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August 02, 2019

Mr. Steven Scannell
Director of Community Development
274 Main Street
Antigonish, Nova Scotia
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Dear Mr. Scannell:

*RE: Antigonish Floodplain Delineation Study – Final Report*

We are very pleased to submit for your review this draft report on the analysis conducted to support the Antigonish Floodplain Delineation Maps, that have been transmitted you. We hope the information below provides you with the information you are looking for.

# 1 Introduction

The Town of Antigonish is located in Antigonish County, Nova Scotia. The Town has one minor stream, Brierly Brook, and two major waterways (Figure 1), the Rights River and the West River, within the rural town limits and one brook, Brierly Brook, running through the downtown area. The two rivers discharge into Antigonish Harbour, and Brierly Brook discharges into the West River. The tidal waters of St. Georges Bay impact water levels at the Antigonish Harbour estuary. A combination of tidal influence and peak river flows makes this area particularly vulnerable to flooding. During the winter, low temperatures often cause the rivers to freeze, which can then allow ice jams to form during freshet, in turn leading to additional risks of local flooding. Furthermore, the low lying areas of the downtown core close to Brierly Brook, have experienced regular high water levels events, to the extent that some residences and infrastructure have experienced flooding damage on a regular basis, as seen on February 5, 2018. Development in the watershed has also potentially affected runoff.

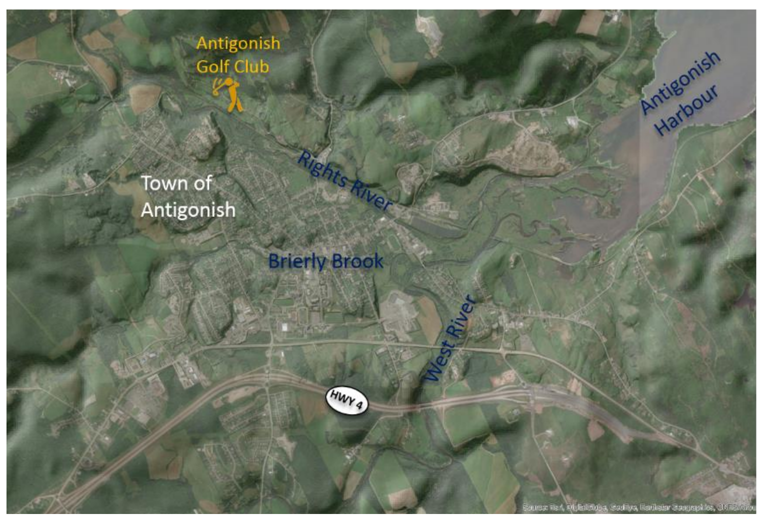



**Figure 1: Study Area Map**

Other changes that will impact the risks of flooding are the climatic changes projected for this region. Expected increases in rainfall intensities and frequency will increase flood flows. Rising sea levels will increase flood levels at the mouth of the rivers and this will be transferred throughout the community.

The Town of Antigonish selected CBCL to conduct a study in the area to understand current and future flooding risks. The study includes the development of flood maps based on a hydrologic and hydraulic assessment of the study area using a computer model of the Rights River, the West River and Brierly Brook.

# 2 HYDROLOGIC ASSESSMENT

The hydrologic assessment involves calculations of the runoff flows on the Rights and West Rivers up to the Antigonish Golf Club and Highway 4, respectively, based on historical flows. The analysis also includes the development a hydrologic computer model to estimate runoff flows through Brierly Brook and the remaining areas of the Rights and West Rivers.

## 2.1 Watershed Characteristics

An assessment of the freshwater hydrologic processes was first performed by analyzing the physiography and topography of the freshwater system draining towards the Antigonish Harbour. Figure 2 shows the watersheds and sub-watersheds tributary to selected locations within the Town, delineated using 5 m contour lines and high resolution LiDAR topographic mapping.

The NSDNR land use database was used to estimate the surface roughness coefficients, impervious percentages, soil types, forested land percentages of the watersheds and sub-watersheds. Other hydrologic characteristics (surface area, maximum overland flow length and average surface slope) were estimated using a three-dimensional ground surface generated by ArcView, based on LiDAR mapping and field survey data.

