumseh based on the actual depth of water above the first floor, not the increments of 1 foot as noted by the datapoints in Figure 3.18.

The structural damage relative to depth above the main floor is presented graphically in Figure 3.19 based on the 'most likely' curve. For example, with 1 ft of water above the main floor, structural damage of 32% is predicted, where the associated economic damages would be estimated at 32% of the assessed value. With 2 ft of flooding above the main floor, the damage estimate increases to 37%. It is worth noting that flooding equal to the first-floor elevation still generates potential economic damages based on structural damage to the building (which includes utilities), due to the threat of basement flooding and associated damages.

Damages to building contents were calculated with similar depth-damage relationships as depicted graphically in Figure 3.20, which shows the percentages for the 'most likely' curve. With 1 ft of flooding above the main floor, damage to the contents is estimated at 29% (relative to the value of the contents in the home). If flooding was equal to the main floor elevation, 9% content damages are predicted based on potential losses in the basements, crawl spaces, and flooring.

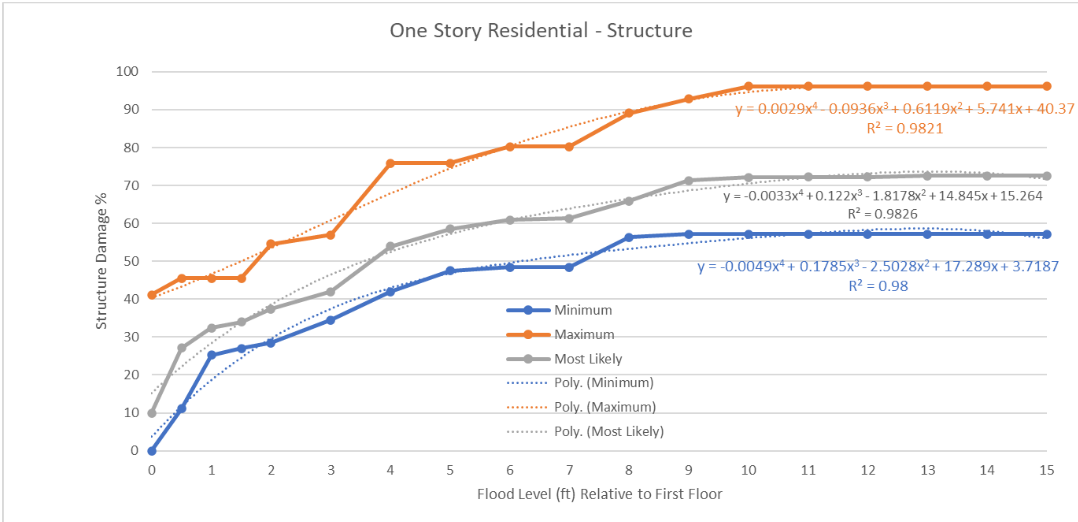



Figure 3.18 Depth-Damage Curves for Flooding above the Main Floor

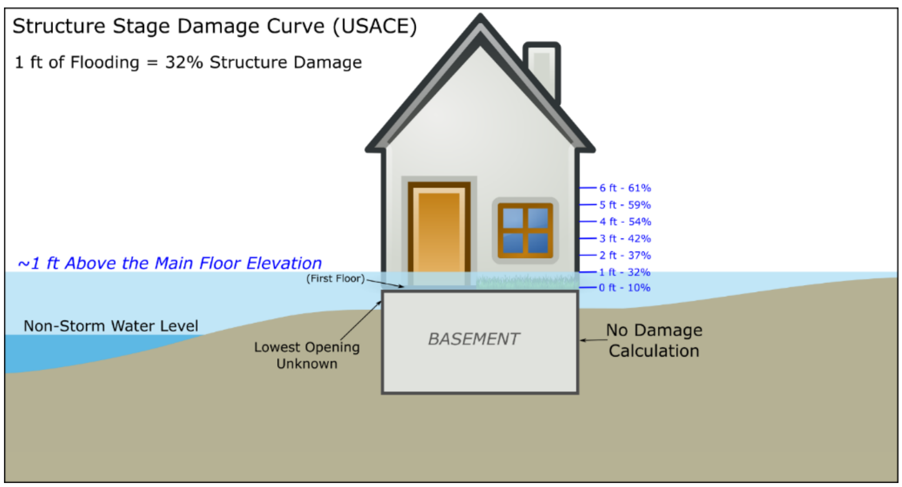



Figure 3.19 Stage Damage Relationship for a One-Storey Residential Building

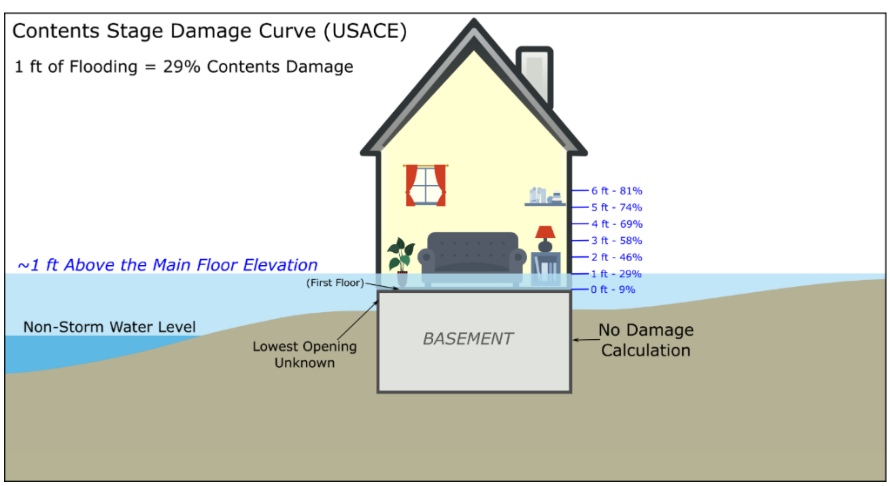



Figure 3.20 Stage Damage Relationship for Contents in a One-Story Residential Building

Several potential pathways for basement flooding are shown visually in the schematic diagram in Figure 3.21, including land grades sloping towards the home, windows and doors below the flood level, cracks in the basement foundation, and storm sewer backup.  Actual conditions will be site-specific to each home and this graphic is for information purposes only.

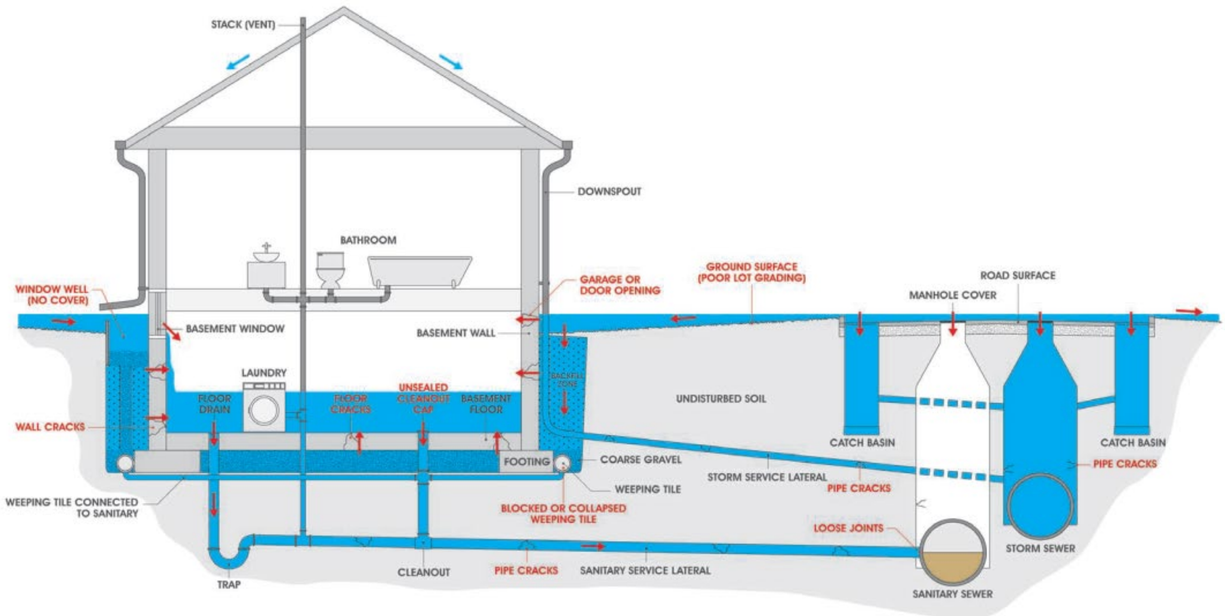



Figure 3.21  Schematic Diagram of Potential Pathways for Basement Flooding from Overland Flow and Storm Sewer Backup (image courtesy of ICLR, 2009)

### 3.5.2 Basement Flooding from Foundation Drains and Sewer Backups

Sewer backups can also contribute to basement flooding in Tecumseh.  For example, some homes constructed prior to 1980 feature foundation drains that are connected to the sanitary sewer system.  In Figure 3.22 all pre-1980s homes are shaded blue.  This is just an estimate and some pre-1980s homes may not have floor drains connected to the sanitary sewer system.

This potential threat is further explained in the schematic diagram in Figure 3.23.  If the sanitary sewer is surcharged (full) above the basement grade and floor drains are connected, water will flow into the home and establish an equilibrium with the level in the manhole.  Grey water connections to the sanitary sewer for bathrooms, sinks, and laundry facilities also represent potential pathways for the water in the sewer system to flow backwards into basements, as depicted in Figure 3.23.  Backflow valves can reduce the risk of the sanitary sewer surcharging basements in Tecumseh.

Lot by lot information on the occurrence of basement drains connected to the sanitary sewer system and the use of backflow valves is not available.  Even with the estimated spatial extent of the flooding in the scenarios presented in Section 4.0, it is not possible to estimate which sanitary sewer systems will reach a surcharge condition during coastal flood.  Therefore, it is not possible to put a quantitative estimate on the number of vulnerable basements.  Every home within the study area should be aware of this risk and their own unique situation.


Figure 3.22 Estimate of Homes Constructed Prior to the 1980s with Potential Basement Drain Connection to the Sanitary Sewer

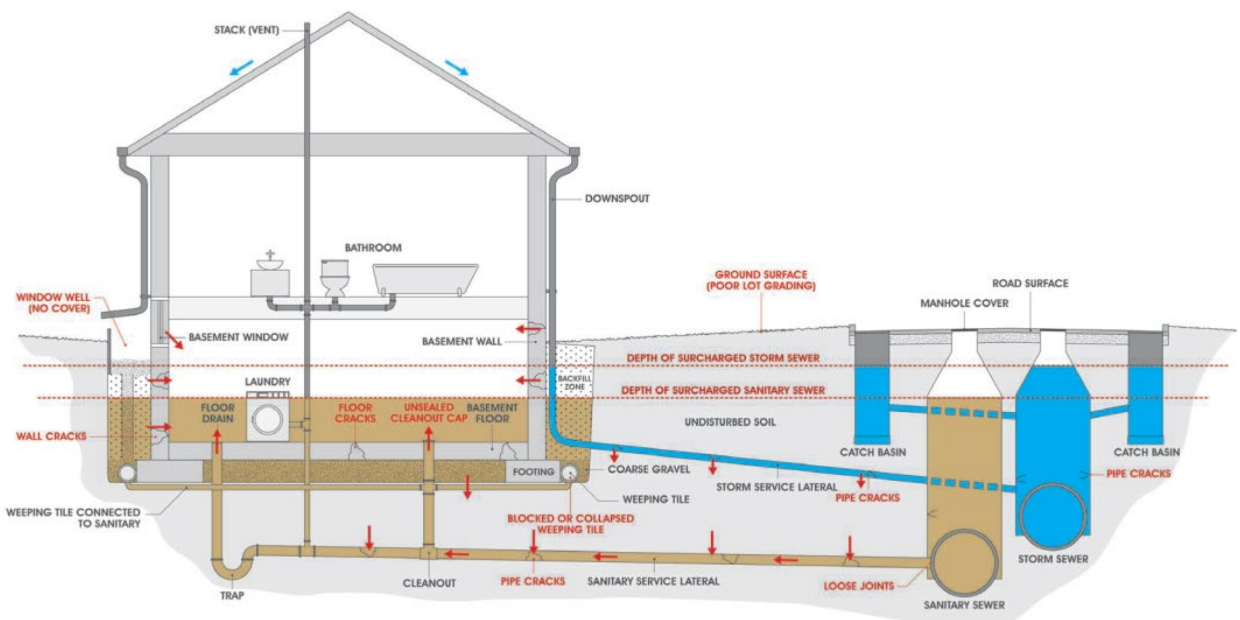



Figure 3.23 Schematic Diagram of Potential Sanitary Sewer Backup (image courtesy of ICLR, 2009)

# 4.0 FLOOD RISK RESULTS

Section 4.0 summarizes the results of the flood risk assessment for the Town of Tecumseh.

## 4.1 Storm Selection for Flood Modelling

The results of the technical investigation were used to select a series of potential severe storm conditions for the flood modelling and risk assessment, including wave overtopping events during coastal storms, intense rainfall events, and storms that featured both wave overtopping and rainfall. Modelling scenarios assumed physical condition for the shoreline, and coastal storm and rainfall inputs are summarized in Table 4.1.

Table 4.1 Modelling Scenario, Physical Conditions, and Inputs

| Scenario | Physical Conditions | Coastal Storm Inputs | Rainfall Event Inputs | Simulated with Model |
|---|---|---|---|---|
| A | Existing Conditions | 100-year Lake Level | n/a | Yes |
| B | Existing Conditions | 100-year Lake Level | 5-year Rainfall | Yes |
| C | Existing Conditions | 100-year Climate Change Lake Level | n/a | Yes |
| D | Existing Conditions | 100-year Climate Change Lake Level | 5-year Rainfall | Yes |
| E | Existing Conditions | 5-year Lake Level | Urban Stress Test | Yes |
| F | Overtopping Limited to 2 L/s/m | 100-year Lake Level | n/a | No |
| G | Overtopping Limited to 10 L/s/m | 100-year Lake Level | n/a | Yes |
| H | Overtopping Limited to 50 L/s/m | 100-year Lake Level | n/a | Yes |
| I | Overtopping Limited to 2 L/s/m | 100-year Climate Change Lake Level | n/a | No |
| J | Overtopping Limited to 10 L/s/m | 100-year Climate Change Lake Level | n/a | Yes |
| K | Overtopping Limited to 50 L/s/m | 100-year Climate Change Lake Level | n/a | Yes |
| L | Riverside Drive Flood Barrier | 100-year Lake Level | n/a | Yes |
| M | Riverside Drive Flood Barrier | 100-year Climate Change Lake Level | n/a | Yes |

## 4.2 Flood Simulations for Existing Conditions and Mitigation Scenarios

The results of the flood modelling, risk assessment, and mitigation approaches are summarized for the existing conditions and the assumed hypothetical mitigation options, such as upgraded shore protection across the shoreline and updated pump stations, are implemented. The estimated economic damages are based on assessed property values, not market values, and thus will underestimate actual damages based on 2022 real estate valuations.

### 4.2.1 Scenario A – 100-year Coastal Flood

The maximum inundation across the study area for the 100-year flood level, 176.23 m IGLD'85, is plotted in Figure 4.1. Flood depths along the lakefront are generally less than 0.3 m, although there are local hotspots where the flooding is greater. In the west along Riverside Drive, Lesperance Road and the connecting road network to the south, flood depths up to 0.9 m are widespread. For the central portion of the study area, the flooding is generally limited to the road network and less than 0.3 m in most locations. In the east, a significant portion of Riverside Drive, the golf course, and neighbouring residential areas are flooded for Scenario A. Road flooding is in the range of 0.6 to 0.9 m.

The potential building and content damage associated with Scenario A are summarized in Table 4.2. The flood waters resulted in 850 residential and commercial buildings with water against the exterior (outside) foundation. See Figure 4.2. We've assumed between 10 and 20% of the basements would be flooded via lowest openings, such as window wells and basement doors. The potential for surcharging of the sanitary sewer and basement flooding is high but not possible to quantify, as discussed in Section 3.4.2. Over 100 buildings featured structural and contents damage due to flood waters above the first-floor elevation, with predicted damages ranging from $24M to $37M.

