

MEMORANDUM

TO: Lisa Vespi, Town of Fort Erie

FROM: Hamish Smith and Karen Hofbauer, Matrix Solutions Inc.

SUBJECT: Modelling Approach for Six Mile Creek Flooding Project

DATE: May 1, 2024

VERSION: 1.0

1 INTRODUCTION

This technical memorandum outlines the hydrologic and hydraulic modeling approach for assessing the impacts of combined riverine and lake-induced flooding along Six Mile Creek in the community of Thunder Bay, Ontario (Figure 1). The purpose of this analysis is to understand the potential consequences of concurrent riverine and coastal flooding events, which have historically had a significant impact on residents of the community of Thunder Bay and municipal infrastructure located along Six Mile Creek and the area along the shores of Lake Erie and inland estuaries. The modeling approach described in this memorandum will help facilitate the Environmental Assessment process, contribute to the development of a long-list of planning alternatives focused on flood mitigation, help inform stakeholders and decision makers, define levels of service, assess impacts on emergency service management, and long-term infrastructure planning.

2 BACKGROUND

Riverine and lake-level induced flooding events are common natural hazards that can lead to significant property damage, impacts on municipal infrastructure, disruptions in emergency services access/egress, and in extreme cases, loss of life.

Town staff reported to Matrix that high water levels in the creek have resulted in closures of either Shirly Road 9 times between February 2019 and the present. The Town and residents have experienced flooding over the past decades. Recently elevated lake level and wind gusts caused significant flooding on 31 October 2019, 15 November 2020 and December 2022 during Winter Storm Elliot (suspected cause was SW wind gusts of 70km/hr).

The combination of riverine and lake-level induced flooding, often referred to as compound flooding, poses unique challenges for risk assessment and resilience planning. These events occur when high river discharge driven by local precipitation coincides with extreme lake water levels, which are driven by wind induced storm surge, and seasonal fluctuation in lake level which vary each from catchment inflow, and wind conditions.

The Six Mile Creek Flooding Environmental Assessment study intends to model and assess the potential impacts of compound flooding events on the affected area, including flooding extent, depths, and duration. Ultimately, the assessment of compound flooding will be used as a key criterion when evaluating flooding mitigation alternatives for the community of Thunder Bay.

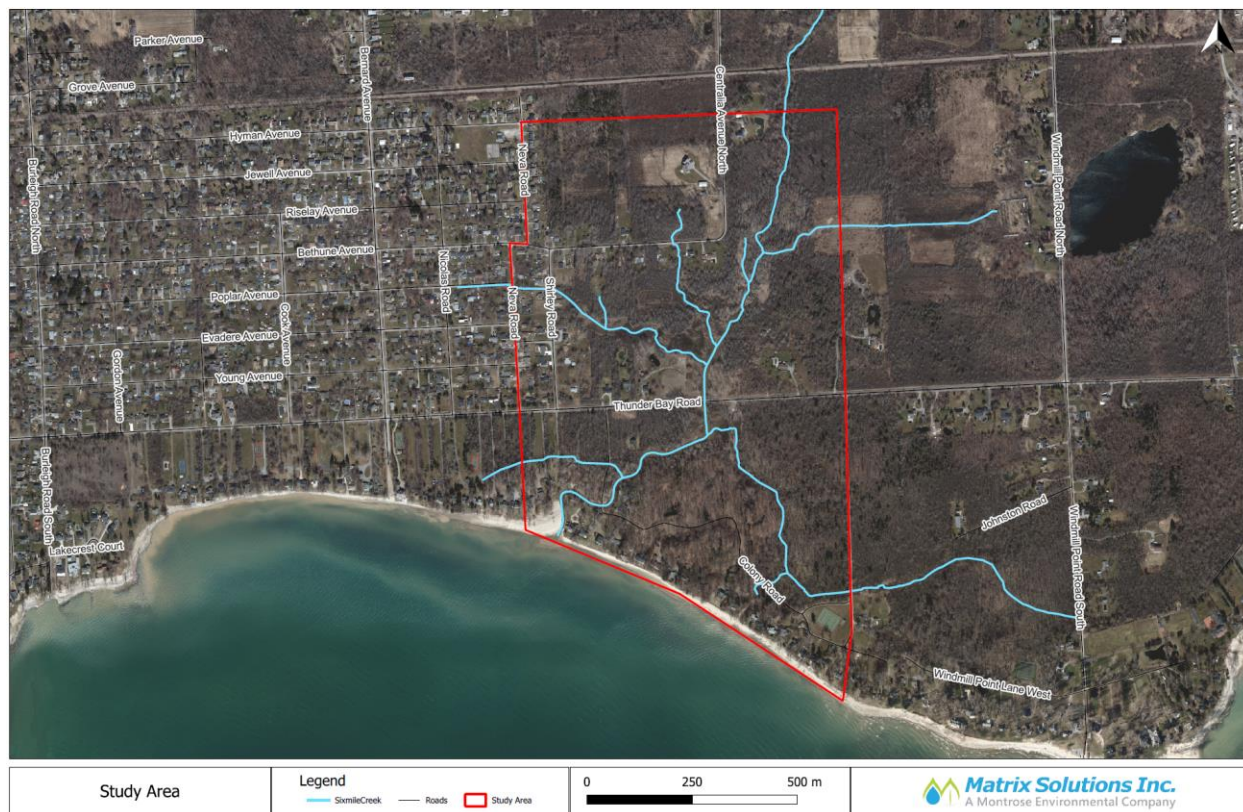


Figure 1: Six Mile Creek Environmental Assessment Study Area

3 MODELLING APPROACH

3.1 Seasonality Assessment

Riverine and lake-level induced flooding have different seasonality. In southern Ontario, the highest levels of riverine flooding tend to be a result of summer convective thunderstorms. Figure 2 demonstrates this summer thunderstorm event clustering in summer showing the average number of days in each month where a rainfall greater than 25mm fell¹. Therefore, severe riverine flood events are most likely in July and August. However, in November to March months, freshet and rain-on-snow events can also cause high riverine flood events, particularly in rural catchments. Lake Erie, with its long axis oriented with the

¹ Government of Canada Environment and Natural Resources, 2024. Canadian Climate Normals 1981-2010 Station Data for PORT COLBORNE. Accessed 16 April 2024.
https://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=4671&autofwd=1#normals-data

dominant winds, experiences the most severe wind-induced storm surges of the Great Lakes. The eastern shoreline of Lake Erie experiences storm surge heights of approximately 1.5 to 2.5 m (see Section 3.2). The peak storm surges generally occur in November to February and do not typically coincide with the peak rainfall events. We seek to find an appropriate and pragmatic selection of combination rainfall and lake level design events with this consideration in mind.