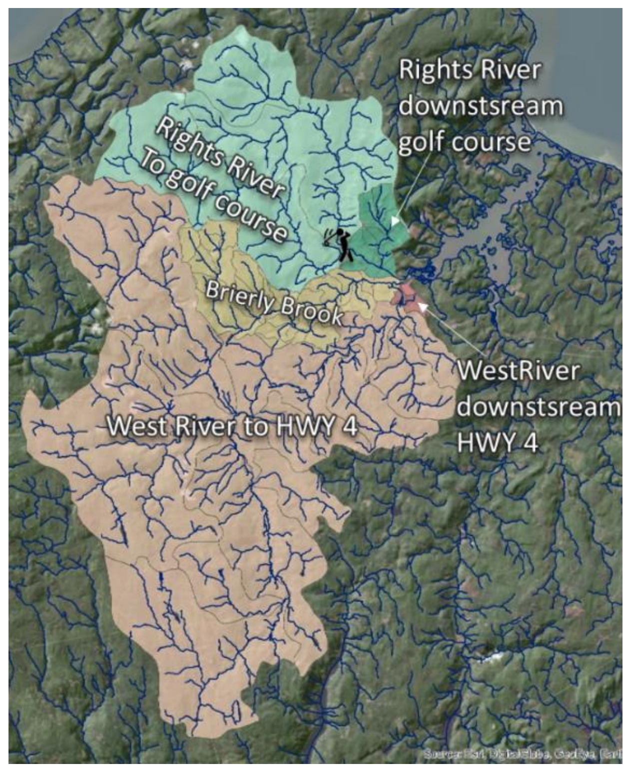



**Figure 2: West Rivers, Right Rivers and Brierly Brook Watersheds**

## 2.2 River Flow Analysis

Modelling of flood risks throughout the Town of Antigonish required the estimation of extreme peak flows for the West Rivers and the Rights River. The calculation of extreme peak flows consist of a statistical analysis on the instantaneous annual peak flow records at hydrometric stations. However, existing hydrometric data for the Rights River is insufficient for a complete statistical analysis and no hydrometric records are available for the West River. Therefore, surrounding river watersheds with available data were evaluated to identify a river with flow patterns similar to those that would be observed in the Rights and West Rivers. Flow estimates are calculated or prorated to the rivers of interest using watershed areas as scaling factor. The Antigonish Golf Course and the highway 4 bridge, on the Rights River and the West River respectively, were selected as the locations for flow estimation using this method as land uses at this point change from mostly rural to urban.

The rivers evaluated for prorating were chosen based on their proximity to the Rights and West Rivers, similarities in their hydrological characteristics and the quality of the available data.  Including the minimal data from the Right's River hydrometric station, seven hydrometric stations were selected from seven separate rivers for the statistical analysis. The watershed delineation and location of each hydrometric station used in the analysis is shown in **Figure 3**.

Table ***1*** shows the river and tributary watershed characteristics (percentage forested, drainage area, slope, lakes, wetlands, development) extracted for each of the stations using aerial photos and the NSDNR land use database. This information was used to evaluate the representativeness of each station and compare the flow behaviour of the rivers to that expected from the West and Right rivers.