Table 4.2 Scenario A Building Risk and Potential Flood Damages

| Risk Factor | Count | Damage |
|---|---|---|
| Wet Exterior Basement Foundation | 850 Buildings | Assume 10% to 20% of basements would be flooded via lowest opening |
| Sanitary Sewer Surcharging during the Flood | High risk during a coastal flood | Not possible to quantify economic damages (and not included) |
| First Floor Flooding and Content Damages | 110 Buildings | $24 to $37 million |

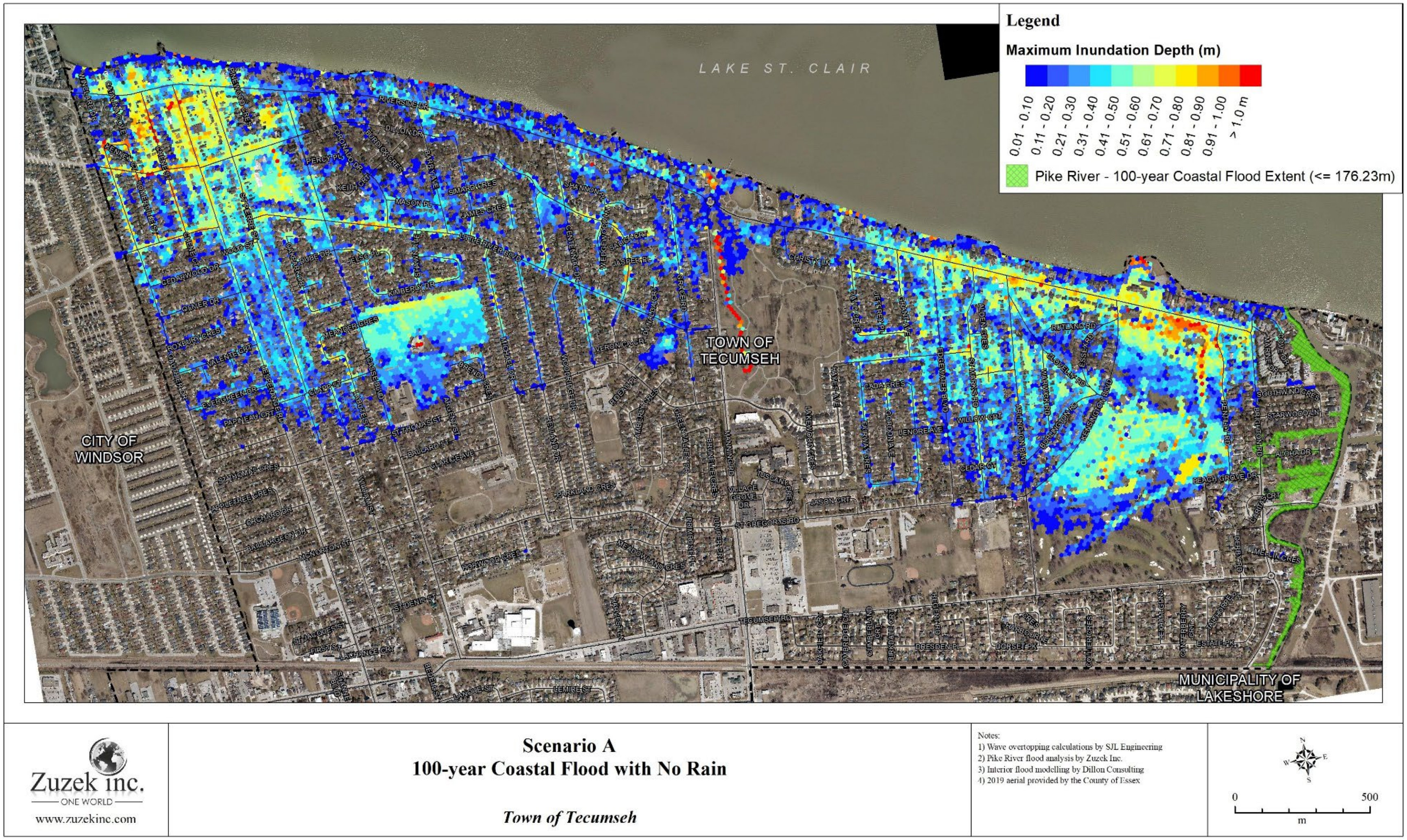



Figure 4.1 Scenario A 100-year Coastal Flood

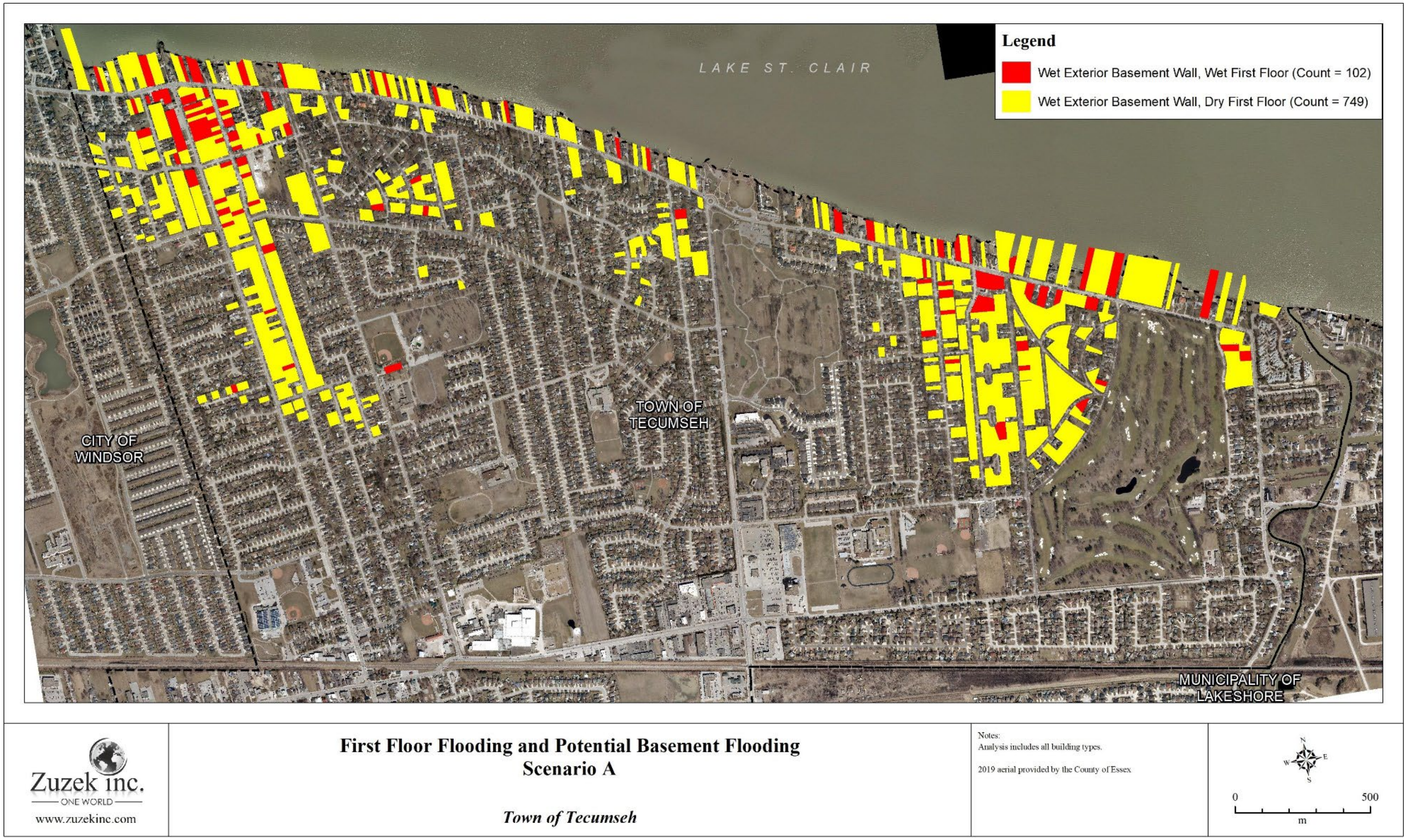



Figure 4.2 Shaded Residential Parcels with Flood Risk for Scenario A (red=wet exterior basement wall and wet first floor; yellow=wet exterior basement wall only)

### 4.2.2 Scenario H – 100-year Coastal Flood with Minor Shore Protection Upgrades

In Scenario H the 100-year coastal flood was re-simulated with hypothetical targeted upgrades to existing shoreline protection structures to limit wave overtopping to 50 L/s/m. See Figure 4.3 for the extent of the flooding at the peak of the storm. To limit wave overtopping to 50 L/s/m, upgrades would be required to shoreline infrastructure for approximately 30 of the lakefront properties. The remainder already featured wave overtopping rates less than 50 L/s/m during the 100-year event.

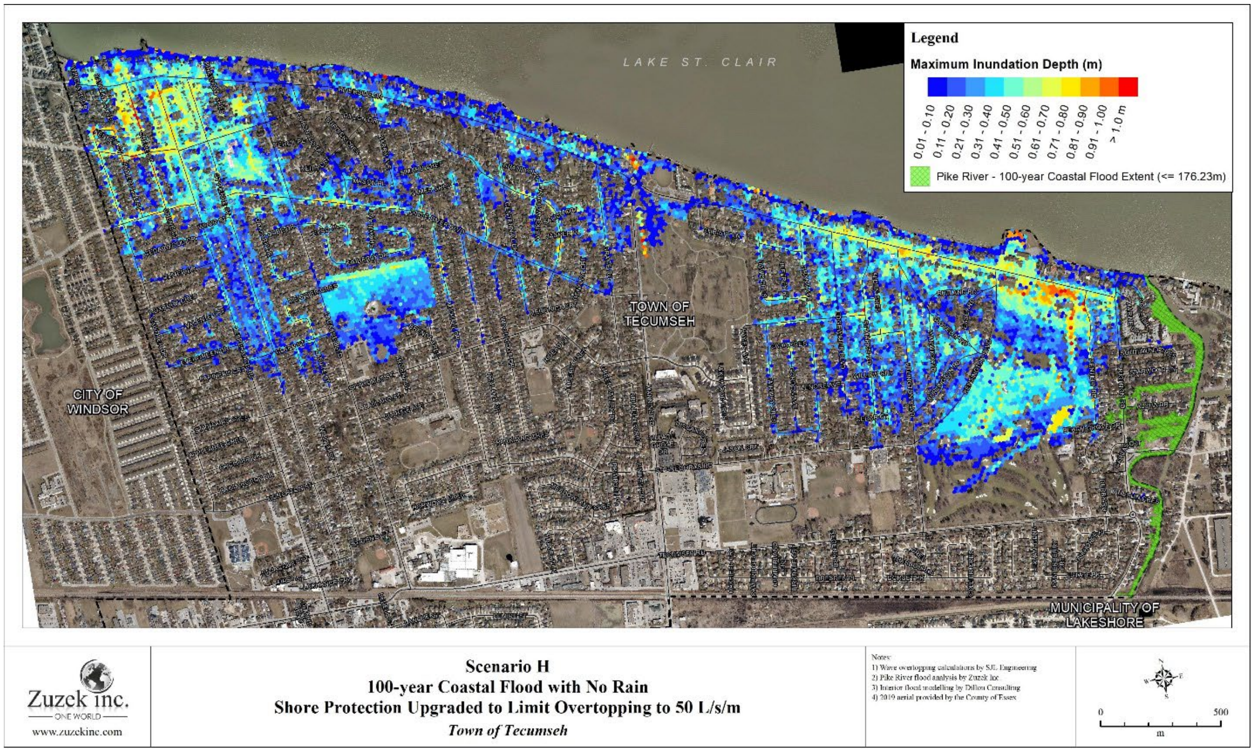



Figure 4.3 Scenario H 100-year Coastal Flood with Overtopping Limited to 50 L/s/m

Scenario H resulted in a modest reduction of the potential flood risk and damages compared to Scenario A. Refer to the results in Table 4.2 versus Table 4.3. For example, the number of wet exterior basement walls was reduced from 850 for Scenario A to 670 for Scenario H. The number of buildings with first floor flooding decreased from 110 to 80. Collectively, the shore protection upgrades reduced flood exposure and potential economic damages by $5M to $7M.

Since the reductions in flood exposure were estimated to cost $1 million in shoreline protection upgrades, the benefit-cost ratio was quite substantial at 5 to 7. Typically for water resource and hazard risk reduction planning, a project with a benefit-cost ratio of greater than 1 is considered a legitimate and beneficial undertaking. If implemented, Scenario H would be consistent with addressing the most vulnerable waterfront properties with minor upgrades to their shore protection.

Table 4.3 Scenario H Mitigation Simulation Results

<table>
<tr><th colspan="3">Mitigation Scenario: Shore protection crest elevation upgraded at approximately 30 properties (avg. height = 0.2 m) to limit wave overtopping during the coastal storm to 50 L/s/m. Cost $1 million.</th></tr>
<tr><td>Risk Factor</td><td>Count</td><td>Damage</td></tr>
<tr><td>Wet Exterior Basement Foundation</td><td>670 Buildings</td><td>Assume 10% to 20% of basements would be flooded via lowest opening</td></tr>
<tr><td>Sanitary Sewer Surcharging during the Flood</td><td>High risk during a coastal flood</td><td>Not possible to quantify economic damages (and not included)</td></tr>
<tr><td>First Floor Flooding and Content Damages</td><td>80 Buildings</td><td>$19 to $30 million</td></tr>
<tr><td colspan="3">Reduction in Potential Damages versus Scenario A: $5 to $7 million.</td></tr>
<tr><td colspan="3">Benefit-cost Ratio: 5 to 7 (for every dollar spent on mitigation, avoided damages are 5 to 7 dollars).</td></tr>
</table>

### 4.2.3 Scenario G – 100-year Coastal Flood with Moderate Shore Protection Upgrades

Scenario G assumes a more significant hypothetical shoreline protection structure upgrade program has been implemented. Where necessary, the crest of the individual structures would be upgraded to limit wave overtopping to 10 L/s/m for Scenario G, which is consistent with the design standard for a well-engineered private property shoreline protection structure. The wave overtopping calculations and numerical models were re-run to estimate the spatial extent and depth of flooding for Scenario G. This concept substantially reduces the shoreline and interior flooding, as seen in Figure 4.4. To achieve a 10 L/s/m wave overtopping limit during the 100-year event, 140 properties would require shoreline structure upgrades. Those upgrades would include an increase in the structure crest elevation by an average of 0.5 m with the range across the 140 properties being 0.2 m to 1.0 m. This hypothetical scenario would cost approximately $6M to $7M.

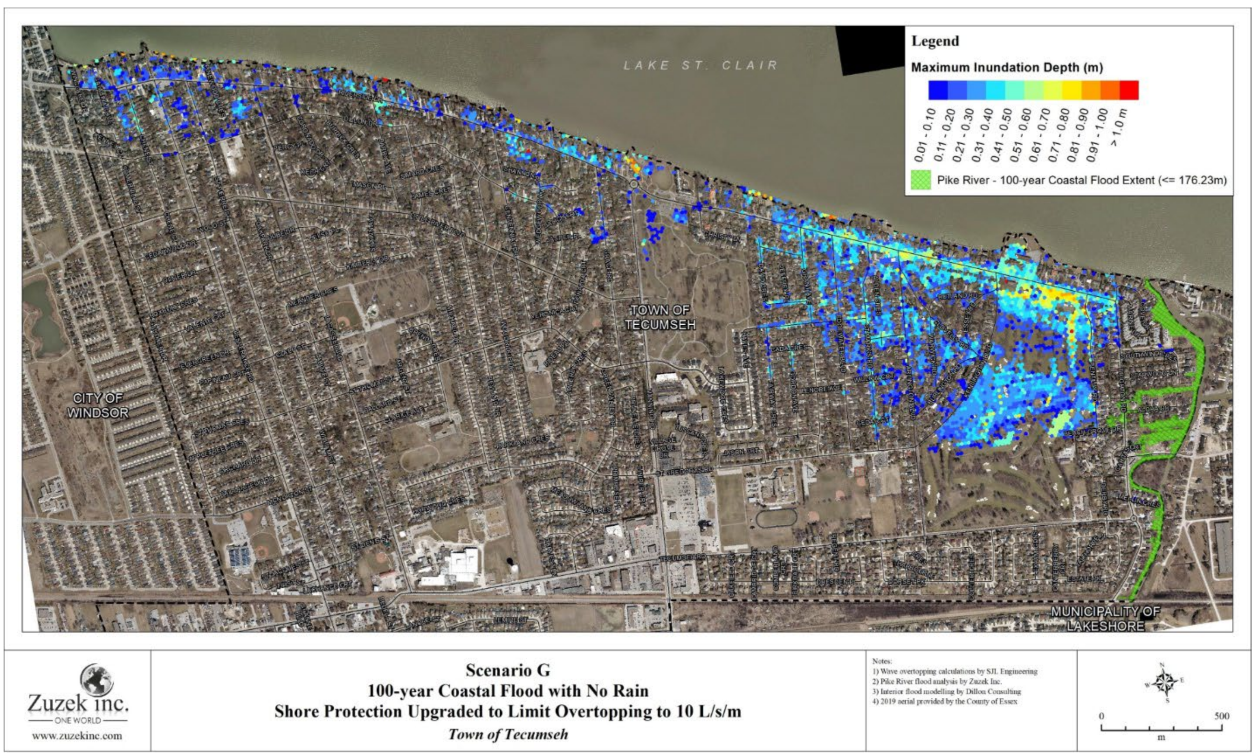



Figure 4.4 Scenario G 100-year Coastal Flood with Wave Overtopping Limited to 10 L/s/m by Community-scale Shore Protection Upgrades

The reduction in potential economic damages due to building flooding is substantial for Scenario G, ranging from $21M to $32M. With the $6M to $7M investment in upgraded shore protection, a positive benefit-cost ratio of 3 to 5 based on avoided flood damages would be realized. While such a project would require a significant consultation, planning, investment, and community wide implementation, the potential reduction in flooding damages are substantial and worthy of a future feasibility investigation.

Table 4.4 Scenario G Mitigation Simulation Results

| Mitigation Scenario: Shore protection crest elevation raised at approximately 140 properties (avg. height = 0.5 m) to limit wave overtopping during the coastal storm to 10 L/s/m. Cost $6 to $7 million. | | |
|---|---|---|
| Risk Factor | Count | Damage |
| Wet Exterior Basement Foundation | 190 Buildings | Assume 10% to 20% of basements would be flooded via lowest opening |
| Sanitary Sewer Surcharging during the Flood | High risk during a coastal flood | Not possible to quantify economic damages (and not included) |
| First Flood Flooding and Content Damages | 10 Buildings | $3 to $5 million |
| Reduction in Potential Damages versus Scenario A: $21 to $32 million. | | |
| Benefit-cost Ratio: 3 to 5 (for every dollar spent on mitigation, avoided damages are 3 to 5 dollars). | | |

### 4.2.5 Scenario F – 100-year Coastal Flood with Major Shore Protection Upgrades

The coastal flood risk for Scenario F is eliminated by a hypothetical project that would reduce the wave overtopping volume to a maximum of 2 L/s/m across the entire study area. This is equivalent to typical wave spray during a storm. Refer to Figure 4.5. This scenario did not require a model simulation, since such a substantial reduction in wave overtopping would eliminate the coastal flood risk for the 100-year flood.


Figure 4.5 No Coastal Flooding for Scenario F due to Substantial Shore Protection Upgrades

The details of the mitigation scenario are provided in Table 4.5. Shore protection upgrades would be required for approximately 180 properties to implement Scenario F, with an average increase in the crest elevation of 0.8 m. The range of required lot by lot crest elevation upgrades is 0.2 m to 1.5 m. The cost to implement the shore protection upgrades is $9M to $11M.

With the Scenario A potential flood damages eliminated, the resulting benefit-cost ratio for Scenario F is 2 to 4. While this is still a very attractive project from an economic risk reduction perspective, it is worth noting it would be more disruption to the existing uses of the shoreline by private landowners versus Scenario G due to the number and magnitude of shoreline infrastructure upgrades required.

Table 4.5 Scenario F Mitigation Simulation Results

| Mitigation Scenario: Shore protection crest elevation raised for approximately 180 properties (avg. height = 0.8 m) to limit wave overtopping during the coastal storm to 2 L/s/m. Cost $9 to $11 million. | | |
|---|---|---|
| Risk Factor | Count | Damage |
| Wet Exterior Basement Foundation | 0 Buildings | none |
| Sanitary Sewer Surcharging during the Flood | None | none |
| First Floor Flooding and Content Damages | 0 Buildings | none |
| Reduction in Damages versus Scenario A: $24 to $37 million. | | |
| Benefit-cost Ratio: 2 to 4 (for every dollar spent on mitigation, avoided damages are 2 to 4 dollars). | | |

### 4.2.6 Scenario L – 100-year Coastal Flood with Continuous Riverside Drive Barrier

Scenario L is a hypothetical mitigation scenario where the coastal flooding along the Lake St. Clair shoreline and the banks of Pike Creek are contained with a flood barrier. The barrier (permanent or removable) extends along 4.5 km of Riverside Drive and 1 km south along Brighton Road. There are many design and logistical challenges with this scenario, such as how to deal with intersections, existing infrastructure, and private property. However, as seen in Figure 4.6 a continuous flood barrier would be very successful at mitigating interior flooding in Tecumseh. For example, aside from very isolated and minor locations of sewer surcharging (e.g., west of the Beach Grove Golf and Country Club), the model does not predict any interior flooding. In other words, the coastal flood is contained to the lakefront properties north of Riverside Drive and east of Brighton Road.