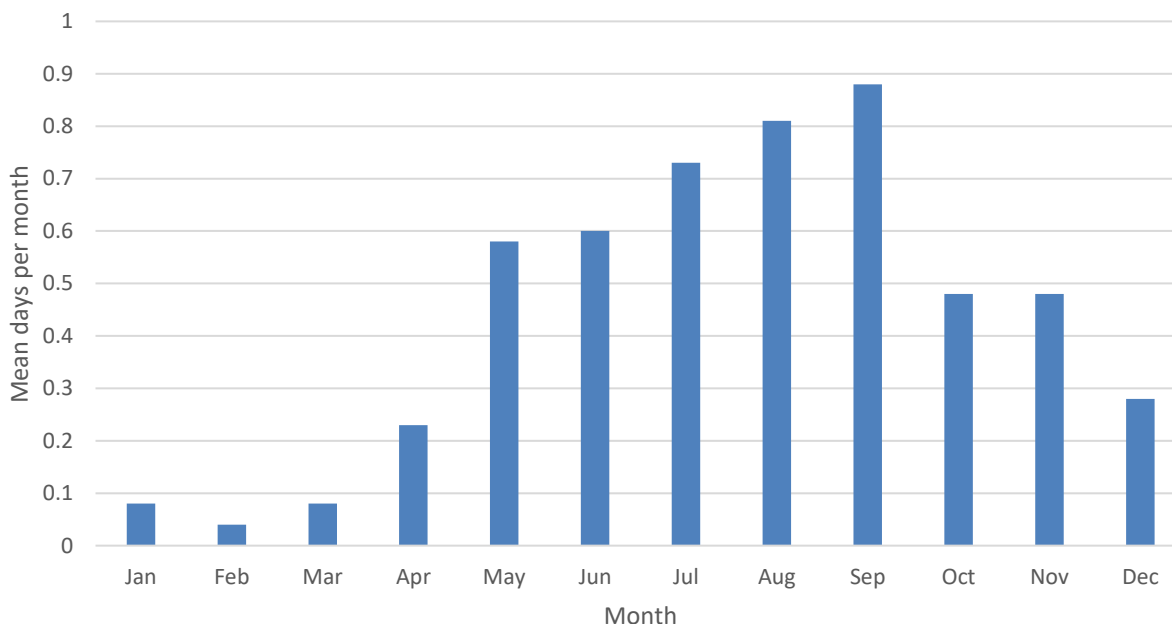


Figure 2: Mean days per month with rainfall > 25mm at Port Colborne between 1981 and 2010

We have conducted a preliminary assessment of the seasonality of rainfall, flood and surge to assist with model scope development. As part of the modelling phase we will review the seasonality of rainfall and lake levels in more depth and conduct frequency analysis from local long-term gauges for various months of the year. This monthly frequency analysis will guide us to appropriate combination events (e.g., 1:100-year November riverine flows with 1:100-year November lake surge levels, or 1:100-year July riverine flows with 1:100-year July lake levels). Our modelling analysis will help determine the potential impact of combined riverine and lake surge flooding. This analysis will be conducted with an initial investigative stage, which will be presented to the Town before continuing with a detailed assessment. The investigative stage will determine if further analysis of the coincident frequency and impact of combined riverine and surge events is needed.

We will consider the impacts of climate change and lake-level rise on riverine and lake-level induced flooding components through literature review.

3.2 Lake Level Modelling

Dr. Prodanovic developed a calibrated Lake Erie storm surge model using the TELEMAC 2D coastal circulation model. This model was used in a project in Port Dover to refine storm surge elevation for a harbour development project. In the numerical model applied surface winds over the lake caused storm surges, with the model providing computed storm surge elevations at any point in its computational domain. This model allows us to estimate accurate historical lake levels including the effects of storm

surge in our analysis. We have used this model to obtain calibration results for storm surge at Port Colborne and Buffalo to obtain several surge levels for use as downstream boundary conditions for riverine flood modelling.

3.3 Consideration of coincident lake surge and rainfall induced flooding

Matrix have obtained daily total precipitation datasets, and river gauge flow datasets from Climate Data Canada and Environment and Natural Resources Water Office websites and calibrated hindcast modelled lake level and storm surge data from Dr. Prodanovic. Using this data, an interim seasonality assessment has been conducted.

The assessment of the seasonality of extreme river, rainfall and lake surge events helps us to consider the potential likelihood of extreme lake levels occurring at the same time as extreme rainfall events causing a 'coincident flood event' in Six Mile Creek. These flood events could be completely independent and caused by different meteorological systems or completely dependent, caused by the same meteorological system, or somewhere in between. The most complex case for analysis is where there is partial dependence, or the lake and rainfall events are sometimes caused by the same system. This allows us to determine appropriate analysis methods, ways to simplify the analysis (for time and cost effectiveness) and therefore determine appropriate design rainfall events and lake level parameters.

Figure 3 and Figure 4 show plots of 'significant' events for the available records for each month of the year. Here we have filtered out events where 'significant' is defined as events above a 1:2-year AEP threshold. That is an event that is 'significant' enough to occur on average once every year or so. This filter allows us to see which months these events have typically occurred.

Figure 3 plots the occurrences of discharges above the monthly maxima flood discharge at nearby river gauges for each month of the year. The river flow data indicates a historical precedence for rainfall or snowmelt driven flood events occurring during the winter months close to the study area (Upper Welland River and 20 Mile Creek), though these catchments lie further inland than Six Mile Creek. This indicates that for these inland catchments, flood events often occur in December through January, indicating snow melt has a significance, and there is historical precedence for flood events occurring at the same time of year as wind induced storm surge events which occur almost exclusively in the winter months. This finding means that there is some possibility of extreme surge and wind coinciding which should be a consideration for boundary condition selection at Six Mile Creek.