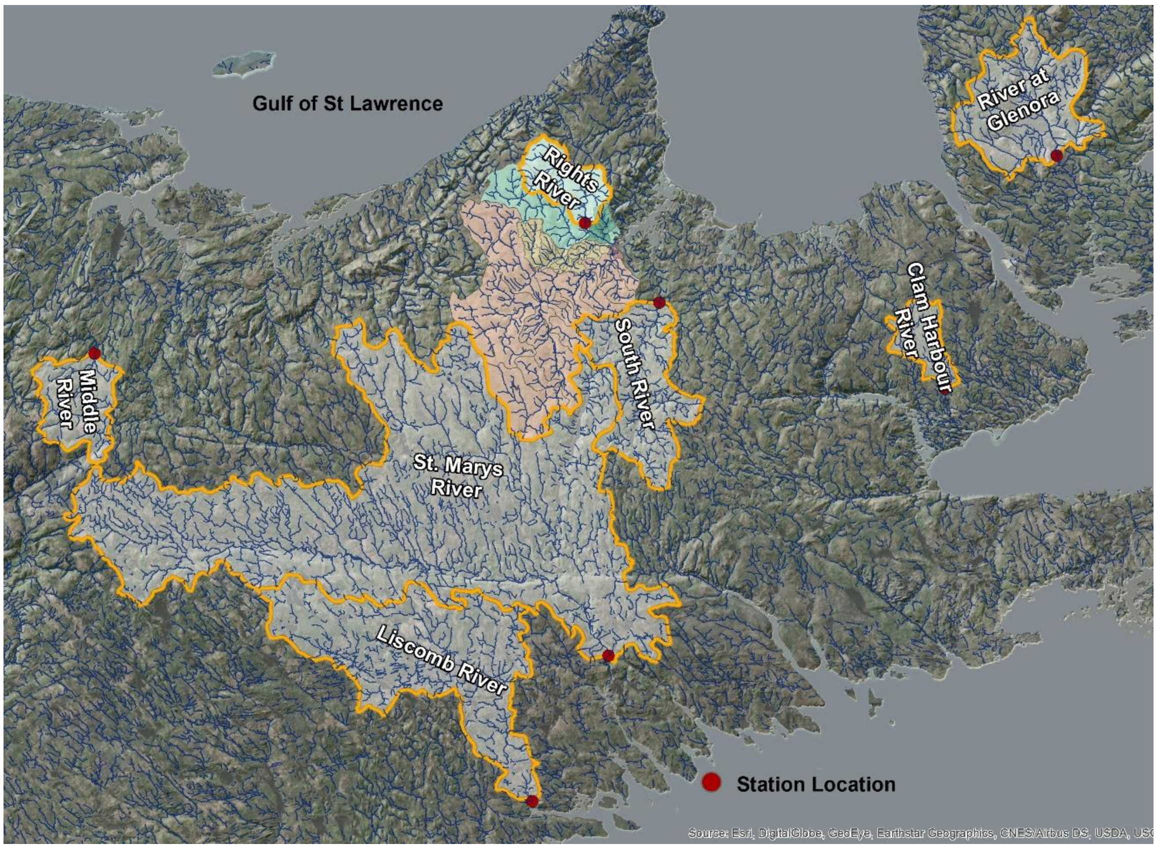



**Figure 3: Watersheds Selected for Hydrologic Evaluation of Flows**

**Table 1: Hydrologic Characteristics of Selected Watersheds for Flow Analysis**

| Station | Station ID | Latitude | Longitude | Peak Flow Data Points | Proximity | Slope | Drainage Area | Forested Area |
|---|---|---|---|---|---|---|---|---|
| | | | | years | km | % | $km^2$ | % |
| Rights River Near Antigonish | 01DR003 | 45.65 | -62.02 | 7 | N/A | 7.64 | 64.2 | 65 |
| South River At St. Andrews | 01DR001 | 45.56 | -61.90 | 38 | 13.07 | 6.25 | 177 | 63 |
| Clam Harbour River Near Birchtown | 01ER001 | 45.47 | -61.46 | 35 | 47.59 | 3.13 | 45.1 | 70 |
| St. Marys River at Stillwater | 01EO001 | 45.17 | -61.98 | 49 | 52.52 | 4.94 | 1350 | 57 |
| River Inhabitants at Glenora | 01FA001 | 45.72 | -61.29 | 42 | 57.69 | 7.62 | 193 | 70 |
| Middle River of Pictou at Rocklin | 01DP004 | 45.50 | -62.78 | 31 | 59.28 | 7.13 | 92.2 | 55 |
| Liscomb River at Liscomb Mills | 01EN002 | 45.02 | -62.10 | 28 | 70.54 | 3.08 | 389 | 64 |

As shown in Figure 3, St. Mary's and Liscomb rivers flow south-easterly into the south shore of Nova Scotia and the Middle river and the South River flow northerly into the Gulf of St. Lawrence. Also note that both the South and Rights rivers discharge into the Antigonish Harbour. From the information in the table above, the South River and the Middle Rivers would seem to be good candidates to represent flows in the Rights River. To confirm this, a statistical analysis of the gauged flows will be conducted.