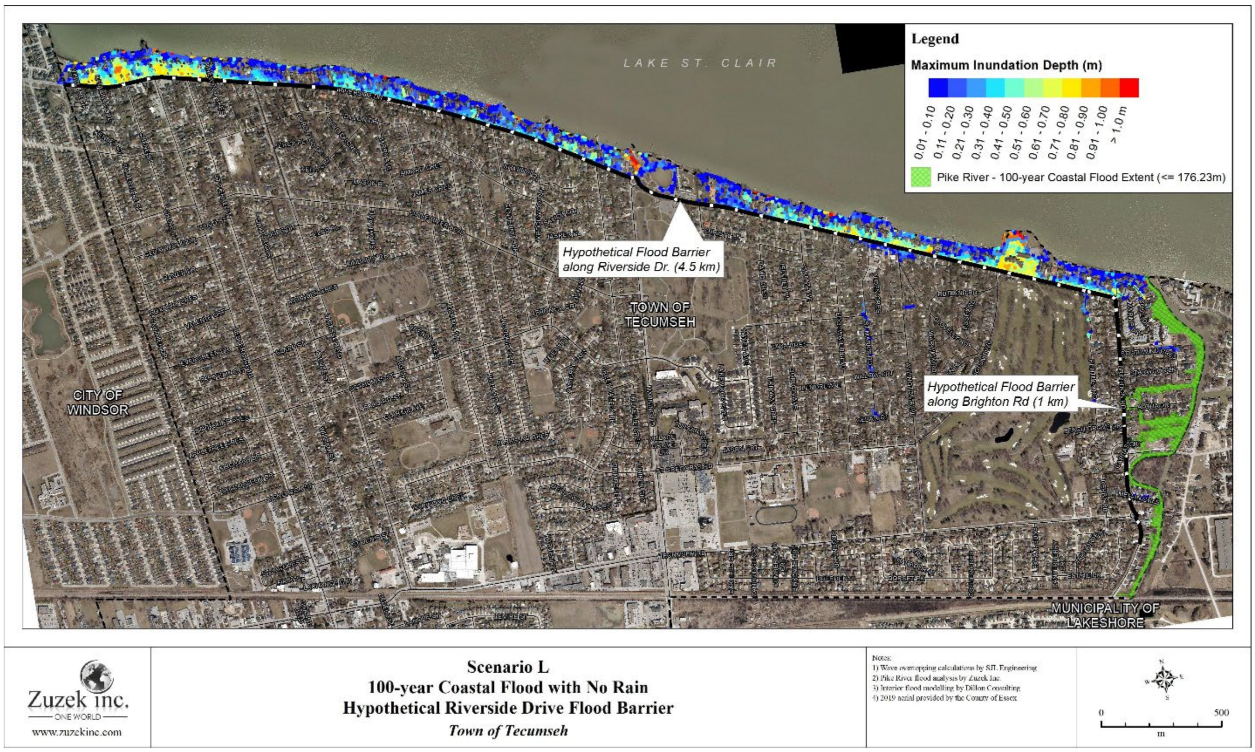



Figure 4.6 Model Simulation Results for Scenario L Hypothetical Flood Barrier

When compared to Scenario A, the Scenario L mitigation concept reduces wet exterior basement foundations from 850 to 126 (refer to Table 4.6). A sanitary sewer surcharging threat still exists but as with the other scenarios, the magnitude, spatial extent, or potential economic damages can not be estimated. However, the threat would be substantially reduced compared to Scenario A, especially for the interior south of Riverside Drive. The potential impacts to buildings from first floor flooding and contents damage decreases from $24M - $37M to $9M to $14M.

While Scenario L reduced the potential flooding damages by roughly 65% for the entire study area, the potential implications for the properties between the hypothetical flood wall and the lake were investigated further to see if they were disproportionally impacted. The Scenario A damages for shoreline properties north of Riverside Drive ranged from $7M to 11M. With the hypothetical flood wall installed, the potential damages north of Riverside Drive increased to $9M to 14M.

Table 4.6 Scenario L Mitigation Simulation Results

| Mitigation Scenario: A flood barrier is constructed along 4.5 km of Riverside Drive and 1 km of Brighton Road. Cost unknown. | | |
|---|---|---|
| Risk Factor | Count | Damage |
| Wet Exterior Basement Foundation | 126 Buildings | Assume 10% to 20% of basements would be flooded via lowest opening |
| Sanitary Sewer Surcharging during the Flood | High risk during a coastal flood | Not possible to quantify economic damages |
| First Floor Flooding and Content Damages | 33 Buildings | $9 to $14 million |
| Reduction in Potential Damages versus Scenario A: $15 to $23 million. | | |
| Benefit-cost Ratio: not available as the cost of the flood barrier was not estimated. | | |

### 4.2.7 Scenario C – 100-year Climate Change Coastal Flood

The 100-year coastal storm was re-run for Scenario C, at a higher lake level of 176.61 m IGLD'85, to account for the projected impacts of climate change on future water levels (refer to Section 3.1.4). The spatial extent and depth of this significant flooding event are depicted in Figure 4.7.

The Scenario C flood extends 1.5 km inland and the depth of flooding exceeds 1.0 m in many locations. In the west, the communities centred on Lesperance Road and Dillon Drive, including an extensive portion of Riverside Drive have flood waters exceeding 1.0 m for Scenario C. The majority of the buildings would be surrounded by water during the flood, as seen in Figure 4.7.

In the centre of the study area, Lacasse Park and Lakewood Park South also feature flooding depths greater than 1.0 m. Many of the buildings, especially in the older neighbourhoods, feature wet exterior basement foundation walls and first-floor flooding. Refer to Figure 4.8.

For the eastern half of the study area, there is extensive flooding along the lake and in the interior residential areas between Lakewood Park South and the Beach Grove Golf and Country Club. Along the banks of Pike Creek, most of the buildings east of Brighton Road are protected from flooding by the higher land elevations. Road access would be compromised for conventional vehicles and emergency responders.

Table 4.7 summarizes the potential economic damages to buildings and contents for the peak flood conditions with Scenario C. A total of 2,840 buildings would have a wet exterior basement foundation, which is a 230% increase over the number of buildings with wet exterior basement foundations for Scenario A (100-year flood based on historical extremes). In addition, the flood would result in 730 buildings with structural damage at or above the main floor and to the building contents, which is more than a 500% increase over Scenario A. Projected damages to buildings and contents are $124 to $188 million.

Sanitary sewer surcharging is not possible to predict with the existing model but the potential for basement flooding would be very high for the Scenario C flood.

Table 4.7 Scenario C Building Risk and Potential Flood Damages

| Risk Factor | Count | Damage |
|---|---|---|
| Wet Exterior Basement Foundation | 2840 Buildings | Assume 10% to 20% of basements would be flooded via lowest opening |
| Sanitary Sewer Surcharging during the Flood | High risk during a coastal flood | Not possible to quantify economic damages |
| First Flood Flooding and Content Damages | 730 Buildings | $124 to $188 million |

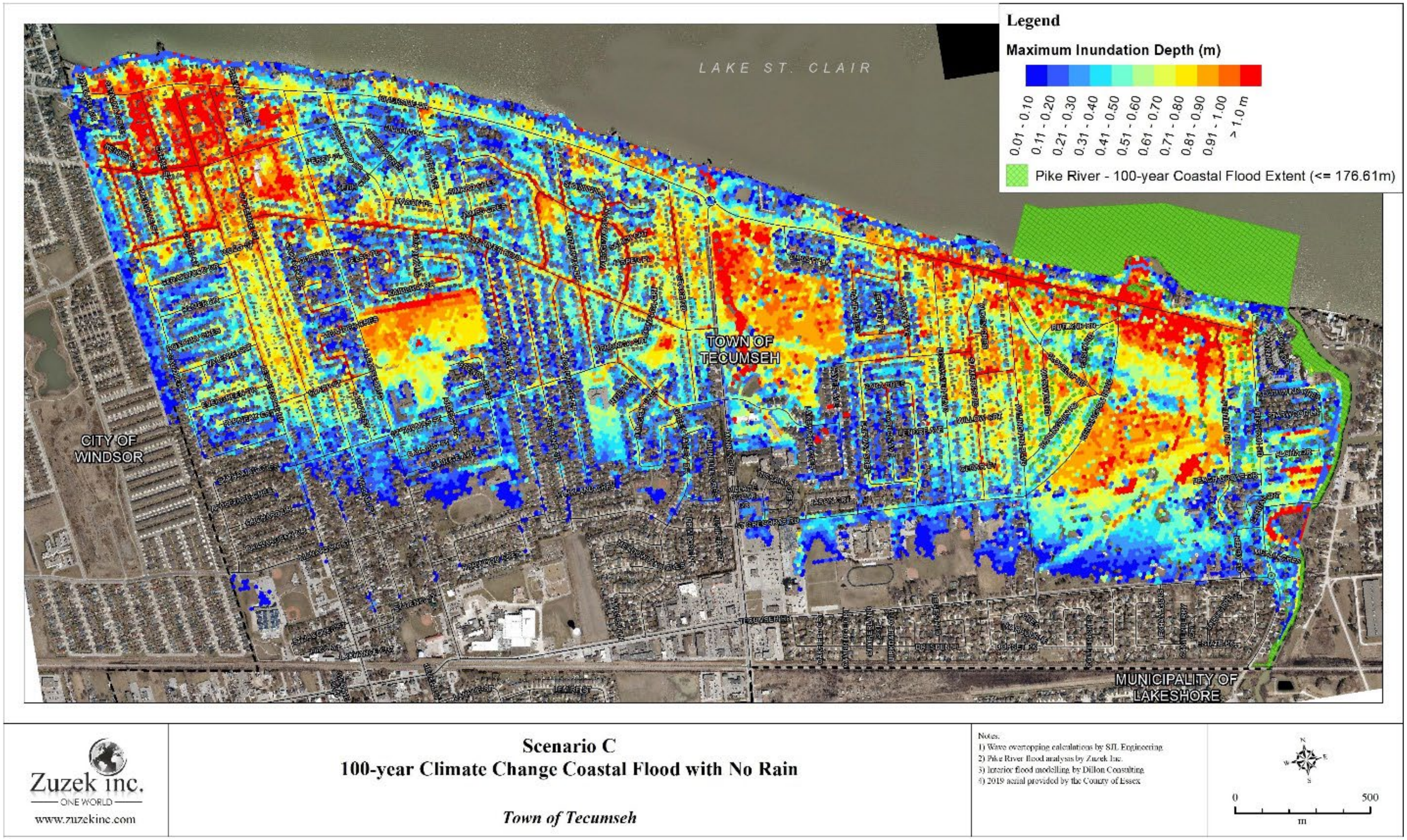



Figure 4.7 Scenario C 100-year Climate Change Coastal Flood

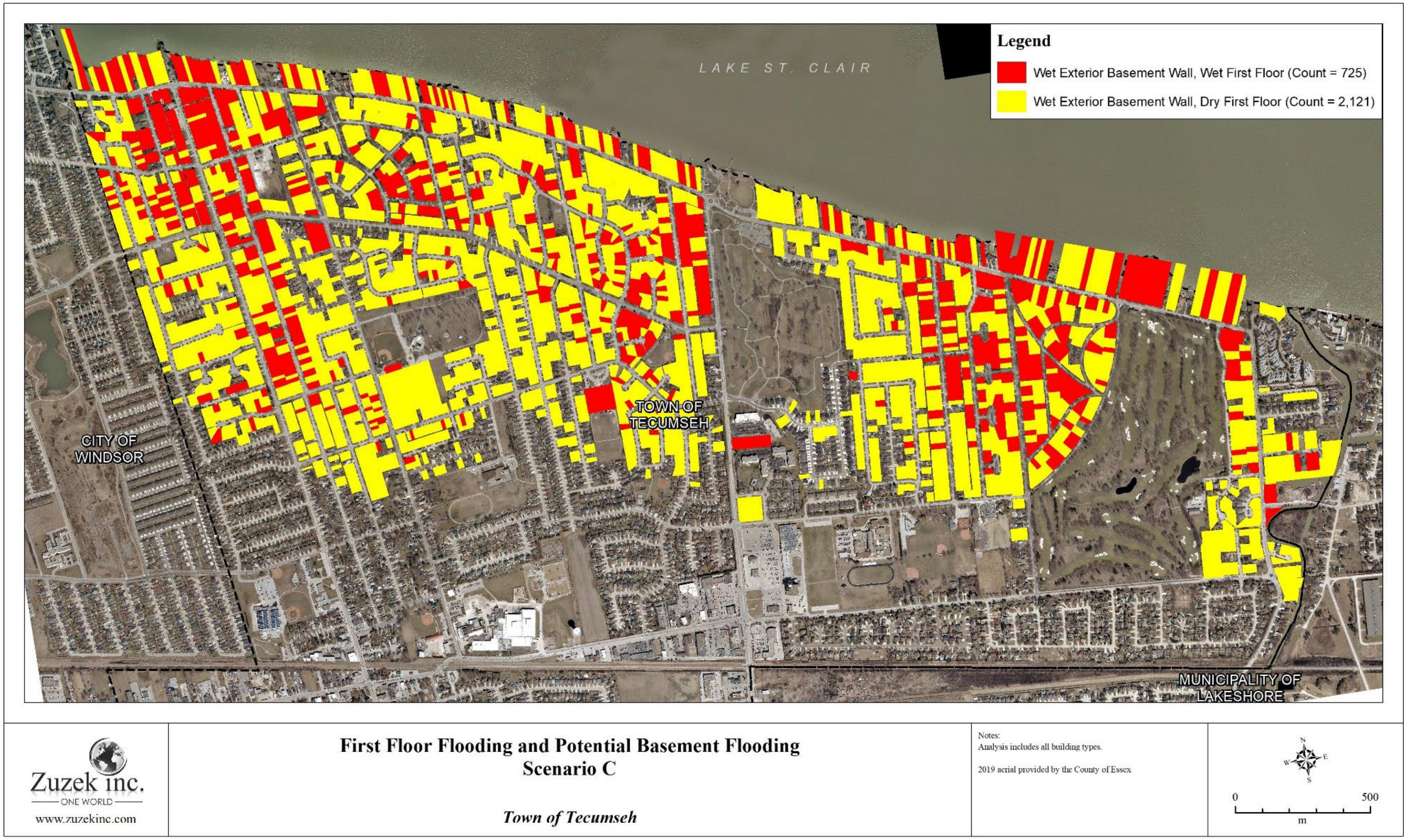



Figure 4.8 Shaded Parcels with Basement Flood Risk for Scenario C (red=wet exterior basement foundation and wet first floor; yellow=wet exterior basement foundation only)

### 4.2.8 Scenario K - 100-year Climate Change Coastal Flood with Minor Shore Protection Upgrades

For the Scenario K simulation, the 100-year climate change coastal flood was re-run assuming a hypothetical targeted shore protection upgrade project was implemented for the lowest properties across the Tecumseh shoreline. With these hypothetical upgrades, wave overtopping was limited to 50 L/s/m or less across the entire shoreline for Scenario K. The extent of the flooding is still significant, as depicted in Figure 4.9.

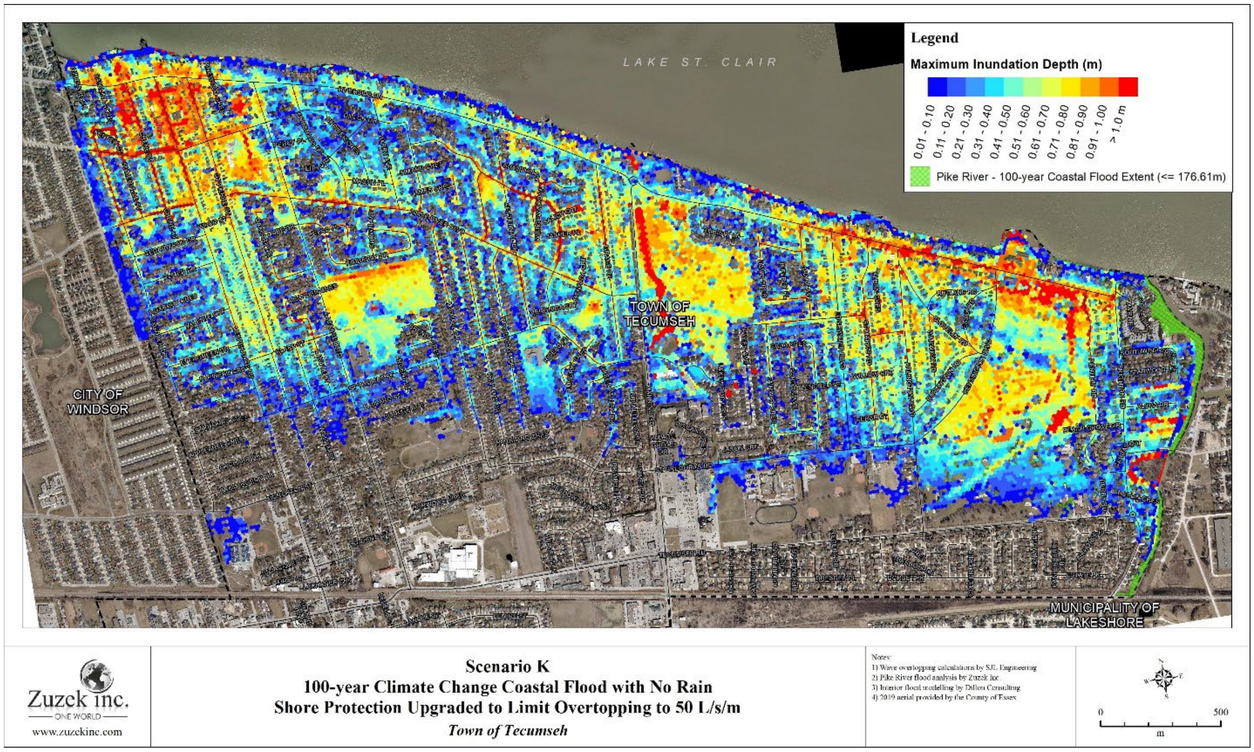



Figure 4.9 Maximum Flood Depth for 100-year Climate Change Flood with Overtopping Limited to 50 L/s/m

Table 4.5 summarizes the flood risks and potential economic damages. The number of homes with the potential for wet exterior foundation walls decreased by almost 600 but is still extensive, with 2,271 impacted. If these homes feature basement windows or walkout basement doors, they would be vulnerable to basement flooding.

The number of homes with flood waters at or above the main floor decreased by about 300 but is still very high, at 447. The potential economic damages from the Scenario K flooding ranges from $80 to $123 million, compared to $124 to $188 million for Scenario C.

The costs associated with the minor shoreline protection upgrades modelled in this scenario were estimated to be on the order of $7 to 8 million. Shoreline structure upgrades would be required for 170 properties with the average increase in structure crest elevation being 0.5 m. Based on the economic damages mitigated when compared to Scenario C, the cost benefit ratio for Scenario K is between 6 and 8.