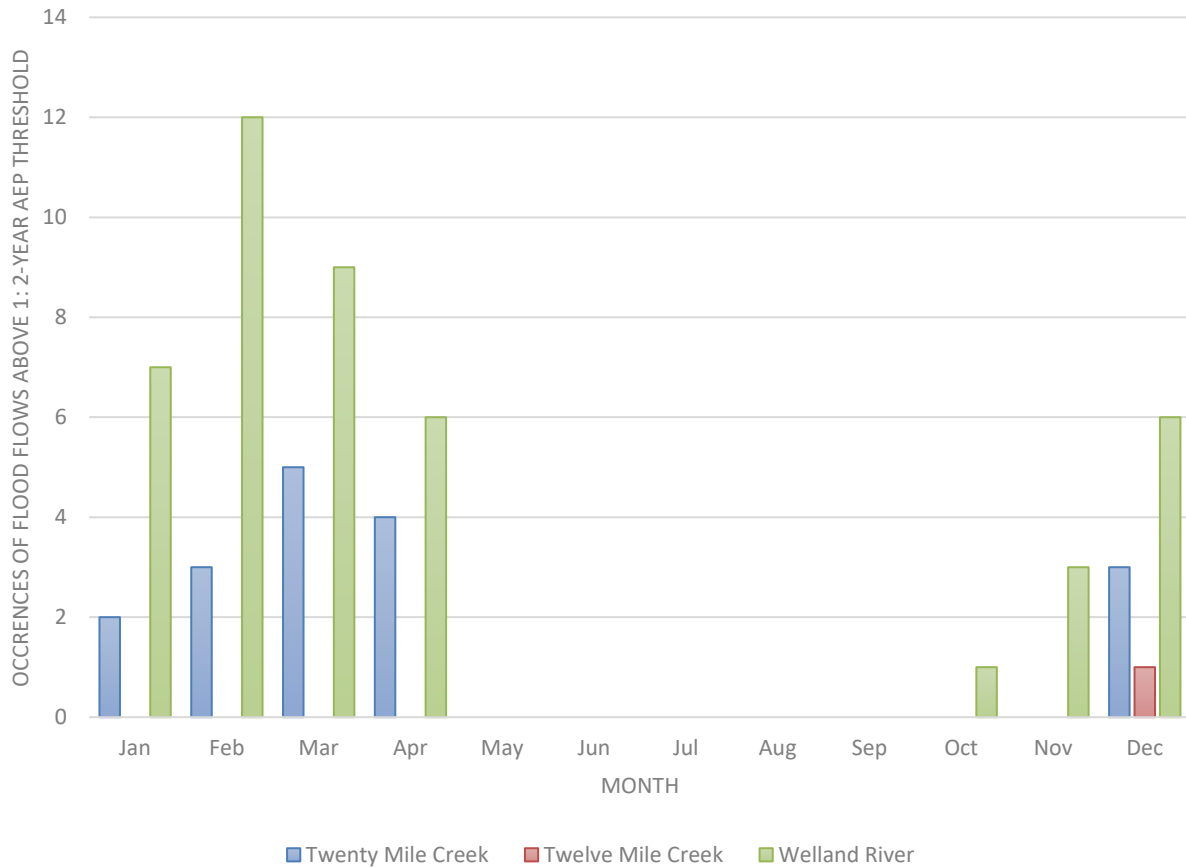


Figure 3: Frequency of monthly maxima river levels above 1:2-year AEP threshold in each month across record (Environment and Natural Resources Water Office)

Figure 4 plots the occurrences of daily precipitation maxima at nearby rainfall gauges for each month of the year filtered above a 1:2-year AEP threshold again, to filter out ‘significant’ events. Figure 4 shows that significant precipitation can fall in the winter months but predominately occurs during the summer months.

Figure 3 and Figure 4 indicate that rainfall and flow driven events do have a history of occurring in the winter months, which is of significance to the Six Mile Creek study as this is when surge events have historically occurred. For the Fort Erie rain gauge site closest to the Six Mile Creek study area from the inland catchments most heavy rainfall events occur in the summer months.

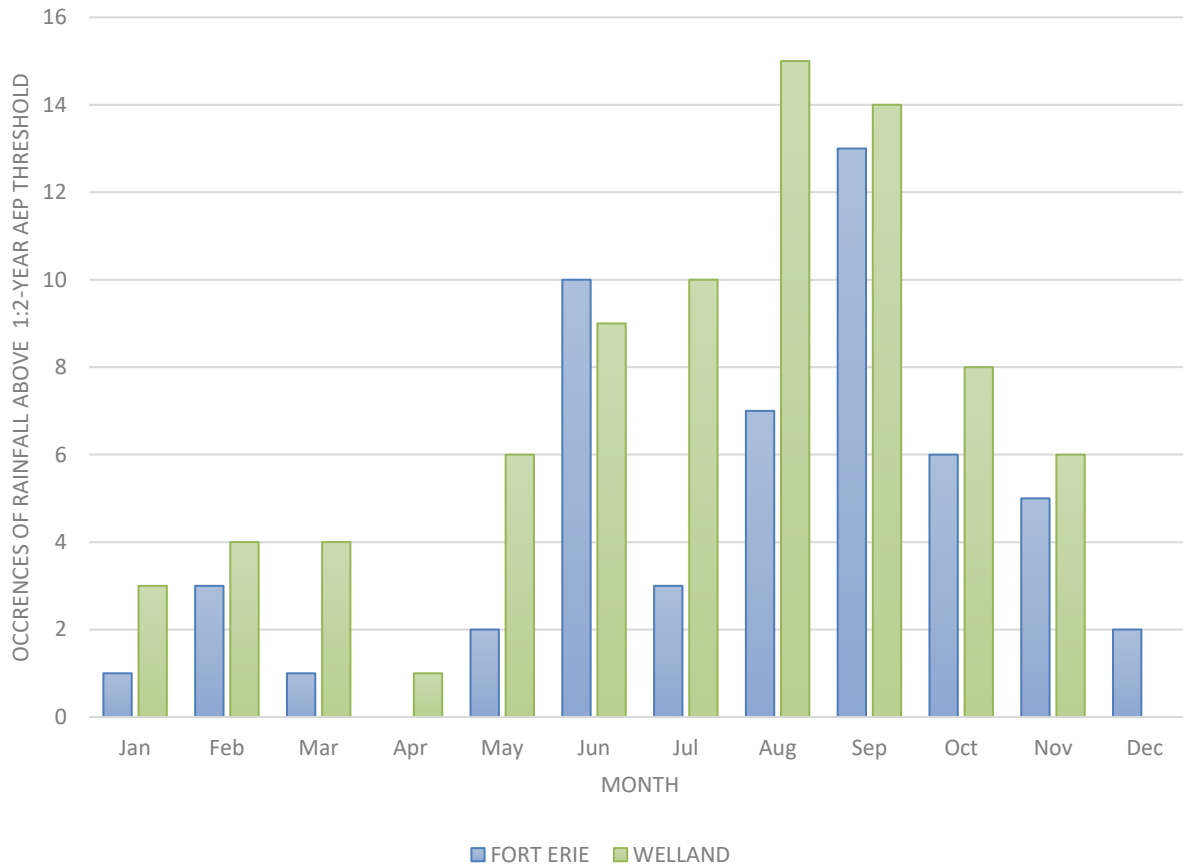


Figure 4: Frequency of monthly daily total precipitation maxima above 1:2-year AEP threshold in each month across record (Climate Data Canada)

Lake levels vary both gradually over weeks and months as inflow and outflows occur into Lake Erie, and over shorter periods of time (hours to days) as a result of storm surge which occurs primarily as a result of wind action driving water to one end or the other of Lake Erie. This effect is also called wind setup. Surge also occurs as a result of varying atmospheric pressure across a water body pushes the water surface down with more force in one area, and less in another. This wind induced effect can cause an oscillation where water ‘sloshes’ back in forth like in a bathtub which is called a seiche wave. Sometimes the terms storm surge, seiche and wind set-up are used interchangeably, however here we have used storm surge to mean high lake levels induced over a period of hours to days as a result of wind action on the lake surface.