To produce statistical models for the flows at each river, the analysis used several statistical distributions (Normal, Log-Normal, Three-Parameter-Log-Normal, Gumbel, Fréchet, Weibull and Log-Pearson III). The most representative distribution for each data set was then selected using statistical hypothesis testing (Chi-square test, T-test, correlation, coefficient of determination). The Weibull distribution was selected as the best fit model.

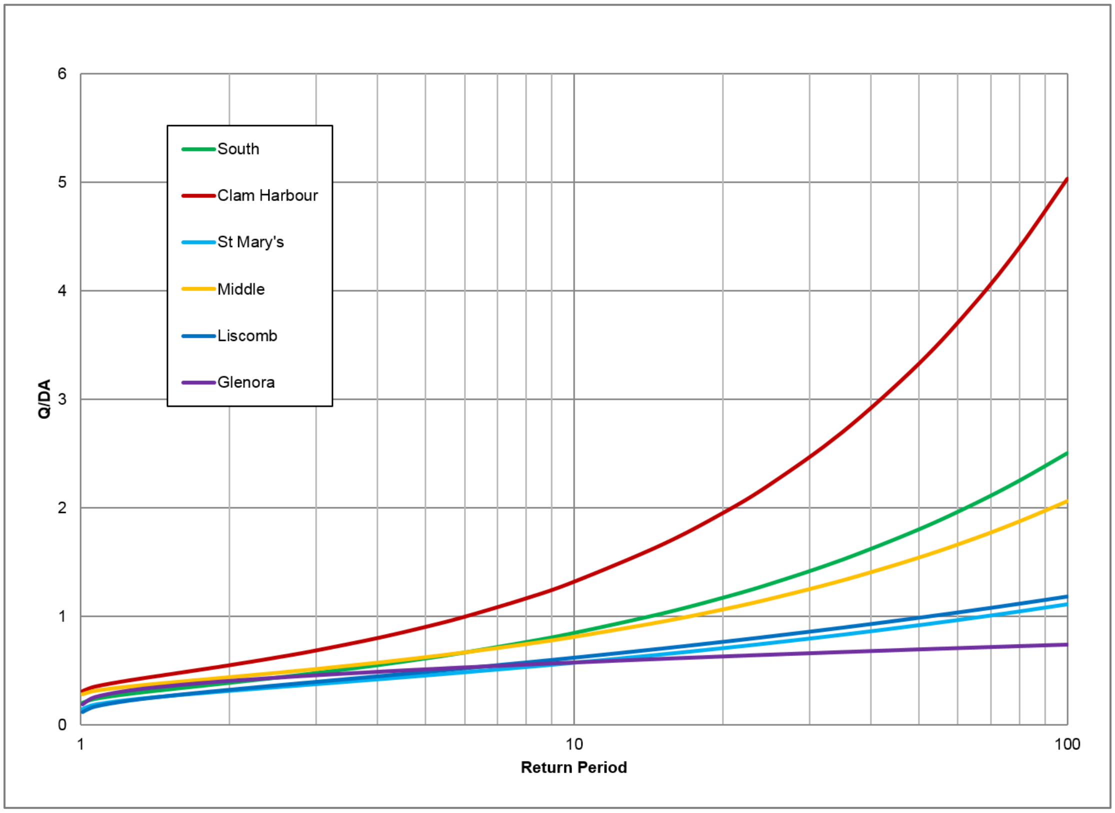



**Figure 4: Prorated Statistical Models**

The statistical models for each river were then compared by prorating the river instantaneous peak flows to the tributary watershed areas of each hydrometric station (see **Figure 4**). The calculations produced similar prorated trends between the South and Middle rivers and between the St. Mary's and Liscomb rivers. The Rights River was not included in this prorated comparison, as existing data did not allow for a best fit model of the same degree of accuracy. The proximity and flow direction of South River suggested that the statistical model for the South River hydrometric station was the most representative model for analyzing both the Rights and West rivers.