Table 4.8 Scenario K Mitigation Simulation Results

| Mitigation Scenario: Shore protection crest elevation raised for approximately 170 properties (avg. height = 0.5 m) to limit wave overtopping during the coastal storm to 50 L/s/m. Cost $7 to $8 million. | | |
|---|---|---|
| Risk Factor | Count | Damage |
| Wet Exterior Basement Foundation | 2,271 Buildings | Assume 10% to 20% of basements would be flooded via lowest opening |
| Sanitary Sewer Surcharging during the Flood | High risk during a coastal flood | Not possible to quantify economic damages |
| First Floor Flooding and Content Damages | 447 Buildings | $80 to $123 million |
| Reduction in Damages versus Scenario C: $44 to $65 million. | | |
| Benefit-cost Ratio: 6 to 8 (for every dollar spent on mitigation, avoided damages are 6 to 8 dollars). | | |

### 4.2.9 Scenario J - 100-year Climate Change Coastal Flood with Major Shore Protection Upgrades

For the Scenario J simulation, the 100-year coastal flood was re-run assuming a hypothetical major community-scale shore protection upgrade project was implemented across the study area. The mitigation project would reduce wave overtopping to 10 L/s/m or less for each shoreline property during the 100-year climate change coastal flooding event and require an upgrade to roughly 210 shoreline properties. The modelling results are summarized visually in Figure 4.10. While the extent of the inundation is still significant across the study area, major reductions in flooding were realized when compared to the base climate change simulation without any shore protection upgrades (refer to Scenario C results in Figure 4.7).

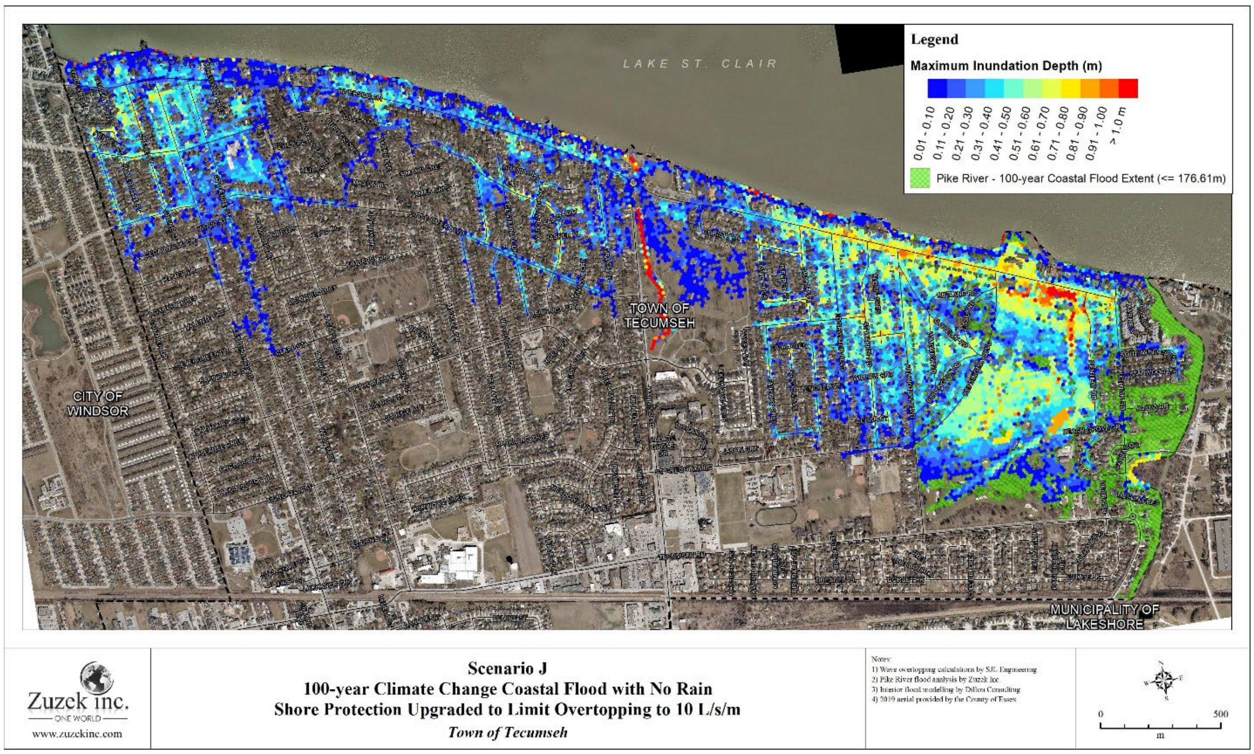



Figure 4.10 Maximum Flood Depth for 100-year Climate Change Flood with Major Shore Protection Limiting Overtopping to 10 L/s/m

For Scenario J the number of buildings with a wet exterior basement foundation wall is substantially reduced from 2,840 to 620. The threat of sanitary sewer surcharging is still significant for Scenario J, but also reduced when compared to the base climate change scenario (Scenario C).

The most dramatic benefit of Scenario J is the reduction in potential building and content damages, which are $101 to $153 million, when compared to Scenario C. The estimated number of buildings with first floor flooding decreased from 730 to 90. Given the estimated construction cost of $12 to $13 million to limit the wave overtopping rate to 10 L/s/m, the benefit-cost ratio is 8 to 12 for Scenario J.

Table 4.9 Scenario J Mitigation Simulation Results

| Mitigation Scenario: Shore protection crest elevation raised for approximately 210 properties (avg. height = 1.0 m) to limit wave overtopping during the coastal storm to 10 L/s/m. Cost $12 to $13 million. | | |
|---|---|---|
| Risk Factor | Count | Damage |
| Wet Exterior Basement Foundation | 620 Buildings | Assume 10% to 20% of basements would be flooded via lowest opening |
| Sanitary Sewer Surcharging during the Flood | High risk during a coastal flood | Not possible to quantify economic damages |
| First Floor Flooding and Content Damages | 90 Buildings | $23 to $35 million |
| Reduction in Damages versus Scenario C: $101 to $153 million. | | |
| Benefit-cost Ratio: 8 to 12 (for every dollar spent on mitigation, avoided damages are 8 to 12 dollars). | | |

### 4.2.10 Scenario M - 100-year Climate Change Coastal Flood with Continuous Riverside Drive Flood Barrier

In Scenario M the 100-year Climate Change lake level was re-simulated with a hypothetical flood barrier along the Riverside Drive corridor and 1 km of Brighton Road. As noted in Section 4.2.6, this mitigation scenario was not designed, so specific details are not available for location, construction materials, height, etc. The resulting model simulation is presented in Figure 4.11. The coastal flood is successfully contained north of the hypothetical flood barrier, with limited flooding south of Riverside Drive related to storm sewer surcharging.

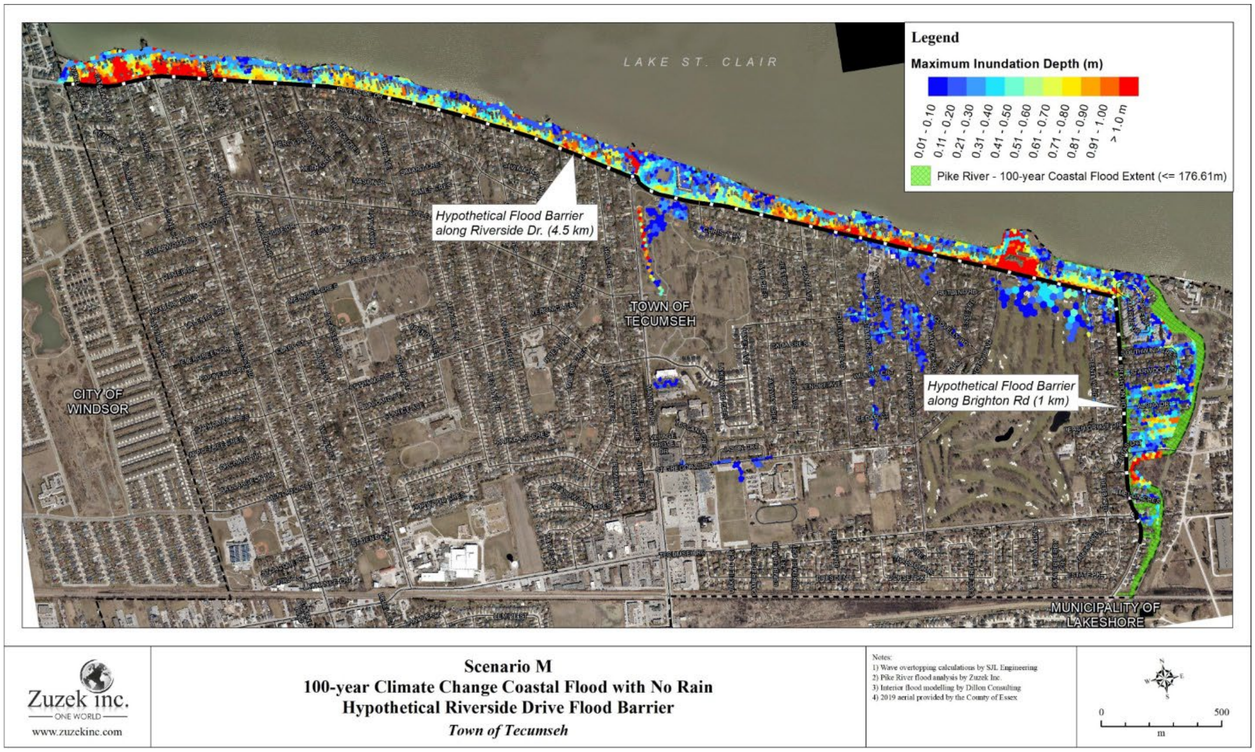



Figure 4.11 Maximum Flood Depth for 100-year Climate Change Flood with Hypothetical Flood Barrier on Riverside Drive and Brighton Road

The flood risks associated with Scenario M including buildings impacted and potential economic damages are summarized in Table 4.10. Roughly 200 buildings are predicted to have wet exterior foundation walls, which is a reduction of 2,600 from the Scenario C climate change flood with no mitigation. Only 88 buildings featured main flood flooding damage for Scenario M, versus 730 for Scenario C. The potential economic damages associated with Scenario M are $31 to $45 million, which represents a reduction of $93 to $143 million when compared to Scenario C flooding with no mitigation. It is interesting to note that this reduction in flood damages for the Riverside Drive barrier in Scenario M is very similar to the reduction for the community wide shoreline protection upgrades in Scenario J ($101 to $153 million). They represent two conceptual solutions with different trade-offs (i.e., continuous modifications to the shore protection along the lake or re-engineering Riverside Drive and a portion of Brighton Road). These trade-offs could be explored further in follow-up feasibility studies.

Finally, while the challenges related to designing and implementing a Riverside Drive flood barrier are significant, the flood modelling clearly demonstrates that it could be a very effective mitigation strategy for the properties south of Riverside Drive.

Table 4.10 Scenario M Mitigation Simulation Results

| Mitigation Scenario: A flood barrier is constructed along 4.5 km of Riverside Drive and 1 km of Brighton Road. Cost unknown. | | |
|---|---|---|
| Risk Factor | Count | Damage |
| Wet Exterior Basement Foundation | 211 Buildings | Assume 10% to 20% of basements would be flooded via lowest opening |
| Sanitary Sewer Surcharging during the Flood | High risk during a coastal flood | Not possible to quantify economic damages |
| First Floor Flooding and Content Damages | 88 Buildings | $31 to $45 million |
| Reduction in Potential Damages versus Scenario C: $93 to $143 million. | | |
| Benefit-cost Ratio: not available, as the cost of the flood barrier was not estimated. | | |

### 4.2.11 Scenario E – Urban Stress Test Rainfall and 5-year Coastal Storm

The Urban Stress Test rainfall event, as specified by the County of Essex, was simulated in Scenario E with wave induced flooding from a coastal storm with a return period of 5-years. The peak lake level and wave height associated with the storm were considerably smaller than the 100-year lake level. The hypothetical rainfall was 150 mm over a 24-hour period. The resultant coastal and interior flooding associated with Scenario E is mapped on Figure 4.12. There is limited flooding north of Riverside Drive associated with wave runup and overtopping. The interior flooding is mostly limited to road ponding for Scenario E. As with the other scenarios, it is not possible to predict basement flooding or the potential occurrence of a sewer backup for the simulation.

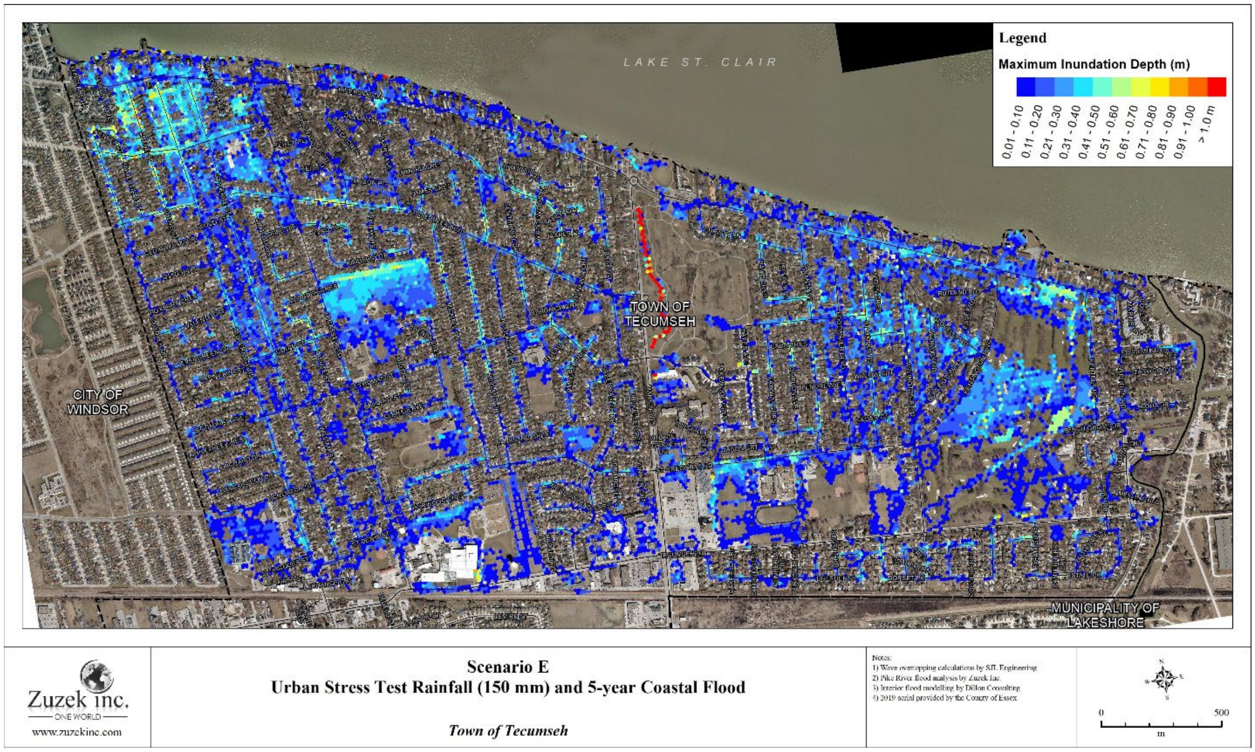



Figure 4.12 Extent of Shoreline and Interior Flooding from the Urban Stress Test Rainfall

## 4.3 Urban Stormwater and Sanitary Sewer System

During the analysis of each flood simulation outlined within Section 4.2, it was determined that the existing storm sewer infrastructure within the study area would be prone to surcharging during a coastal flooding event. This is due to the excessive inland inundation from a coastal flood event and the storm sewer system having a direct connection with the ground surface through catch basins and storm manhole lids. The existing storm pump stations are also shown to be operating at maximum capacity during all the flooding scenarios and pumping coastal flood waters from inland back into the lake.

Under the "No Rain" scenarios, both a 100-year and 100-year climate change coastal flooding event are shown to surcharge the majority of the storm sewer system within the regions of the Town of Tecumseh north of the E C Row Expressway due to the coastal surface flood inundation. With the northern regions of the storm sewer system surcharged and the pump stations working at maximum capacity from the coastal flooding, this puts a higher boundary condition on the remainder of the storm sewer system within the southern regions of the service areas. During the flooding scenarios, both the 5-year and Urban Stress Test rainfall events would cause localized surcharging of the system outside of the northern coastal flood areas. The Town storm sewer system south of the County Road 22 would therefore also be susceptible to sewer surcharging and surface flooding during these events.

Through a review of the existing condition flood simulations where rainfall is incorporated, it was identified that there was little change in flood inundation along the Lake St. Clair coastline regions of the municipality with and without rainfall. The 100-year and 100-year climate change coastal floods are shown to govern the surface flooding and duration of flooding during these events within the northern areas of the Town.

Review of the existing pump stations and recommended improvements from the SDMP identified that it would not be practical to upgrade existing storm infrastructure pump capacities to reduce the impacts of coastal flooding. This is due to the amount of coastal flood water volume entering inland during these scenario events and the requirement for the pump stations to recirculate lake water back into the watercourse. A more enhanced level of service at each storm pump station will not provide an increased reduction in surface flood inundation during coastal flood events and would only slightly decrease the pump station drawdown times during these events. Therefore, the hypothetical shoreline protection measures included in Scenarios F to M (raising the crest of existing shoreline protection or a Riverside Drive flood barrier) are the only feasible approaches to reduce the risks and potential economic damages associated with coastal flooding.

Based on the assessment of both existing and proposed conditions, surface flooding drawdown times were also reviewed due to coastal flooding. The general surface ponding drawdown times are provided below in Table 4.11 for each pump station service area beginning from the start of the coastal flooding event until after the coastal surface flooding has peaked and flood depths are brought down to an acceptable level of 0.30 m or less where safe access would be feasible for most vehicles on local roads. Surface ponding that does not reach the 0.30 m ponding depth threshold was assigned 0 hours to represent coastal flooding depths never reaching that allowable depth limit. The proposed mitigation scenarios (F to M) include the upgrades to the storm pump stations and main storm trunk sewers along Riverside Drive recommended through the SDMP to reduce the susceptibility of surface flooding during the simulations, including the Lesperance and West St. Louis Pump Station upgrades, consolidated Scully/St. Marks Pump Station, PJ Cecile Pump Station upgrade, and the new Starwood/Southwind Pump Station.