When analysing lake levels it is useful to separate the effects of variations in level from inflow and outflow, to variations caused by wind, as these are caused by different phenomena, and occur over different timescales. We can refer to these different effects on the lake level record as ‘signals’. There is a signal from wind, and one from inflow and outflows.

Figure 5 shows a plot of the instantaneous hourly hindcast storm surge levels as well as annual maxima, and smoothed and monthly averaged maxima lake levels (which removes the impact of storm surge on the level record). Storm surge historically occurs for relatively short durations, with peaks lasting for only a few hours, and positive surge typically lasting for approximately 12-24 hours. Seasonal lake levels

fluctuate by around 0.5 m from summer to winter in most years. Plotting monthly average lake level has the effect of filtering out the 'signal' from of surge. Seasonal high lake levels occur during the summer months and seasonal low lake levels occur during the winter months indicating a negative correlation with storm surge. The storm surge 'signal' dominates the instantaneous extreme lake level records, with several significant peaks recorded during the 2000 to 2015 period where year over year lake levels were not at or below average. Recent noted flood events reported by the Town of Fort Erie in Figure 5 show that these occurred during periods of higher lake level, though many of the highest peak surge levels in the 2000 to 2010 period occurred at lower lake levels.

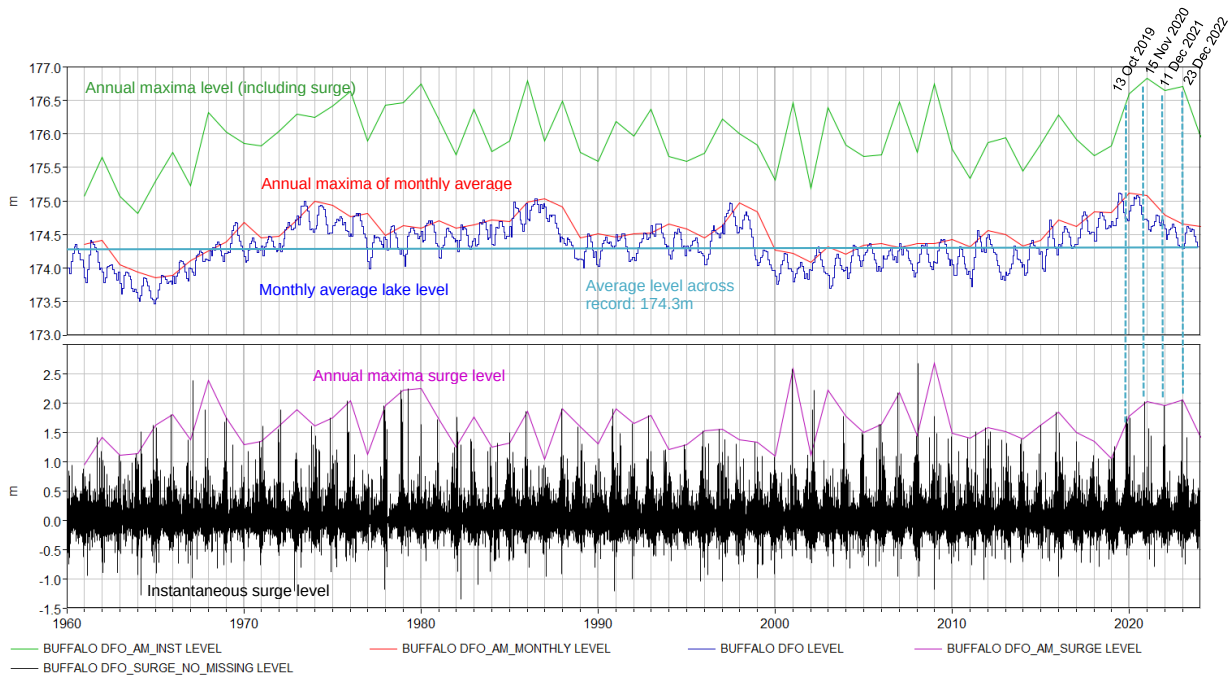


Figure 5: Lake level and storm surge plots generated from Hindcast storm surge model of Lake Erie (Prodonovic 2023). Storm surge events where the Town of Fort Erie reported flooding between 2019-2023 are noted.

Figure 6 shows scatter plots of Daily Maxima Storm Surge at Buffalo against Total Precipitation at Fort Erie for 'wet' days (days on which precipitation was recorded). Figure 8 shows the same data filtered for days where more than 20 mm of precipitation was recorded. These figures do show one significant data point where significant rainfall (approximately 58 mm) fell on a day (14 Nov 1974) that experienced a 1.7 m storm surge, meaning coincident events are somewhat rare, but possible, and are weakly correlated, or are independent. No significant rain fell during the events the Town of Fort Erie reported between 2019 and 2023.