### *2.2.1 Validation of South, Rights and West Rivers Hydrologic Similarity using Water Level Field Data*

On June 26th, CBCL deployed three water level gauges at the Saint Andrews Bridge, the Church Street Bridge and the North Rail Bridge. Figure 5 compares the response of water levels at the South river, measured in real time at the South River EC Station, with the water level response measured in the field at Brierly Brook and the Rights and West River. The figure show that the three rivers responded with similar trends to the higher flows observed in October and November. This validates the use of the prorated flows at the South River for estimating the flows at the Rights and West Rivers. Church St, located at Brierly Brook showed also a similar pattern at the peak of the events, however this stream drains a smaller area in an urban setting, therefore a hydrological model was selected to estimate the flow rates of the brook.

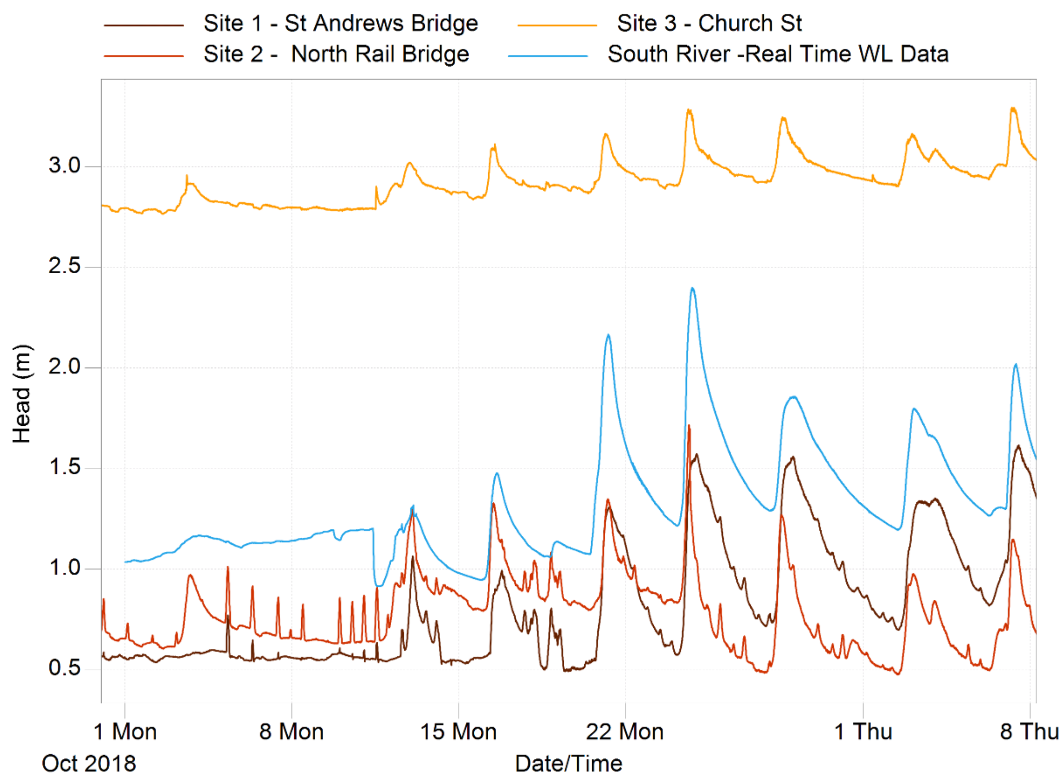



**Figure 5: Comparison of South River Water Level Response with Measured Data at Brierly Brook, Rights River and West Rivers during Field Monitoring Period**

### *2.2.2 Extreme Flow Calculation*

Figure 6 shows the extreme flows calculated for the South River using instantaneous peak flows and annual maximum average flows. Table 2 shows the flows prorated to the West and Rights Rivers.