Table 4.11 Joint Probability Scenario Surface Flooding Drawdown Times

| Pump Station | Existing Conditions Drawdown (hours) | | | | | Proposed Conditions (hours) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | G | H | J | K | L** | M** |
| Lesperance | 29 | 29 | 40 | 40 | 14 | 8 | 18 | 12 | 31 | N/A | N/A |
| West St. Louis | 17 | 17 | 26 | 27 | 13 | 19 | 20 | 21 | 25 | N/A | N/A |
| East St. Louis | 18 | 19 | 29 | 31 | 4 | 17 | 18 | 18 | 26 | N/A | N/A |
| East Townline Drain | 3 | 7 | 29 | 30 | 3 | 18 | 20 | 20 | 26 | N/A | N/A |
| Scully | 20 | 21 | 40 | 41 | 16 | - | - | - | - | - | - |
| St. Marks | 36 | 37 | 56 | 57 | 17 | - | - | - | - | - | - |
| PJ Cecile | 40 | 45 | 53 | 56 | 23 | 12 | 23 | 25 | 34 | N/A | N/A |
| Brighton | 8 | 9 | 27 | 27 | 4 | 0 | 9 | 9 | 24 | N/A | N/A |
| *Consolidated Scully/St. Marks | - | - | - | - | - | 13 | 23 | 25 | 38 | N/A | N/A |
| *Starwood/ Southwind | - | - | - | - | - | 0 | 0 | 0 | 0 | N/A | N/A |

* Consolidated or New Pump Stations Based on Recommendations from the SDMP

** No surface ponding drawdown time determined due to barrier landform

Based on the results of the flood modelling and capacity of the storm sewer system, the best approach to limit coastal flooding is to incorporate new flood mitigation measures that limit wave overtopping from entering inland. This has been identified through a number of mitigation strategies, including shoreline protection upgrades (Scenarios F, G, H, I, J, and K) and/or the Riverside Drive flood barrier (Scenarios L and M) to protect the municipality from coastal flooding, as discussed in Section 4.2.

### 4.3.1 Sanitary Infrastructure

Inflow into the sanitary sewer infrastructure from coastal flooding has the potential to overwhelm the sanitary sewer system, as discussed in Section 4.2. Whether the coastal flood inundation enters the sanitary system through direct inflow from sanitary manhole lids, sanitary drains on private property, or infiltration into the underlying soils, these factors can result in a high risk of basement flooding in large parts of the northern urban area of the Town. Under existing conditions, the sanitary system in the Town's northern urban area is divided into two drainage areas by the County Road 22 (CR22)/EC Row Expressway. The following drainage areas are identified:

1. Areas north of County Road 22 drain to the Little River Pollution Control Plant (LRPCP), located in the City of Windsor, through a sanitary pumping station (PS) located along Cedarwood Drive in the Town of Tecumseh.

2. Areas south of County Road 22 drain to the LRPCP through a gravity outlet along County Road 22.

The two drainage areas are hydraulically disconnected through a sluice gate located along the Lesperance Road sanitary trunk sewer at County Road 22. The sluice gate is kept closed, under existing conditions, so no sanitary sewage flow can enter from the south area to the north and vice versa.

Flood inundation waters from a coastal flooding event can enter the underground sanitary sewer system through several sources. The following sources of inflow into the sanitary sewer system from coastal flooding waters are identified:

- Pick holes in sanitary Maintenance Holes (MHs).

- Surface water entering basements through building openings and entering the sanitary system through floor drains and bathroom inlets (shower drains, toilets).

- Infiltration into sanitary sewers from cracks and deficiencies in underground sanitary sewer infrastructure when soils are saturated from a coastal flooding event.

- Foundation drains connected to sanitary sewer system in older residential neighbourhoods.

- Inflow from interconnections between storm and sanitary sewer systems.

The risk of basement flooding due to sanitary sewer surcharge is also higher during a significant wet-weather event, since the sewer infrastructure is already surcharged due to sources of Rainfall Derived Inflow and Infiltration (RDII) into the sanitary sewers. These factors could ultimately increase the chances of basement flooding during a joint coastal and rainfall-based flood event.

The Town of Tecumseh has completed several improvements to the municipal sanitary sewer infrastructure over the last few years. These include:

- Installation of rain catchers at sanitary MH cover locations which prevent flood waters collected in low-lying areas from entering the underground sanitary sewer system.

- An ongoing RDII reduction program through which the Town has completed repairs on the sanitary sewer system to reduce sources of inflow and infiltration into the sanitary system.

- In-line storage and improvements to sanitary pumping station at Lakewood Park to provide added resiliency during a wet-weather event.

- Voluntary foundation drain disconnection (FDD) program that provides a subsidy to residents who want to disconnect foundation drains connected directly to the sanitary sewer system.

Additionally, Dillon is currently completing a study to calibrate a hydraulic model of the Town's sanitary sewer system, identify areas at risk of basement flooding due to sanitary sewer surcharging, and propose solutions to reduce the risk.

While the above measures have resulted in a reduction in risk of basement flooding due to sanitary sewer surcharging during wet weather rainfall-based flood events, high volumes of water are expected to flow inland during a coastal flooding event. As such, inflows into the sanitary sewer system from one or more of the above-mentioned sources can potentially cause the sanitary sewer system to surcharge and increase the risk of basement flooding. Since sanitary sewers are typically not designed to convey heavy flows, any inflows from coastal flooding can quickly overwhelm the sanitary system. While the risk of inflows into the sanitary system are higher in areas along the shoreline, the water can cause backflow in the sanitary system, resulting in a higher risk of basement flooding in areas further inland.

The sanitary drainage areas of the Cedarwood pump station and the County Road 22 gravity outlet are presently disconnected by the closed sluice gate at County Road 22. The recently completed sanitary assessment for the Manning Road Secondary Plan Area (MRSPA) recommended an interim solution of allowing some sanitary flows through the sluice gate into the Cedarwood pump station service area. Maintaining the existing separation was the preferred approach recommended in the MRSPA sanitary assessment. Therefore, the risk of basement flooding due sanitary sewer surcharging during coastal flooding events is expected to be restricted to the Cedarwood sanitary pump station drainage area. This includes the urban areas of the Town of Tecumseh north of County Road 22, both east and west of Manning Road. Figure 4.13 shows the areas at risk of basement flooding due to sanitary sewer surcharging during a coastal flooding event.

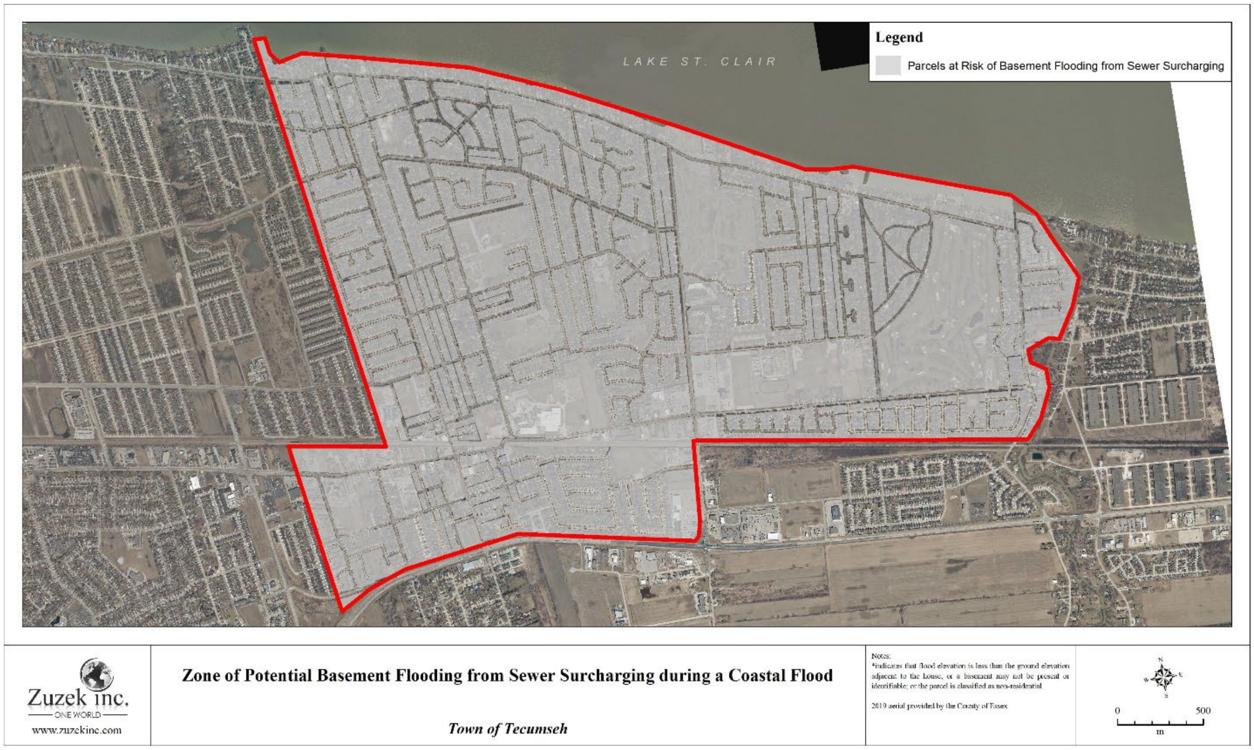



Figure 4.13 Area of Basement Flood Risk from Sanitary Sewer Surcharging

### 4.3.2 Emergency Ingress and Egress

The ability to evacuate during a flooding event (egress) or deliver emergency services to residential or commercial areas (ingress) will be challenging in many parts of the Tecumseh study area during the 100-year coastal flood and the 100-year climate change coastal flood. The associated flooding for these events has been recategorized into bins of 0.3 m in Figure 4.14 and Figure 4.15. The Provincial Policy Statement (PPS, 2020) and the Great Lakes Technical Guide (2001) both reference the importance of maintaining safe ingress and egress during a coastal flood.

As a general rule of thumb, water depths greater than 0.3 m can limit vehicle access during a flooding event. The binned flood surfaces could be used in conjunction with details on the existing emergency vehicle fleet to evaluate locations that are inaccessible during the 100-year flood. Upgrading the emergency fleet to include vehicles that can function in water depths greater than 0.3 m may be a viable adaptation strategy. For example, the high water rescue vehicle recently purchased by Tecumseh is an innovative adaptation strategy to address road flooding and emergency response.

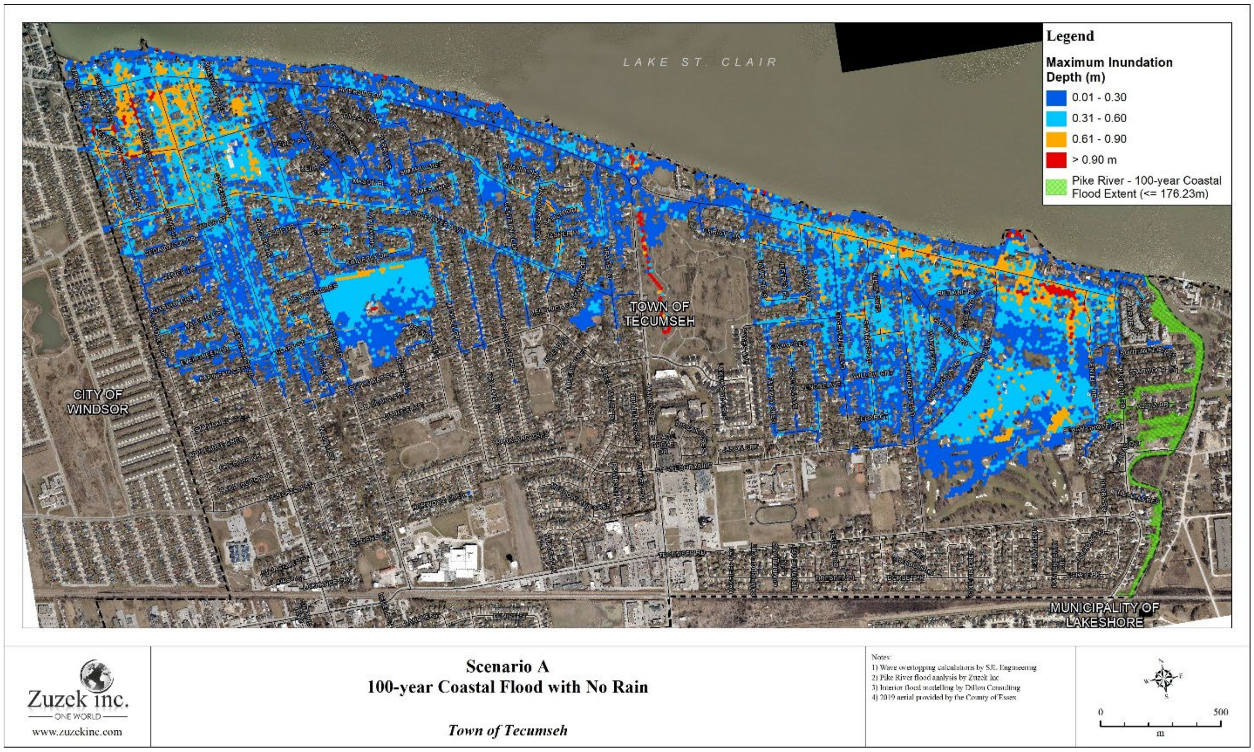



Figure 4.14 Depth of Flooding for Scenario A: 100-Year Flood (increments of 0.3 m)

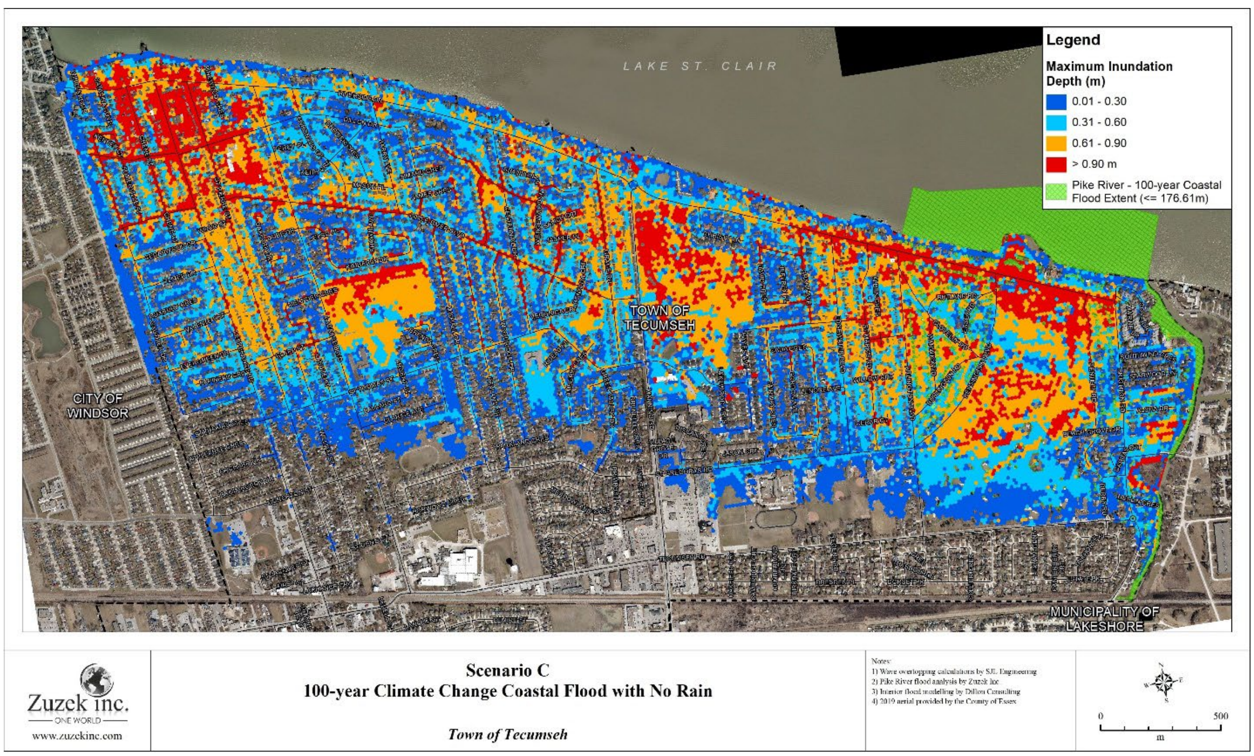



Figure 4.15 Depth of Flooding for Scenario C: 100-Year Climate Change Flood (increments of 0.3 m)

# 5.0 FLOOD MITIGATION ALTERNATIVES

Section 5.0 provides background on a wide range of flood mitigation strategies and specific recommendations for Tecumseh based on the findings of this study.

## 5.1 Coastal Flood Mitigation Strategies

When evaluating coastal flood mitigation strategies in the Great Lakes, the PARA framework (Doberstein et al, 2018) provides a logical way of grouping concepts into the protect, accommodate, retreat and re-align, and avoid categories.  Examples of mitigation concepts following the PARA framework are provided.  Prior to implementing, most of these concepts will require engineering support and approvals/permits from regulatory agencies.

### 5.1.1 Avoid

The goal of the avoid strategy is to locate new development away from hazardous lands, which is also the cornerstone of Ontario's hazard policies outlined in the PPS (2020) and the Technical Guide (MNR, 2001).  This planning strategy is best applied when locating development on greenfield sites but is also applicable for infill development or construction on lots of record. Refer to Table 5.1 for an example of a large natural buffer that protects new development from coastal erosion on Lake Ontario.  An example of new development (home reconstruction) on a low-lying lot of record is also provided in Table 5.1 and the avoid principles should be applied to these situations as well.  In general, avoid is the most cost effective hazard mitigation strategy but unfortunately it is not very applicable to Tecumseh, given the high density of existing coastal development and constrained lots along Riverside Drive.

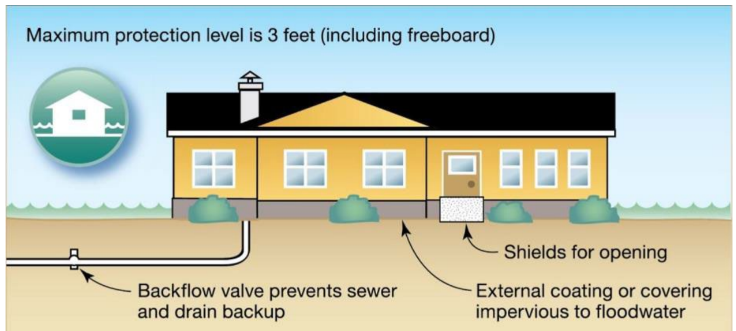
Table 5.1  Examples of Avoid Strategy

| AVOID | |
|---|---|
| New development is protected from coastal erosion hazards with a large natural area buffer on Lake Ontario. |  |
| Avoid principles should be applied to infill development or redevelopment on hazardous lands.  In the adjacent example, development is occurring on a low-lying lot of record. |  |

### 5.1.2 Accommodate

The accommodate strategy leverages a wide range of approaches to reduce coastal risk and permit continued occupation of communities on hazardous lands. Examples include floodproofing existing buildings, raising building foundations, upgrading components of an urban stormwater management system, upgrading the emergency management fleet for first responders, and completing preparedness planning. Examples are provided in Table 5.2.