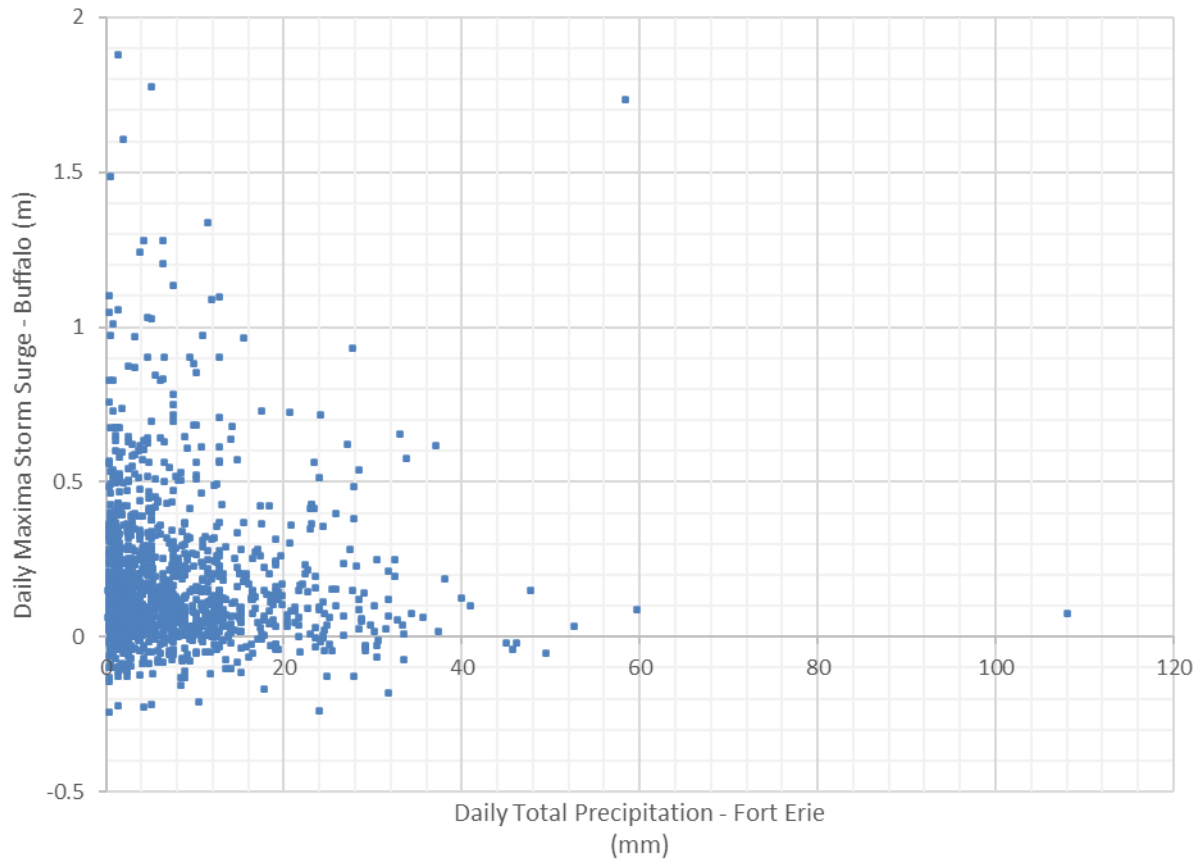


Figure 6: Scatter plot - Daily Maxima Storm Surge vs Total Precipitation for 'wet' days

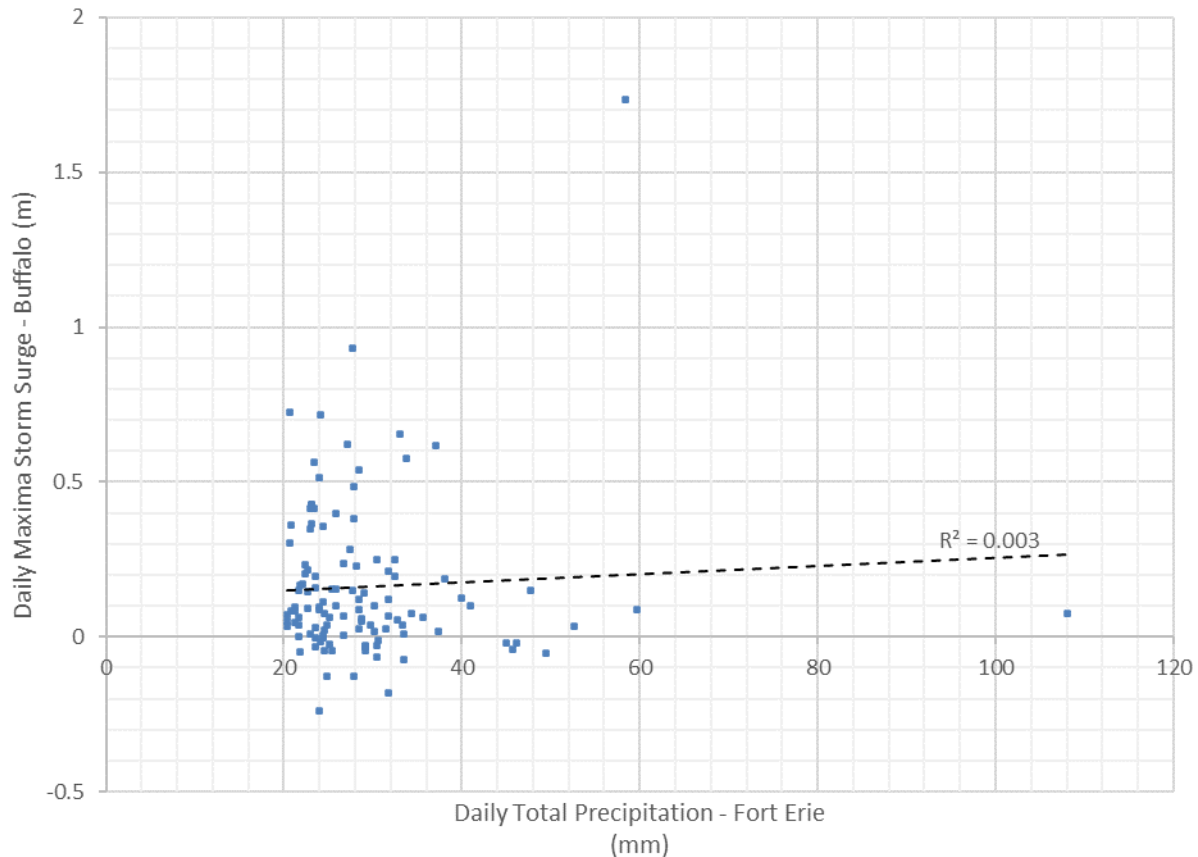


Figure 8: Scatter plot - Daily Maxima Storm Surge vs Total Precipitation for days with ≥ 20 mm total precipitation

3.4 Coincidence of riverine flooding with storm surge

The monthly occurrence of river flood and storm surge in the winter months indicates that there may be very weak or no dependence between riverine flooding and storm surge during the winter months rather than complete independence. This means that there is a possibility of coincident lake surge and riverine flooding based on the historical records Matrix have analysed, but the possibility of coincident events is low. It suggests lake surge and river floodings are not generally occurring during the same meteorological event.