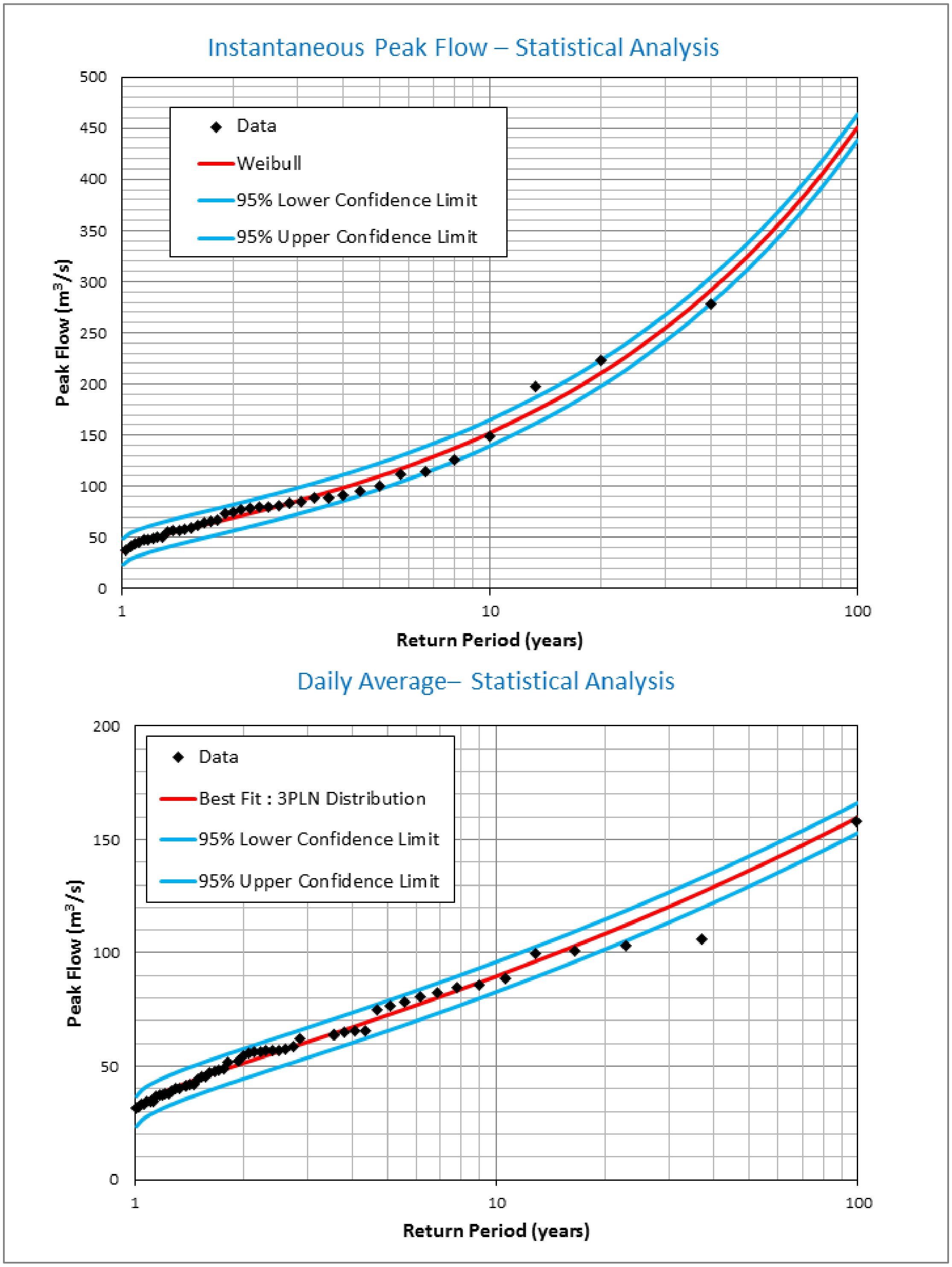



**Figure 6: Instantaneous and Daily Average – Statistical Analysis**

**Table 2: Calculated Extreme Flows**

| River Name | Watershed Area ($Km^2$) | Instantaneous Peak | | Daily Average | |
|---|---|---|---|---|---|
| | | 1 in 20 Year Flow ($m^3/s$) | 1 in 100 Year Flow ($m^3/s$) | 1 in 20 Year Flow ($m^3/s$) | 1 in 100 Year Flow ($m^3/s$) |
| West | 317.082 | 376.81 | 806.81 | 194.10 | 285.85 |
| Rights | 118.494 | 140.82 | 301.51 | 72.53 | 106.82 |
| South | 177 | 210.34 | 450.38 | 108.35 | 159.56 |