Table 5.2 Accommodate Adaptation Strategies

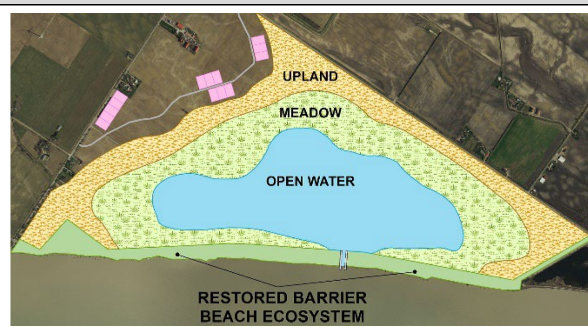
| ACCOMMODATE | |
|---|---|
| Floodproof existing buildings. |   |
| Raise building foundations. |  |
| Upgrade stormwater management system.<br><br>Upgraded East Townline Pump Station in adjacent image. |  |
| Upgrade emergency vehicle fleet so first responders can access flooded streets. |   |

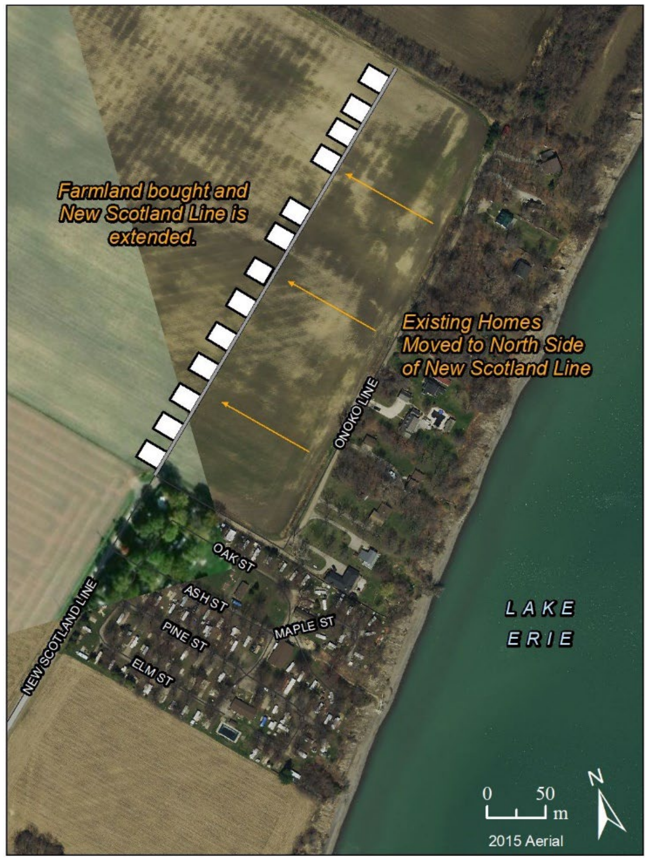
| | |
|---|---|
| Be prepared for water evaluations and rescues. |  |
| Deploy sandbags for short-term flood relief. |  |

### 5.1.3 Retreat and Re-align

Retreat and re-align is an effective adaptation strategy when communities are exposed to significant coastal hazards, especially when the cost to mitigate the risk is greater than the assets under threat. The necessary planning for this strategy is extensive and it requires ongoing consultation with communities. Funding and fair compensation for landowners is also required. Buildings can be moved further inland on existing lots or relocated to new lots further inland. Once the at-risk infrastructure has been removed, the land use can be transformed to more resilient options, such as coastal wetlands that also create habitat and ecosystem benefits. General examples of retreat and re-align are provided in Table 5.3

Table 5.3 Retreat and Re-align Examples

| RETREAT AND RE-ALIGN LAND USE | |
|---|---|
| Diked agricultural land located below lake level converted to a coastal wetland. |  |
| Flood prone building relocated inland. |  |

| | |
|---|---|
| Homes vulnerable to coastal erosion are relocated further inland away from hazardous lands. |  |



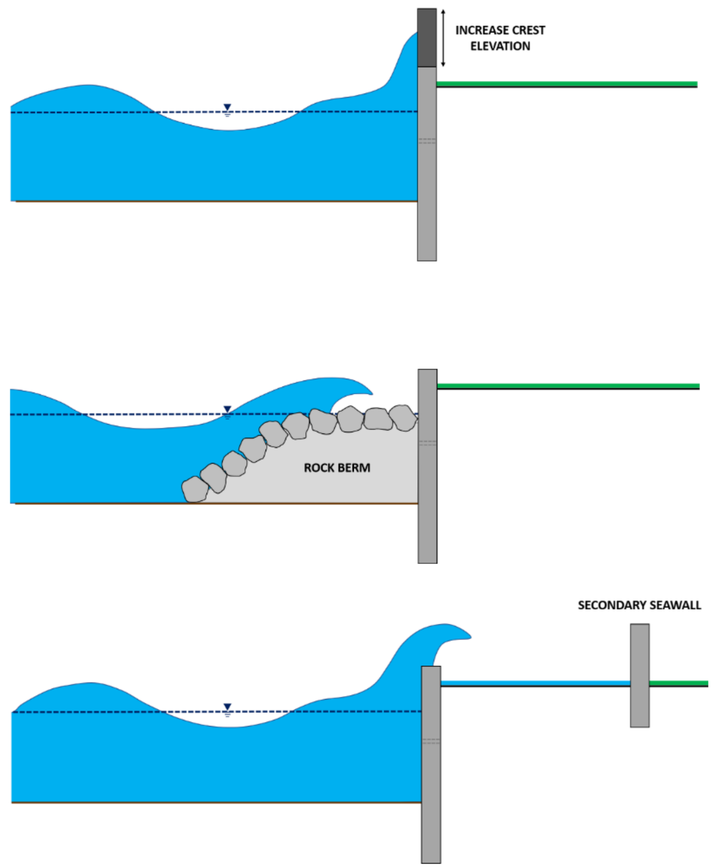
### 5.1.4 Protect

Historically protect has been the most common approach deployed to address coastal hazards in Ontario for existing development and at-risk infrastructure. There are many types of different shoreline protection structures that can reduce flood risk, including flood berms, vertical seawalls, sloping rock structures, nature-based solutions (e.g., beaches), and hybrid grey-green designs. Examples are provided in Table 5.4.

Table 5.4 Protect Strategy Examples

| PROTECT | |
|---|---|
| Flood berm constructed at Chippewa Park, foot of Lesperance Road. |  |

| | |
|---|---|
| Seawall with secondary wall to reduce wave overtopping. |  |
| Hybrid solution with block wall and natural vegetation at the back of the beach to reduce flooding and erosion hazards. |  |
| Enhance existing beach properties to increase protection. For example, the adjacent beach provides some protection to the property but is low-lying and flood prone. A flood berm could be constructed inshore of the beach. |  |
| Repair failed shore protection. |  |

| | |
|---|---|
| Upgrade existing shoreline protection structures. Raise crest (top), add a rock berm at the toe of the structure (middle), or construct a secondary wall (bottom). |  |

## 5.2 Flood Mitigation Recommendations

The flood modelling and potential economic damages presented in Section 4.0 highlight the severe flood risk that exists across the northern portion of the Town of Tecumseh. Potential economic damages to buildings and contents, which is just one type of flood impact, were estimated at $24 to $37 million for the 100-year coastal storm. This is a conservative estimate given our inability to quantify basement flooding from sanitary sewer surcharging and the use of assessed property values (not market values). When the higher lake level was simulated for the projected impact of climate change, the potential economic damages to buildings and contents increased roughly 400% to $124 to $188 million.

There are many other types of primary impacts associated with flooding not included in this analysis, such as damage to vehicles in the floodplain, above and below ground utilities, roads and bridges, impacts to habitat and natural areas, social and emotional stress on flood victims, and the risk of casualties. Secondary impacts including lost employment and other economic hardships, water borne diseases, and inundation impacts to non-tolerant vegetation.

Fortunately, the Town of Tecumseh has been working on strategies to reduce flood risk and increase resilience to coastal flooding and rainfall events for several years, including regular emergency response planning, flood berm construction in vulnerable locations, purchase of a high water rescue vehicle, completion of upgrades to the stormwater management system and sanitary sewer system (with additional projects in the planning/design phase). In addition, the Town is currently investigating additional measures to reduce the risk of basement flooding from sanitary sewer surcharging.

New recommendations and measures based on the technical findings of this study are outlined in the following report sections, with the focus being on reducing coastal flooding due to wave uprush and overtopping of existing shoreline protection structures.

### 5.2.1 Shoreline Protection Upgrades to Reduce Coastal Flooding

The magnitude of the coastal and interior flooding simulated for this study highlights the significant threat in Tecumseh from wave uprush and overtopping during a coastal storm, as seen in modelling scenarios A and C. The 100-year coastal flood was able to propagate more than 1 km inland along Lesperance Road and the Beach Grove Golf and Country Club. This is not a hypothetical event - it has happened before, as noted in our review of the St. Patrick's Day Storm on March 17, 1973.

Further technical studies are recommended to engage the community, evaluate the engineering feasibility of the plan, and refine the costs for a community-scale shoreline protection upgrade program. Such a program would be co-developed by the Town and the affected landowners. The benefit-cost ratios developed to mitigate the impacts of the 100-year flood (Scenarios F, G, H) ranged from 2 to 7, which indicate the economic benefits would be substantial. Recall that a benefit-cost ratio greater than 1 can be economically justified.

Significant technical information has already been generated throughout this study, including a lot-by-lot property parcel database where existing shoreline protection structures and natural shorelines have been characterized by type (e.g., seawall, sloping rock structure, or beach). Toe and crest elevations for existing shoreline infrastructure have been extracted from the shoreline survey described in Section 2.1.1. This information was used to estimate conceptual lot-by-lot shore protection upgrades for each of the modelled scenarios, and to develop a preliminary opinion of cost. Figure 5.1 illustrates the necessary shoreline structure crest elevation increases by waterfront property (from west to east) required to limit overtopping to 10 L/m/s at each property during the 100-year storm event. Figure 5.2 presents generalized relationships for the required crest elevations of sloping rock structures and vertical seawalls to meet 10 and 50 L/m/s overtopping limits during the 100-year event based on available water depth at the toe of the structure (x-axis). Note that Figure 5.2 should be taken as general guidance only and should not be used for the purpose of design. Site-specific investigations and detailed engineering analyses would be required on a property-by-property basis to confirm the necessary structural upgrades to achieve a given overtopping limit for each shoreline property.

An important next step would be verifying this initial work through detailed engineering analyses and getting feedback from the landowners on the type(s) of protection upgrades that would be desired for their properties, refining costs, and establishing funding options.

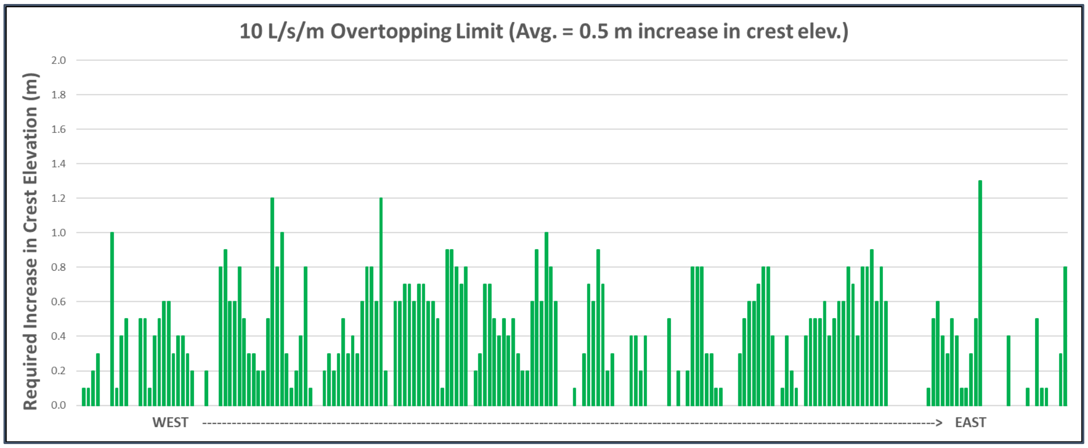



Figure 5.1 Recommended Crest Elevation Upgrades Lot by Lot (Scenario G)

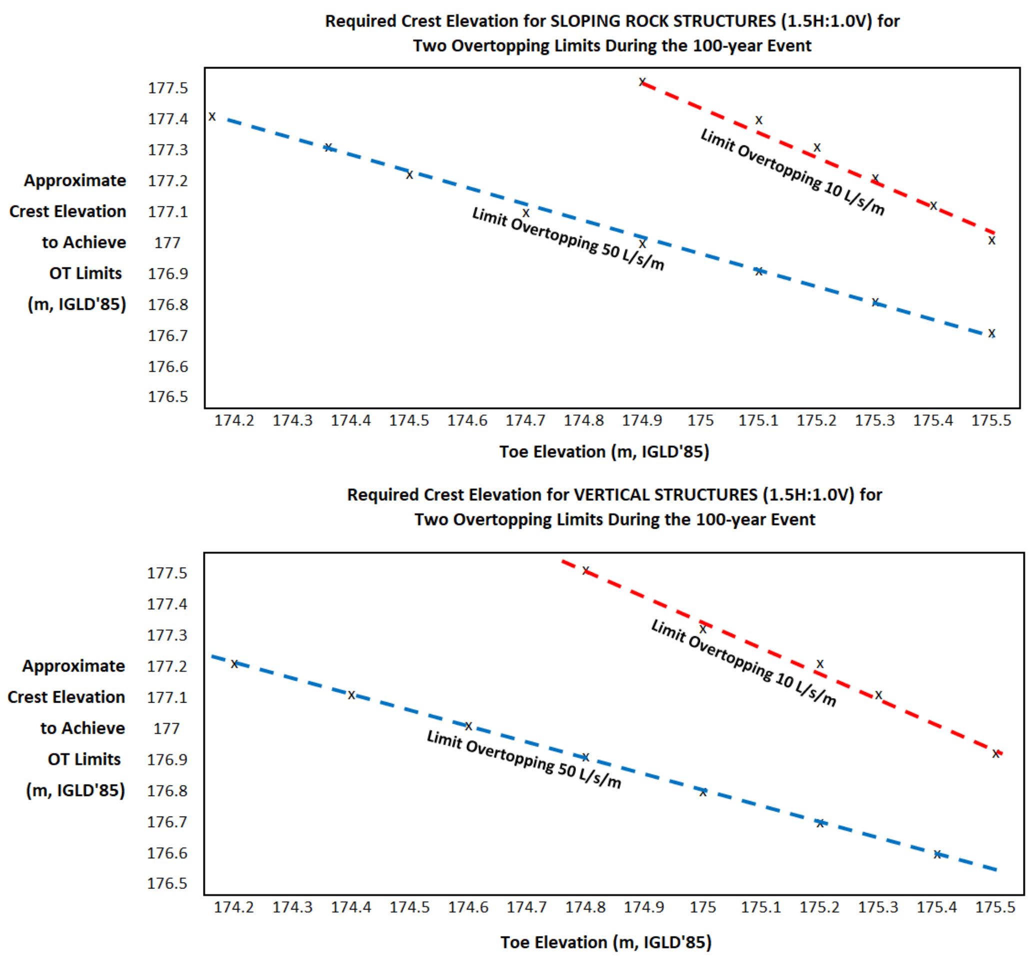



Figure 5.2 Summary of Crest Elevations Required to Limit Overtopping to 10 and 50 L/m/s for Sloping Rock Structures and Vertical Seawalls on Tecumseh Shoreline (General Guidance Only – Not to be Used for Engineering Design)

If concensus and support for a community-scale shoreline protection program is not reached, the existing technical information could still be used to identify the most critical low-lying lots and implement targeted improvements. For example, the 30 lots identify in Scenario H feature the shoreline protection structures most vulnerable to wave overtopping (typically low crested) in the study area or feature a low-crested sloping beach, and could be prioritized if a shore protection upgrade plan is pursued.

Conceptual engineering drawings to raise the crest elevation of existing seawalls, construct secondary walls, increases the crest elevation of existing sloping rock protection, and construct a levee or berm for natural shorelines are provided in Figure 5.3 to Figure 5.7. Pictures of similar shore protection upgrade are provided below. These options could be implemented regardless of whether they are part of a community-scale program or select targeted upgrades for the most vulnerable properties.

Concrete cap on steel sheet pile wall.

Recurved parapet wall added to seawall.

Rock toe protection for existing seawall.

Crest elevation increased for an existing sloping rock structure.