A recent study² conducted on the Buffalo River considered joint probability of wind induced lake surge on Lake Erie and riverine flooding is relevant to our study for Fort Erie. This study presents data indicating that a conditional probability of a +1:100-year surge coinciding with a 1:2-year flood is lower than 1%. This is much more likely than if the events were completely independent but gives an indication of the relatively low risk of coincident events that can be expected. Note that the Buffalo River drains a catchment area of 1158 km² meaning that the duration of flood peaks will be significantly longer than the 18 km² Six Mile Creek catchment, lowering the probability of coincident surge and flood peaks in the study area.

² A.M. Saharia et al. 2021. *Compound flooding from lake seiche and river flow in a freshwater coastal river*. Journal of Hydrology 603 (2021) 126969.

There are several methods of dealing with combined flood effects available depending on time, budget, data availability and potential significance of effects. In all cases an initial screening of independent and dependent cases is recommended as a first step. This typically involves some modelling of ‘optimistic’ and ‘pessimistic’ scenarios to judge the impact of each effect and judge the value in more detailed analysis.

A simple approach to the assessment of dependence is an intuitive one based on general experience, and similar nearby studies. This is a useful first ‘screening’ step, and it is believed to be a practice approach to inform the alternatives for assessment. For example, it may be practical to assume a 1:2-year, 1:5-year riverine flood occurring coincident with storm surge as a standard design event.

A full analysis of dependence and joint probabilities can be done if needed by continuous simulation techniques which are typically computationally and time expensive to conduct and may only be warranted in cases where there is significant dependence and value in doing so. As in the Buffalo River study, modern multivariate joint probability analysis techniques can be used to consider the joint probability of lake and rain driven flooding but this type of analysis is dependent on the quality of the recorded data. A continuous flow record which is not available at Six Mile Creek would need to be generated from hydrological model to conduct this which is time intensive.

3.5 Hydrologic Modelling Approach

We have reviewed the NPCA’s SWMHYMO model for Fort Erie and extracted 1:2- through 1:100-year flows and volumes for Six Mile Creek at Thunder Bay. We will use this existing model to gather flows and volumes from the simulated events to be used in HEC-RAS modelling and storage calculations, as appropriate.

3.6 Hydraulic Modelling

NPCA have provided an existing HEC-RAS model developed by Philips Engineering with output presented as part of the 2008 Fort Erie Creeks – Watershed Plan³. This model will provide a good foundation for this assessment but will need several updates (discussed in Section 3.7.1).

3.6.1 Approach to Modelling Coincidence of Extreme Lake Levels and Riverine Flooding

One of the major objectives of the 2008 NPCA HEC-RAS model was to assist with the development of 1:100-year flood lines for Fort Erie Creek watershed. The model was run with a lake level boundary condition of the mean monthly water surface of 174.4 m derived from the Canadian Hydrographic Service, this is close to the average lake level Matrix calculated from Dr. Prodonovic’s work. The Fort Erie Creeks – Watershed Plan flood lines did not consider the impact of extreme lake levels, nor the combination of extreme lake levels with riverine flooding. The 2008 report does acknowledge the significance of the derivation of the lake level to flooding in catchment areas near Lake Erie.

To understand the relative impact on the study area of the lake level and riverine driven flooding scenarios Matrix has conducted a set of ‘test’ model runs using NPCA’s existing HEC-RAS hydraulic model.

³ Philips Engineering Inc., 2008. Fort Erie Creeks – Watershed Plan. Report Prepared for Niagara Peninsula Conservation Authority.

Figure 7 shows flood levels along Six Mile Creek for a range of riverine flood events and the mean monthly lake level (174.4m). This is the model boundary condition used in the 2008 NPCA HEC-RAS model.

Figure 8 shows the model's predicted flood levels for a 1:2-year lake level scenario. Comparison of the profiles for these two arrangements shows the impact of high lake levels on the flood profiles. 1:2-year lake level with a 1:2-year river discharge causes higher flood levels than a 1:25-year riverine flood event and monthly mean lake levels.

Figure 9 shows these flood levels with a 1:10-year lake level across different riverine flood events. The 1:10-year lake level produces higher flood levels in the study area than any of the flood profiles for a mean monthly lake level shown in Figure 7.

Figure 10 shows corresponding extreme lake levels with riverine flooding (1:2-year lake level with 1:2-year riverine, 1:10-year lake level with 1:10-year riverine, etc). This combination of boundary conditions is the most conservative, as it assumes extreme lake levels and rainfall coincide, which our prior analysis has shown is unlikely. The relatively flat water surface profile also indicates the dominance of the effect of lake level on flooding in the study area.

These 'test' model runs indicate that flooding in the Six Mile Creek from the outlet up to Dominion Road (the study area), that lake level flooding dominates the flood impacts in this area. A simple approach to coincident flood event modelling, such as modelling extreme lake levels with a 1:2-year or 1:5-year riverine flood, will be appropriate as flood levels are less sensitive to the riverine flood discharge.