Examples of Shore Protection Structure Upgrades

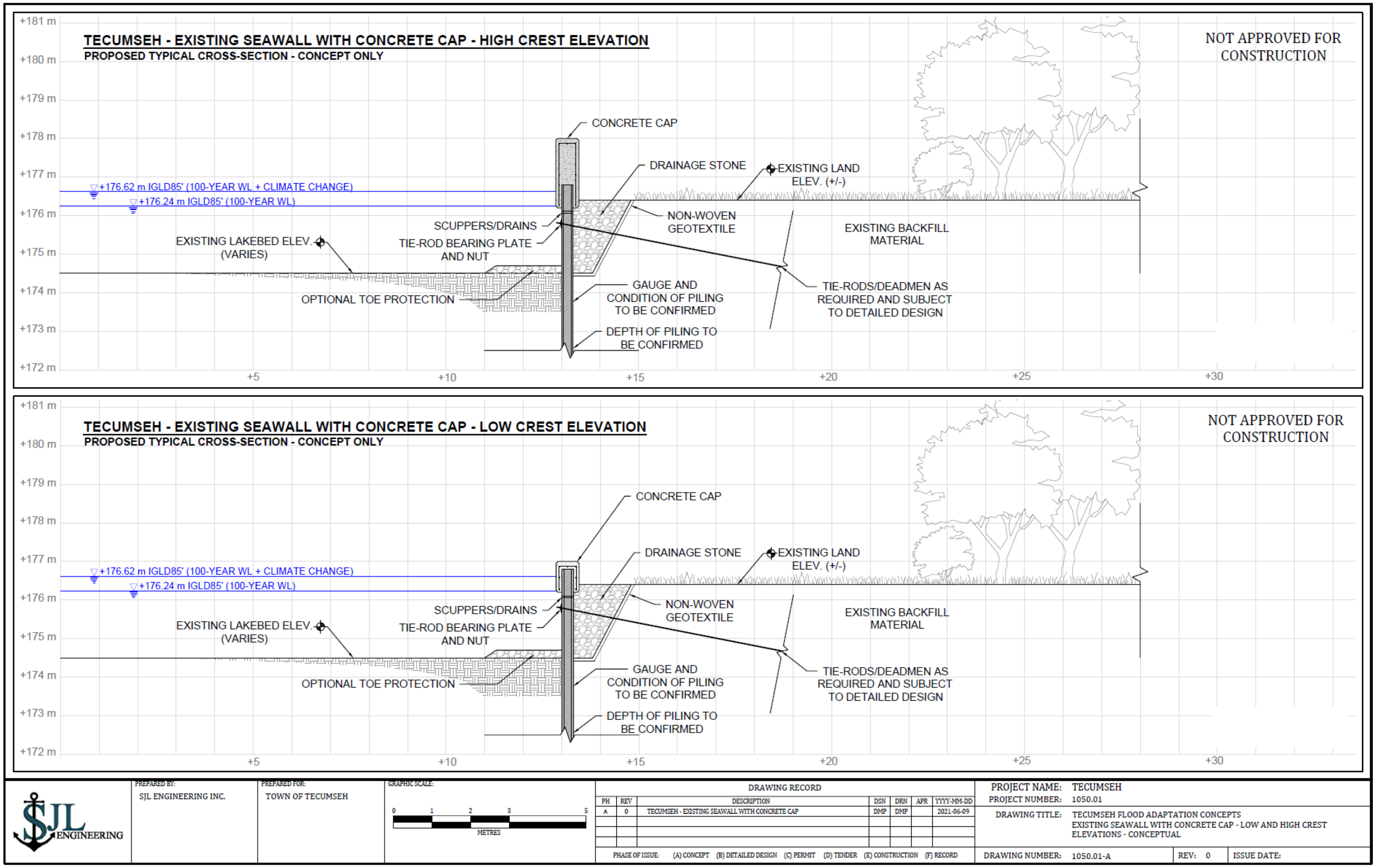



Figure 5.3 Conceptual Drawing for Crest Upgrades to Existing Seawalls

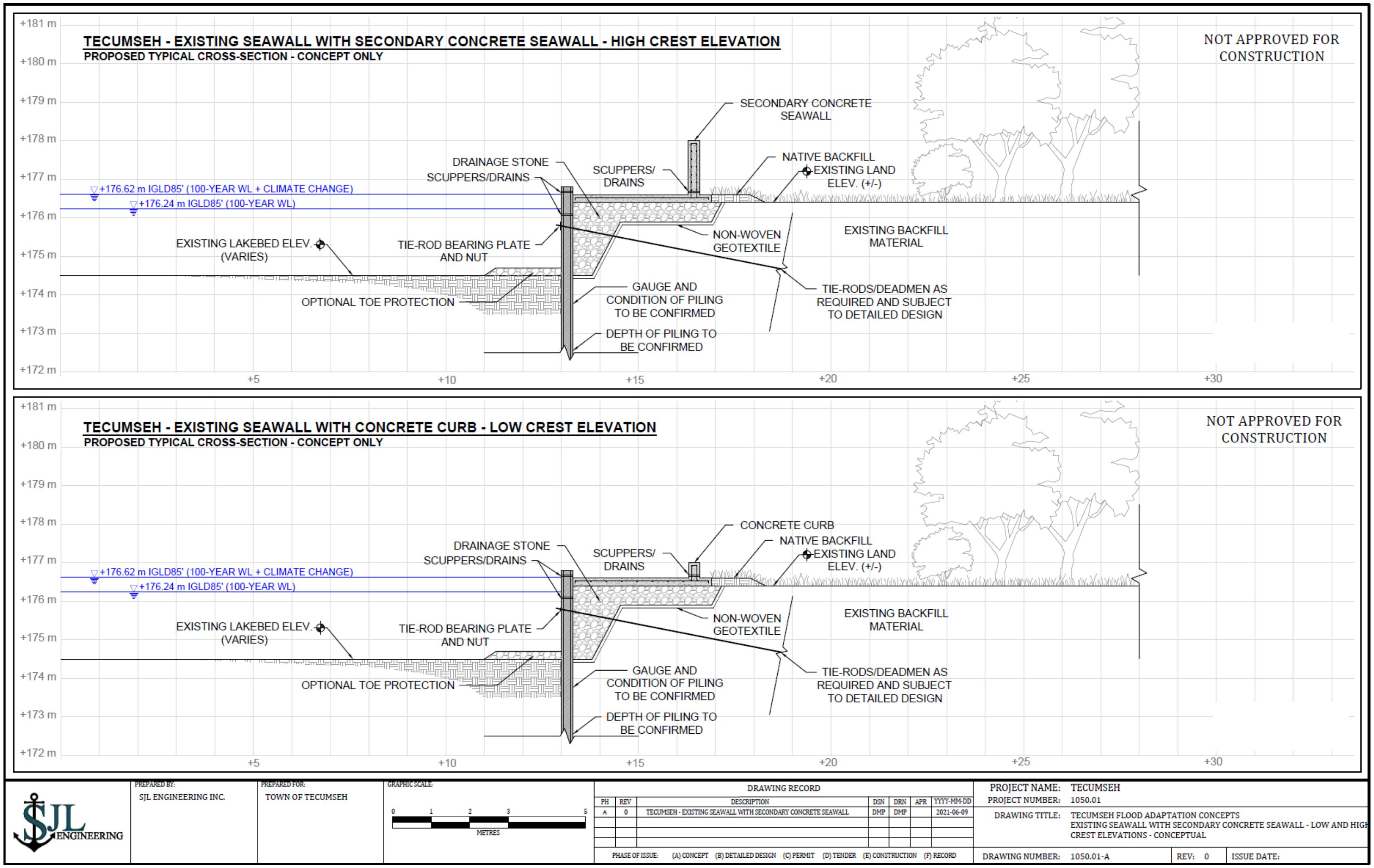



**Figure 5.4 Conceptual Drawing for Secondary Concrete Seawalls to Reduce Flood Risk**

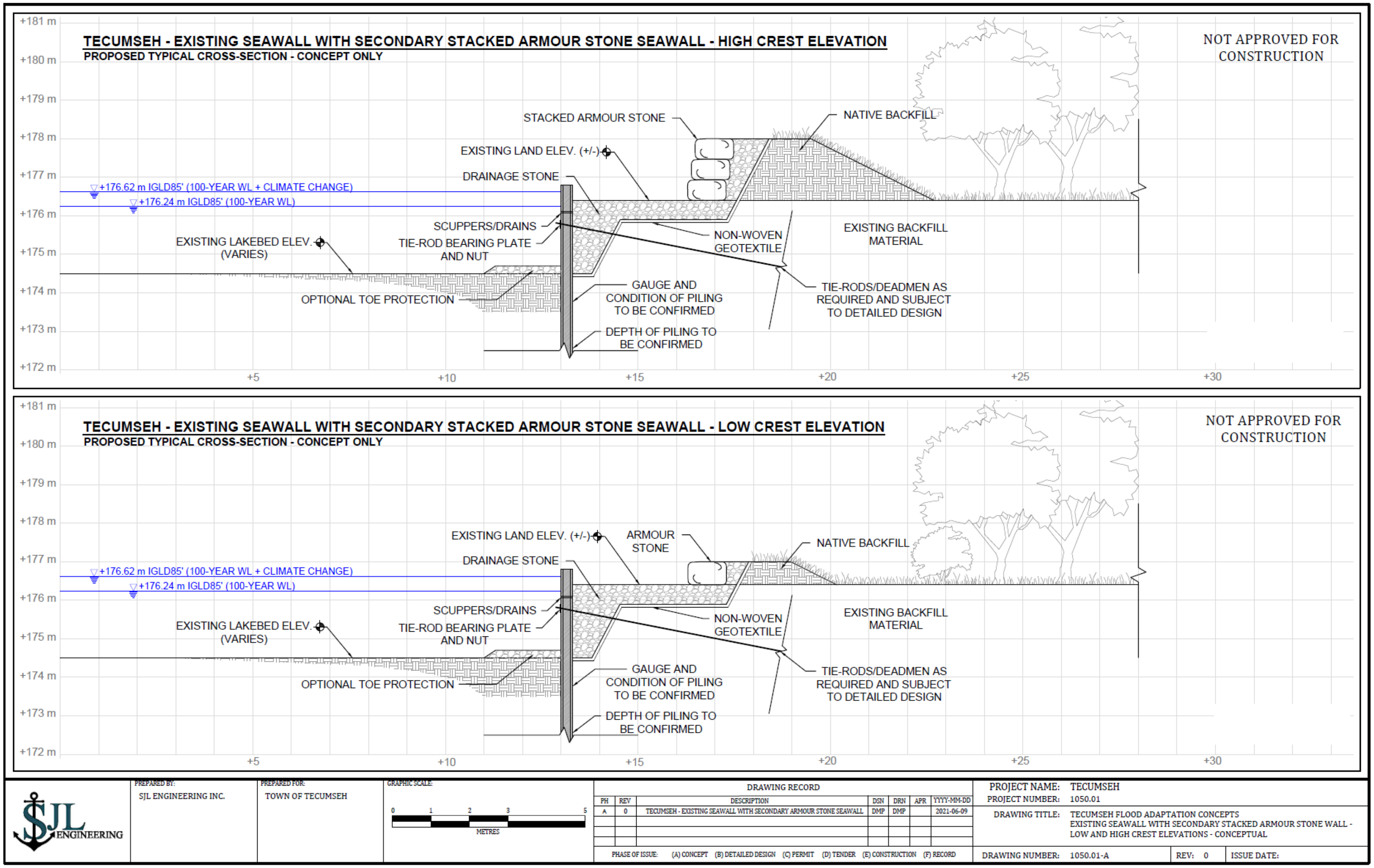



Figure 5.5 Conceptual Drawing for Secondary Stacked Armour Stone Walls to Reduce Flood Risk

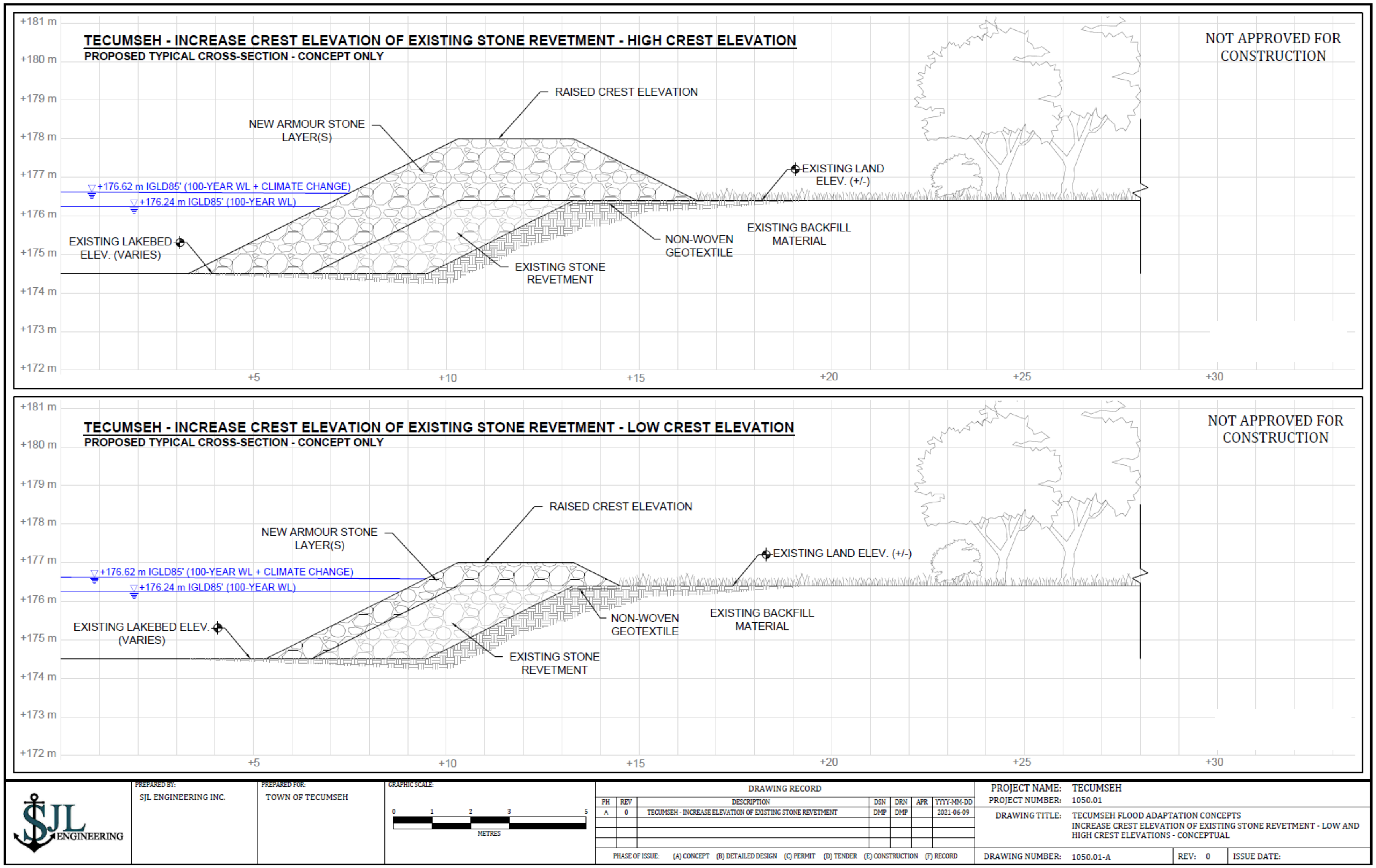



Figure 5.6 Upgrades to Sloping Armour Stone Revetments

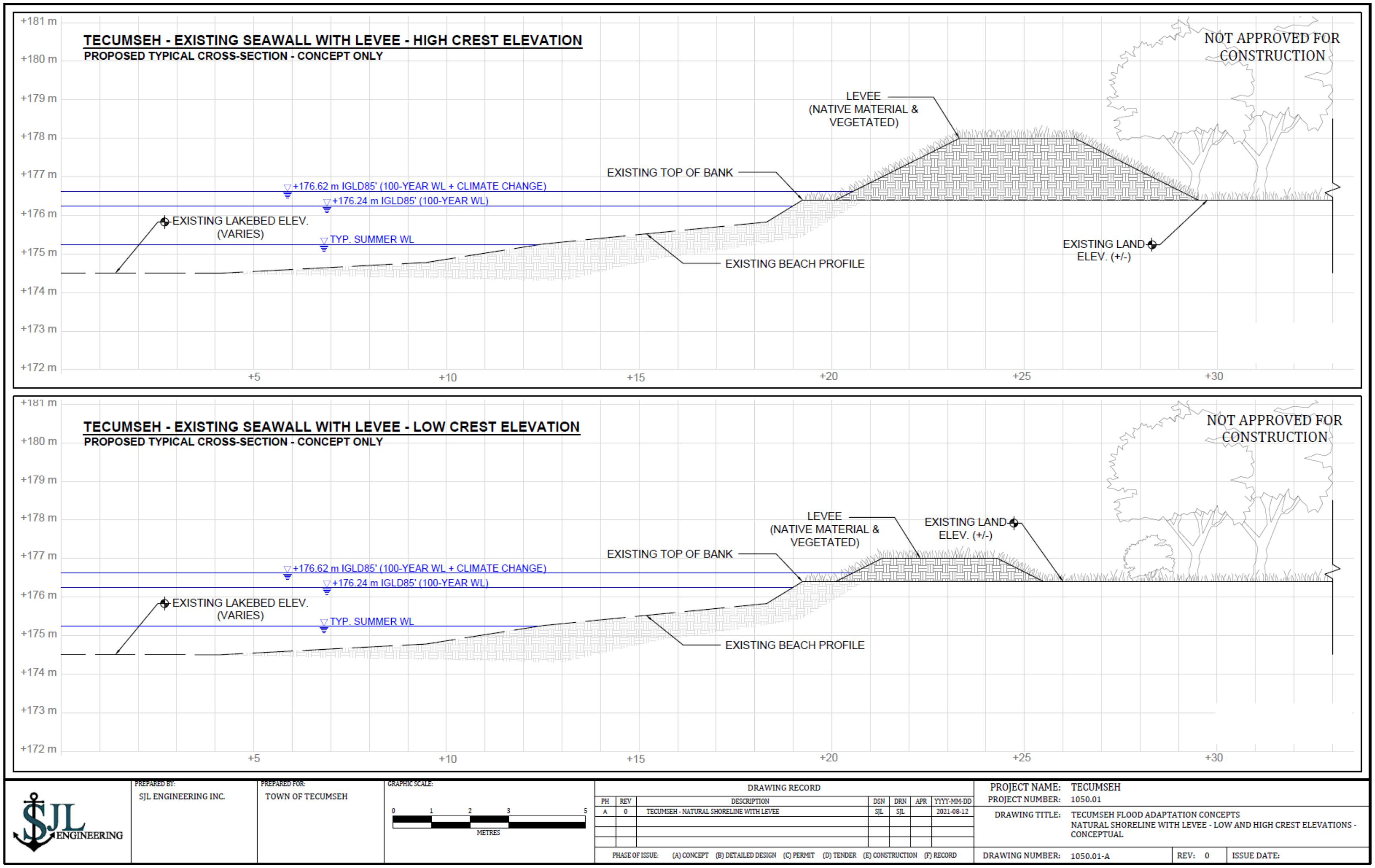



Figure 5.7 Construction of Earth Berm/Levee to Reduce Inland Flooding on Natural Beaches

### 5.2.2 Basement Flooding Threats

While the property parcel database noted the presence or absence of a basement based on available photography, lot by lot conditions were not surveyed to establish the occurrence and elevation of lowest openings such as windows and doors due to privacy concerns and the COVID-19 pandemic. Therefore, as discussed throughout the report, it was not possible to estimate the number of basements that would be flooded by the individual scenarios. However, we can state with a high level of confidence that the coastal flooding would reach the exterior foundations of approximately 850 buildings for the Scenario A 100-year flood. The number of buildings with a wet exterior basement foundation increases to over 2,800 for the 100-year climate change flood.

The threat of basement flooding from overland flow can be reduced with watertight shields, improved drainage and replacing conventional windows with solid glass block windows (left and right pane of Figure 5.8 respectively).

Figure 5.8 Water Shield and Solid Block Basement Window

Landowners potentially affected by basement flooding could be notified in writing based on the results of the computer modelling, if desired. Actual risks could then be investigated by the building owners and mitigation actions taken accordingly.

### 5.2.3 Sanitary Sewer Backups

There are two broad approaches to lower the risk of future sanitary sewer backups: 1) reduce the occurrence of coastal flooding (as outlined in Section 5.2.1), and 2) upgrade the sanitary sewer system. A multi-faceted approach is already ongoing to upgrade the sanitary sewer system to reduce the threat of backups, as outlined in Section 4.3.1. The Town and community are encouraged to continue to work together on existing programs and future initiatives to reduce the threat of sanitary sewer backups and basement flooding.

### 5.2.4 Road Network and Emergency Access

Prior to developing specific adaptation strategies for emergency access in Tecumseh, further assessment of the depth of flooding on local streets and the capacity of the emergency vehicle fleet is required, including the recently purchased high water rescue vehicle. Once depth of flooding and vehicle access has been analyzed and reviewed with emergency responders, limitations can be identified, and appropriate adaptation solutions implemented.

# 6.0 PUBLIC ENGAGEMENT

The public engagement completed throughout the study is summarized in Section 6.0.

## 6.1 Town of Tecumseh Website and Direct Mailouts

Community engagement was a vital component of the Tecumseh Coastal Flood Risk Assessment project. The process was facilitated through written communication and virtual interaction during three Public Information Centres (PICs). PICs were held virtually due to the Public Health measures that were in place in response to the Coronavirus COVID-19 pandemic.

Written communications were disseminated via the Town of Tecumseh website, direct mailouts, and emails. Additional details on the three methods are provided as follows:

Town of Tecumseh Website: Residents have access to the Town of Tecumseh website (link below). The website contains the public notices, session recordings, and presentation slides. Comment sheets were made available through a link on the website after each PIC to allow for residents and stakeholders to provide input regarding the project.

https://www.tecumseh.ca/en/town-hall/shoreline-management-plan.aspx

Direct Mailouts: Residents were contacted through public notices that were sent via direct mail two to three weeks in advance of the PICs. The public notice included the background of the study, the process, PIC goals, and the date, time and how to register for the PIC. A sample notice is provided in Appendix A for reference

Emails: Residents and stakeholders were asked to provide an email during the registration process. Attendees received an email after each PIC thanking them for their participation and providing the link to a comment sheet to elicit additional feedback.

## 6.2 Public Information Centre #1 (PIC1)

PIC1 was held on Thursday October 29, 2020. Attendees were asked to register for the meeting in advance. Overall, 64 residents participated in PIC1, this number excludes the Study Team and employees from the Town of Tecumseh (15 people). The afternoon session ran from 3:00 to 4:30 p.m. with 35 attendees, followed by an evening session from 6:00 to 7:30 p.m. with 29 attendees.

The meeting was conducted through the Zoom webinar platform and provided an overview of the project and work plan, outlined the preliminary findings from the field work, presented examples of flood hazard mitigation, climate change adaptation, and emergency response. Feedback was also received from the attendees on local conditions and evaluation criteria.

The format of PIC1 included a formal presentation, a question-and-answer period, followed by an interactive discussion with three questions:

1. What are the most important aspects of the flood risk assessment?

2. With respect to flooding and erosion hazards, what are the most vulnerable areas in the Town of Tecumseh?
3. What are your priorities when evaluating long-term solutions to flood risks in the Town of Tecumseh?

Public interaction was facilitated through the Q&A function in the Zoom platform. The lead Facilitator read the question and one of the team members responded. Comments from the interactive discussion were shared with the whole group.

All attendees were sent a comment sheet via email after the PIC that included the same discussion questions listed above. Attendees were given the opportunity to submit their comment sheets for a 4-week period after PIC1.

Of the 64 residents that attended PIC1 fourteen (22%) completed comment sheets. Of those who responded, the majority live in study area (92%) and own property and/or live inland (62%). A smaller percentage own property and/or live along the lakeshore (23%).

Respondents indicated that the most important aspects of the flood risk assessment were the following:

- Short-term flood and erosion mitigation concepts.
- Long-term flood and erosion mitigation concepts.
- Accurately assessing and mapping flood risk including future climate change impacts.

With respect to flooding and erosion hazards, the most vulnerable areas in the Town of Tecumseh indicated by respondents were:

- Shoreline properties = 92%.
- Interior properties = 77%.

When asked for priorities when evaluating long-term solutions to flood risks in the Town of Tecumseh, respondents indicated the following:

- Long-term sustainable solutions (77%).
- Cost to landowners (69%).
- Cost the Town of Tecumseh (54%).

Overall, the feedback was very positive. The Project Team utilized the input and insights form PIC1 to inform the project and plan the agenda for PIC2.

## 6.2 Public Information Centre #2 (PIC2)

PIC2 was held on Tuesday April 20, 2021. Attendees were asked to register for the meeting in advance. Overall, 45 residents participated in PIC#2, this number excludes the Study Team and employees from the Town of Tecumseh (15 people). The afternoon session ran from 3:00 to 4:30 p.m. with 24 attendees, followed by an evening session from 6:00 to 7:30 p.m. with 21 attendees.

PIC2 was conducted through the Zoom webinar platform and provided an update on the work plan, shared the latest research on climate change, provided an overview of the methodology to integrate coastal storm flooding (lake) and rainfall events (interior), presented preliminary results of the flood risk analysis for lake and interior flooding, identified potential economic damages with different flooding scenarios and introduced the concept of adaptation options to reduce future flood risk.

The format of PIC2 included a formal presentation, a question-and-answer period, followed by an interactive discussion with four questions:

1. Based on what you learned today, should other priorities or criteria be considered when developing solutions to mitigate flood risk (in addition to: a) long-term sustainable solutions, b) cost to landowners, c) cost to the Town of Tecumseh)?
2. Please share your ideas for short- and long-term options to reduce coastal and interior flood risk.
3. Emergency access for people and first responders may be limited on some roads during flooding events. In addition to the ongoing emergency response planning by the Town of Tecumseh, do you have any suggestions on how to improve emergency access?
4. For the Lakefront landowners, would you be willing to participate in a shoreline protection upgrade program that standardizes criteria and approaches for the Tecumseh lakefront? How should such a program be developed and implemented?

Public interaction was facilitated through the Q&A function in the Zoom platform. The lead Facilitator read the question and one of the team members responded. Comments from the interactive discussion were shared with the whole group.

All attendees were sent a comment sheet via email after the PIC that included the same discussion questions listed above. Attendees were given the opportunity to submit their comment sheets for a 4-week period after PIC2.

Of the 45 residents that attended PIC2, 12 (27%) completed comment sheets with the majority (92%) indicating they live in the study area. Of that group 75% own property and/or live inland.

Respondents indicated two other additional priorities or criteria be considered when developing solutions to mitigate flood risk as follows:

- Standard protection on shoreline.
- Collaboration (co-operation among neighbours, Windsor, Tecumseh, Lakeshore, and ERCA).

When asked to share ideas for short- and long-term options to reduce coastal and interior flood risk respondents offered the following comments:

- Continue installing berms. Upgrade or add pump stations (4)
- Seawalls: increase height, use stepped/return (2).

- Mitigate areas along the shoreline whereby lake waters will flow in first when lake levels reach higher elevations.
- Look at utilizing the alleys in Tecumseh. Drains can be put in, as water tends to sit in those alleyways, to speed the removal of standing water. Could also use rain gardens with pollinator plants for butterflies and bees.
- Build on work already done is best short-term option with the offshore or in-lake barrier over long-term.
- Consider inland dry ponds at neighbourhood parks.
- Review development and construction policies/rules/bylaws including redevelopment requirements (e.g., why do we continue to allow basements in flood prone areas?).
- Rock formation out into the lake possibly 250-400 yards offshore. The waters are still quite shallow, and this could reduce wave damage and flooding on land.
- Huge water storage basins, maybe in the parks, golf courses, etc. Could improve aesthetics and also improve capacity of sewers and pump stations.
- Provide advanced notice of rising waters in the sewers. We have a primary sump pump, battery back-up sump pump, and a third pump we drop in and run a hose out our basement window to the road. This saved our basement from flooding a second time.

The next question asked for suggestions regarding emergency ingress and egress for people and first responders as access may be limited on some roads during flooding events. The top suggestions on how to improve emergency access are as follows:

- Electronic signage that could include flood warnings, flood siren, blue flashing light on street corners (3).
- Rescue boats/rafts (2).
- Onshore water rescue options.
- Notification to get to inland emergency centres (2).

The final question was targeted to Lakefront landowners and their interest in participating in a shoreline protection upgrade program that standardizes criteria and approaches for the Tecumseh lakefront. Limited responses were provided but only 4 of the completed surveys were from lakefront landowners.

## 6.3 Public Information Centre #3 (PIC3)

PIC3 was held on Wednesday August 18, 2021. Attendees were asked to register for the meeting in advance. Overall, 29 residents participated in PIC3, this number excludes the Study Team and employees from the Town of Tecumseh (10 people). The afternoon session ran from 3:00 to 5:00 p.m. with 9 attendees, followed by an evening session from 6:00 to 8:00 p.m. with 20 attendees.

PIC3 was conducted through the Zoom webinar platform and included the presentation of results from the flood risk analysis for lake and interior flooding, a summary of potential economic damages with different flooding scenarios (existing conditions and hypothetical scenarios with potential mitigation options constructed), and presentation of conceptual adaptation alternatives to increase community resilience to coastal flooding. The format of PIC3 included a formal presentation, a question-and-answer period, followed by an interactive discussion with three poll questions as follows:

1. What is your preferred long-term approach to reduce the coastal flood risk in Tecumseh?
    - A community scale program to upgrade the existing shoreline protection,
    - A flood barrier along Riverside Drive and Brighton Road,
    - Other.
2. Should the Town of Tecumseh and the Residents continue with further studies to select, design, and ultimately implement a community scale long-term coastal flood mitigation strategy?
    - Yes,
    - No,
    - Unsure.
3. For the Lakefront landowners, would you be willing to participate in a shoreline protection upgrade program that standardizes criteria and approaches to reduce coastal flooding for the Tecumseh lakefront?
    - Yes,
    - No,
    - Unsure.

All attendees were sent a comment sheet via email after the PIC that included the same discussion questions listed above. Attendees were given the opportunity to submit their comment sheets for a 4-week period after PIC3. Of the 29 residents who attended PIC3, 12 (41%) comment sheets were completed.

Respondents indicated the following when asked about their preferred long-term approach to reduce the coastal flood risk in Tecumseh:

- A community scale program to upgrade the existing shoreline protection (58%).
- A flood barrier along Riverside Drive and Brighton Road (17%).
- Other (25%):
    - Investigate other less costly ways that don't create barriers along the shoreline.
    - Consider the effect of a community program on property values on a case-by-case basis.
    - More investment and calculation of return on investment for storm and sanitary management.

The majority (58%) agreed that the Town of Tecumseh and the Residents should continue with further studies to select, design, and ultimately implement a community scale long-term coastal flood mitigation strategy. 17% preferred the Riverside Drive and Brighton Road flood barrier. 25% provided other suggestions.

Again, the last question was targeted to Lakefront landowners and their interest in participating in a shoreline protection upgrade program that standardizes criteria and approaches for the Tecumseh lakefront. Limited responses were provided, indicating further details of such a program are required for landowners to make an informed decision.

# 7.0 CONCLUSIONS

The conclusions from the study are presented in Section 7.0, including the risk assessment, flood mitigation alternatives, feedback from the public engagement, and next steps.

## 7.1 Risk Assessment

An innovative methodology was developed to investigate the combined impacts of coastal and rainfall flooding in Tecumseh. The key findings include:

- The Town of Tecumseh is vulnerable to rainfall and coastal flooding. There have been several recent flooding events related to record setting rainfall.

- Coastal flooding requires the joint occurrence of high static lake levels and a severe storm surge event with large waves. As such, coastal flooding is less frequent than rainfall flooding. However, the spatial extent and magnitude of damages would be much greater for a coastal flood than a rainfall flood event (e.g., St. Patrick's Day flood, 1973).

- During the 100-year coastal flood, low-lying waterfront lots combined with low-crested shoreline protection structures result in extensive wave uprush and wave overtopping along the lakeshore. These waters propagate inland between homes, along the road network and flood the interior. The potential economic damages to buildings and contents for the 100-year coastal flood is estimated at $24 to $37 million. The flood waters would reach the exterior basement foundation walls of over 800 buildings. The potential economic damages to basements cannot be calculated at this time due to a lack of information on lowest opening elevations.

- When higher lake levels due to climate change were considered, the potential economic damages to buildings and contents increased dramatically to $124 to $188 million. Over 2,200 basements could be impacted by coastal flooding, but basement damages and storm sewer surcharging could not be estimated for this study. In reality, the potential economic damages would be considerably higher than those presented herein if the 100-year coastal flood or the 100-year climate change coastal flood materialized in Tecumseh, especially given the recent increases in residential home values.

- Technical studies are ongoing to continue upgrading the storm sewer infrastructure in Tecumseh, including pumping stations. These efforts should continue and consider the impacts of a changing climate.

- There is a very high risk of sanitary sewer surcharging during a coastal flood, which could lead to extensive basement flooding. Numerous programs are ongoing to reduce this threat. These efforts should continue.

- Due to the depth of flooding on Tecumseh roads, emergency ingress and egress will be challenged during a severe coastal flood. Further emergency planning with depth of flooding maps should be completed.

## 7.2 Flood Mitigation

The PARA framework was used to evaluate a wide range of flood mitigation strategies in Tecumseh, including Avoid, Accommodate, Retreat/Realign, and Protect. There is limited opportunity to leverage Avoid concepts, since the community is nearly 100% developed. Similarly, Retreat is largely non-viable given the dense land use and inability to move buildings further away from the lake on most lots.

Alternatively, there are many types of Accommodate and Protect strategies that are feasible for Tecumseh. The highlights from the investigation include:

- Floodproofing basement windows and doors could substantially reduce flood risk in Tecumseh. A coordinated community program could be developed to notify landowners based on the flood modelling results presented herein. An information campaign could also be developed to share alternatives with interested parties.

- Scenario H: In the model simulation, wave overtopping was limited to 50 L/m/s for all coastal properties, requiring upgrades to shoreline protection structures at the 30 worse-case lakefront properties. The cost for the scenario upgrades is $1 million and avoided damages would be $5 to $7 million for the 100-year coastal flood. Implementing Scenario H would require a relatively small capital investment and create immediate positive benefits by reducing flooding at the 30 most flood prone lots along the shoreline.

- Scenario G: In this simulation, wave overtopping was further reduced to 10 L/m/s at each lot through hypothetical shore protection upgrades, which were required for 140 properties. This scenario is consistent with a community wide program to upgrade shore protection on a lot by lot basis. While more expensive to implement ($6 to $7 million), the avoided damages are $21 to $32 million for the 100-year flood level. Scenario G is consistent with the recommendations from the community engagement for a long-term sustainable solution (77% of respondents). The benefit-cost ratio was 3 to 5, suggesting a very positive financial rationale to initiate further community dialog and planning of the Scenario G upgrades.

- The shore protection costs to reduce wave overtopping to 10 L/s/m for the 100-year coastal storm was $6 to $7 million (Scenario G). The cost to achieve the same overtopping target for the 100-year climate change coastal storm (Scenario J) doubled to $12 to $13 million. However, the benefit-cost ratio for increases from 3 to 5 for Scenario G to 8 to 12 for Scenario J. The significant increase in the benefit-cost ratio for Scenario J is attributed to the much higher damages associated with the climate change flooding. In other words, if lake levels increase in the future due to climate change, even stronger economic arguments can be made for a community scale shoreline protection upgrade program.

- A wide range of shore protection upgrades could be implemented across the Tecumseh shoreline, from raising the crest elevation of existing seawalls or sloping rock revetments, to building secondary walls or a flood berm for existing beach shorelines (to preserve shoreline access). While different options could be adopted by individual landowners based on their lot-specific conditions and personal preference, a standard level of flood protection would be established as part of the community scale program.

## 7.3 Next Steps

The Town of Tecumseh is actively working to reduce its vulnerability to rainfall and coastal flooding. The findings from this study are particularly relevant to the coastal flood risk related to wave uprush and overtopping across the waterfront lots. Due to the conveyance of floodwaters over shoreline properties and throughout the low-lying road network, significant inland areas are also affected by the 100-year coastal flood. Recommendations for next steps include:

- Continue with design work and construction plans to upgrade storm sewer infrastructure and capacity (e.g., pumping stations) to address rainfall flooding.

- Continue with a multi-facetted approach to reducing the potential for basement flooding from sanitary sewer surcharging during rainfall flooding.

- Develop new guidance for landowners to reduce the threat of basement flooding during a coastal flood event, such as floodproofing vulnerable windows and doors.

- The emergency responders, engineering and planning staff in Tecumseh should continue to evaluate the study outputs, such as the time lapse flood inundation video and static depth of flooding mapping for the coastal flood simulations to identify inaccessible roads and buildings due to the depth of flooding. The Town of Tecumseh (2020) Flood Response Plan should be updated based on the findings.

- Increasing resilience to coastal flooding and climate change will require a long-term multi-phase plan for the Town of Tecumseh, including the following recommended steps:

    - Step 1: Complete further engagement on the viability of a community-scale shoreline protection upgrade program. Explore options for implementing such projects on private land.

    - Step 2: Complete additional planning, such as an Environmental Assessment, to refine the flood hazard mitigation options and costs for community-scale initiatives to upgrade existing shore protection at low-lying waterfront lots.

    - Step 3: Explore potential cost sharing models, pursue funding opportunities, and complete a final design investigation at the individual lot scale.

    - Step 4: Secure required agency approvals, implement the flood mitigation measures, and monitor.

  Given the technical study and public engagement was completed virtually during the COVID pandemic, the Town should complete further engagement with the residents in Step 1. The outcomes from that engagement would inform future steps.

- Share technical data and outcomes generated through this study with the Essex Region Conservation Authority and collaborate on further studies to update the existing 1976 coastal regulatory Flood Hazard Limit mapping for Tecumseh.

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# APPENDIX A

## Sample PIC Notice Letter

Town of Tecumseh
Shoreline Management Plan
(Coastal Flood Risk Assessment)

# Notice of Public Information Centre No. 3

## Background

The Town of Tecumseh has retained Zuzek Inc., and their sub-consultants SJL Engineering Inc., Dillon Consulting and Foresight Management Consulting, to complete a Shoreline Management Plan that will assess the Town's existing and future vulnerability to lake flooding and to prepare conceptual adaptation and mitigation strategies to account for the influence of coastal storms, rainfall events, and climate change. The study area includes the Lake St. Clair shoreline of Tecumseh and the portion of the Pike Creek located north of the VIA railway tracks.

## The Process

This study includes the assessment of existing coastal hazards to determine shoreline areas that are vulnerable to the threat of lake flooding. The study is also investigating the potential influence of climate change on future coastal hazards due to changes in storms, rainfall, and ice cover and the associated challenges for the coastal communities of Tecumseh. Updated floodplain mapping will be generated, along with conceptual adaptation options to address the coastal hazards. The ultimate goal is to increase the resilience of the Town of Tecumseh to coastal hazards through the development of potential short- and long-term solutions.

## Public Involvement

As part of the process, virtual Public Information Centres (PIC) are scheduled to provide information to homeowners and community members on the overall project, the work completed to date and to provide an opportunity for questions and feedback. The first PIC, held October 29, 2020, provided an overview of the project and work plan, summarized the preliminary findings from the field work, and presented examples of flood hazard mitigation, climate change adaptation and emergency response. PIC No. 2 on April 20, 2021 provided the latest research on climate change, presented preliminary results of the flood risk analysis for lake and interior flooding and identified potential economic damages and potential adaptation options to reduce future flood risk. Recordings from PIC No. 1 and 2 can be found on the Town's website www.tecumseh.ca\shorelinemanagementplan

## PIC No. 3 Information

| When | Session 1 | Session 2 |
|---|---|---|
| TBD, 2021 | 3:00 PM to 4:30 PM | 6:00 PM to 7:30 PM |

Attendees are asked to register in advance to participate in one of the virtual meetings at www.tecumseh.ca\shorelinemanagementplan. The PIC will also be live streamed on the Town's website for those wishing to view the meeting without participating in the discussion.

The goals of PIC No. 3 include the presentation of results from the flood risk analysis for lake and interior flooding, a summary of potential economic damages with different flooding scenarios (existing conditions and hypothetical scenarios with potential mitigation options constructed), and presentation of conceptual adaptation alternatives to increase community resilience to coastal flooding. A detailed presentation will be followed by participant interaction and an overview of the next steps.

Should you have any questions or concerns feel free to contact: John Henderson, P.Eng., Manager, Engineering Services (519) 735-2184, ext. 166 or Cheryl Curran, Project Technician, at ext.149.

**This notice issued on July 2021**