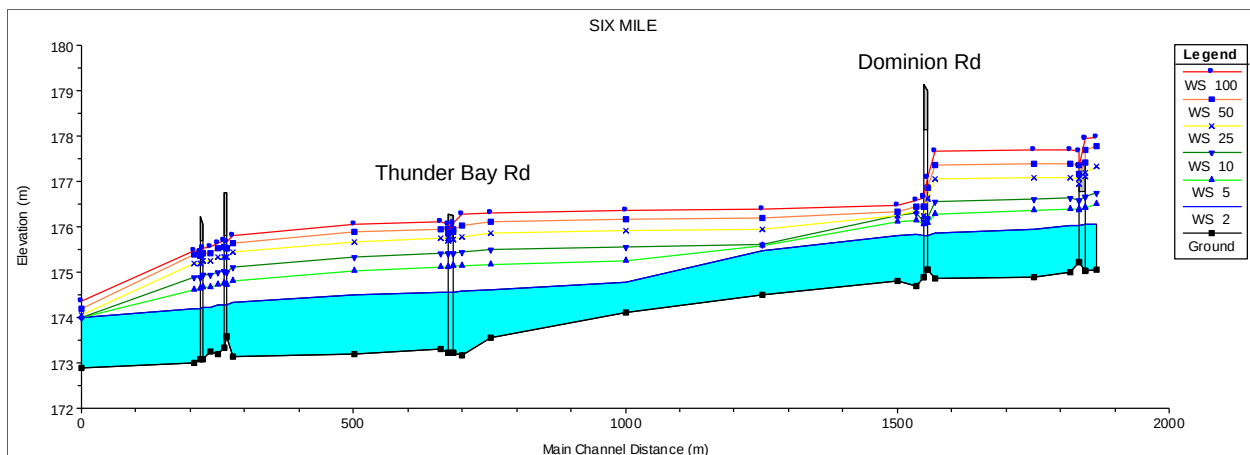


Figure 7: Mean monthly lake level with a range of extreme riverine floods

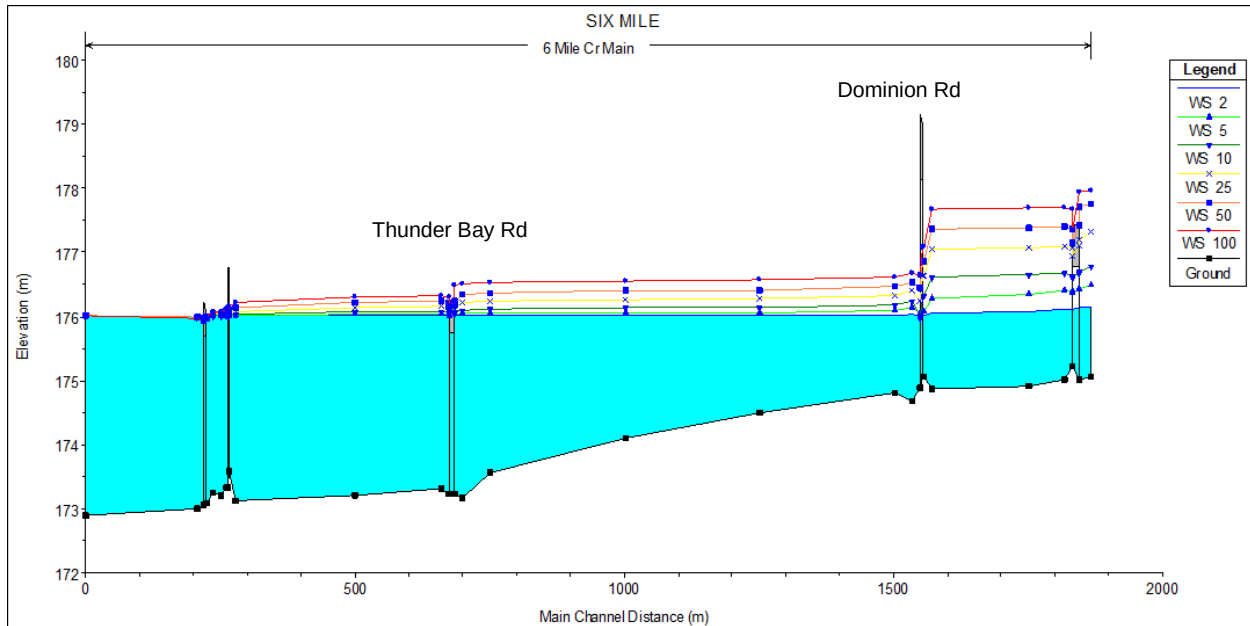


Figure 8: 1:2-year Lake Level with a range of extreme riverine floods

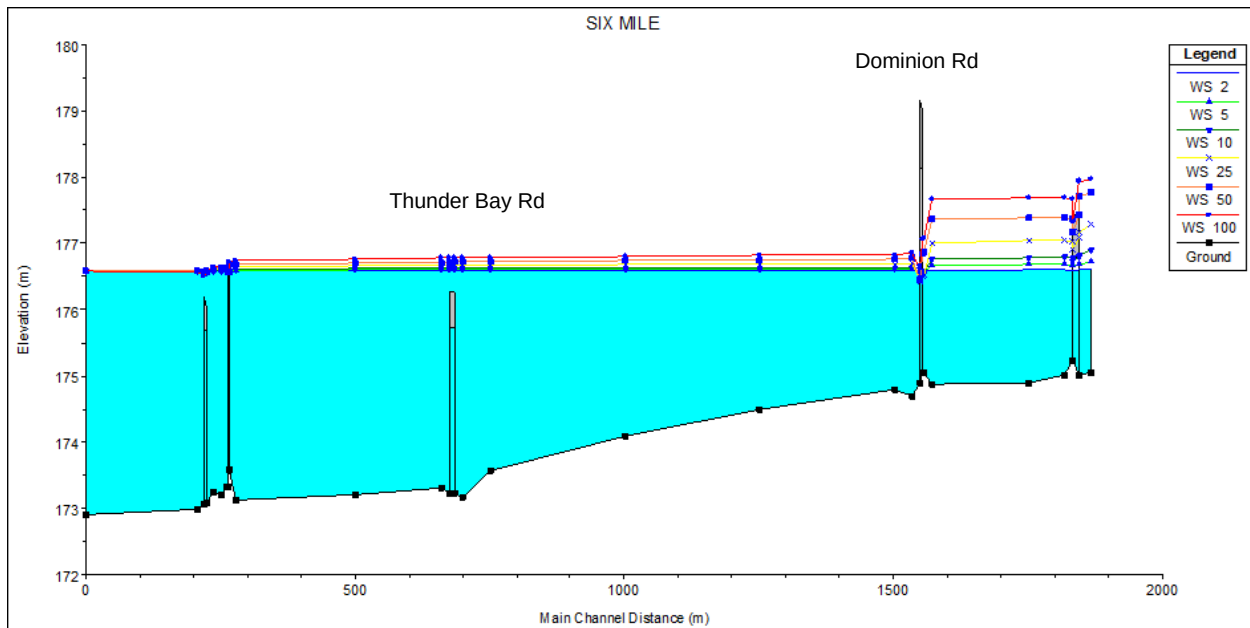


Figure 9: 1:10-year Lake Level with a range of extreme riverine flooding

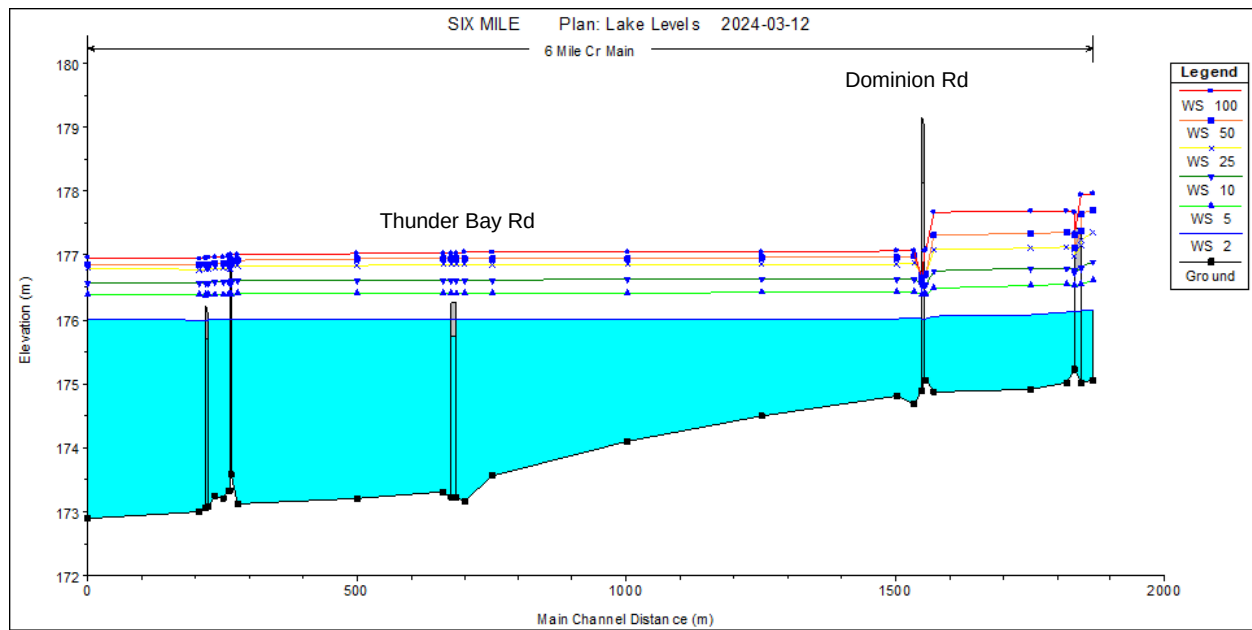


Figure 10: Lake level corresponding with similar riverine flood (1:2-year lake level with 1:2-year riverine, 1:10-year lake level with 1:10-year riverine, etc)

3.6.2 Design Events

The analysis of coincident events conducted so far shows that historically most storm surges have not occurred on days with significant rainfall at Fort Erie, and there is one historical event where a significant storm surge coincided with a day where approximately 60 mm of rainfall fell (Figure 6). In general, extreme lake levels produce higher flood levels for a given AEP than riverine discharge, and have a larger influence on flood levels when they do coincide. Town of Fort Erie Subdivision Control Guidelines for Development of New Subdivisions 2021 provide a 1:5-year storm event design standard for its minor drainage infrastructure.

A reduced number of modelled combinations to consider will simplify the analysis and the associated communication, but still provide a robust analysis. Matrix has considered the Town's existing stormwater standards where a primary level of protection from stormwater infrastructure to a 1:5-year standard is provided, the historical record of coincident rainfall and lake level events and the relative impact of lake levels and river flood discharges on flooding in the study area.

Based on our assessment, Matrix recommends adopting a 1:5-year lake level as a standard design event basis of comparison for the development and analysis of flooding protection alternatives to align with the Town's existing standards. Matrix will consider various coinciding riverine discharges with the 1:5-year lake level. Our aim in reviewing the coinciding events is to confirm that there are no unacceptable flooding impacts that result in these coinciding events and/or the flood protection alternatives have sufficient resilience to accommodate low probability coinciding events. This combination aligns with existing town standards, while allowing for analysis of options to mitigate lake level driven flood events in the study area. Table 1: Event boundary conditions to be modelled Table 1 highlights the events that Matrix will model for the basis of comparison model.

Table 1: Event boundary conditions to be modelled

		Lake Level						
		Mean Lake Level (174.4m)	2y	5y	10y	25y	50y	100y
River Discharge	No Inflow			✓				
	2y			✓				
	5y			✓				
	10y			✓				
	25y			✓				
	50y			✓				
	100y			✓				

3.7 Modelling Approach Stages

We will undertake the modelling to support the project objectives in two stages.

1. Model build stage

The model development stage will provide a refined version of the existing NPCA HEC RAS model for a basis of comparison model for Six Mile Creek. The model will be georeferenced within the study area and optimised for use in the study. The steps involved are discussed in Section 3.7.1.

2. Alternative assessment modelling

Alternative solutions for flood mitigation will be assessed using the revised HEC-RAS model.

3.7.1 Model Build Stage

In the model build stage we will make improvements to the existing hydraulic model tailoring it to the study objectives.

Key steps in updating the model will include:

- Georeferencing the model within the study area.
- Updating the model with the latest available high-resolution topographic data of key locations within the study area, including riverine/floodplain cross-sections, road crown and sag levels where these are likely to be overtopped, culvert soffit and bridge deck levels.
- Using existing LiDAR DEM data to describe the general topography of the study area with some ground-truthing at critical locations (Matrix will provide the town with data requirements in a separate documents with survey to be completed by Town staff).
- Incorporating riverine and lake-level boundary conditions based on the design events described in Section 3.6.2.
- Identify any key features that require site investigation and survey of infrastructure like bridges and culverts, and areas where overtopping occurs like road embankments.
- Representing interim construction in summer 2022 where the town raised Shirley Road to approximately 176.20m between 127 and 137 Shirley Road, replaced the two existing 1000mm dia. CSP with a 1200mm x 900mm box culvert complete with a flat gate, and a new storm manhole with a check valve.

Once the model is developed to a suitable level, Matrix will:

- Run hydraulic simulations for various compound flooding scenarios, including different combinations of river discharge and lake water levels.
- Investigate the storage effects by conducting both dynamic and steady state scenarios.
- Evaluate flood extents, depths, and inundation duration.
- Consider impacts of flooding on the number of dwellings and private properties in the study area.

These model simulations will form the baseline conditions for the hydraulic analysis portion of the EA.

3.7.2 Alternative Assessment Modelling

In this stage we will undertake a full modelling assessment for the alternative solutions in a level of detail appropriate for use in the Environmental Assessment.

This will involve:

- Running hydraulic simulations for various compound flooding scenarios, including different combinations of river discharge and lake water levels.
- Evaluate flood extents, depths, and inundation duration.
- Consider impacts of flooding on the number of dwellings and private properties in the study area.
- Overlay flood extent with exposure data (land use, infrastructure, population) to assess potential impacts.
- Evaluate the flooding potential and resilience of critical infrastructure and vulnerable areas.

4 REPORTING AND COMMUNICATION

The results of the hydrologic and hydraulic modeling will be communicated through comprehensive Environmental Assessment existing conditions summaries, reporting, maps, and visualizations. Findings will be reviewed and accepted by the Town, and then further shared with stakeholders, including local residents, the Conservation Authority, and First Nations , and the general public, to inform decision-making and support the development and evaluation of flood mitigation alternatives.