## 2.3 Rainfall Analysis

Environment Canada (EC) provides Intensity-Duration-Frequency (IDF) curves for 55 locations throughout Atlantic Canada. The IDF curves show extreme rainfall intensities for a range of durations (from 5 minutes to 24 hours) and frequencies (2, 5, 10, 25, 50 and 100 years). These curves are the result of extreme value statistical analysis of 20 years of rainfall intensity records and can be used to calculate synthetic hyetographs (rainfall time series) using methods such as the Chicago Distribution. Figure 7 shows the 1 in 20 and the 1 in 100 year hyetographs calculated using the Chicago distribution method and the IDF curves for Eddy Point, the closest location to the Town of Antigonish with data available.

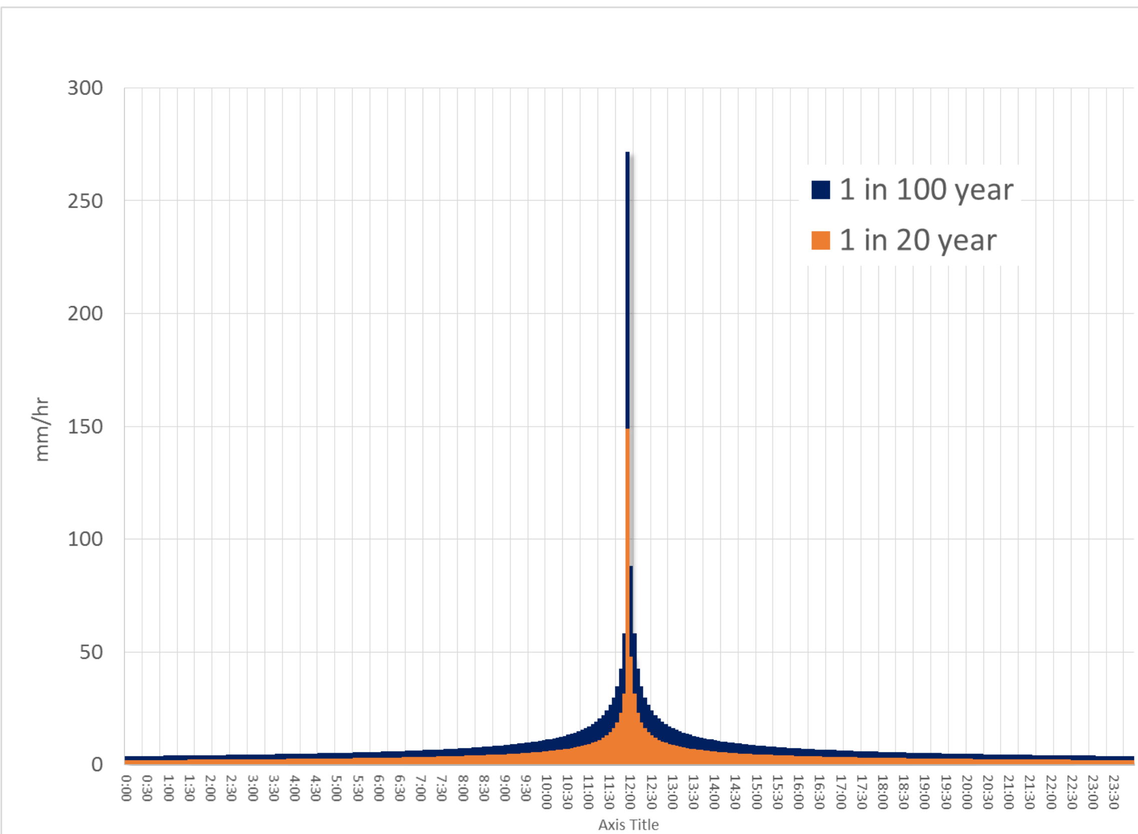



**Figure 7: 1 in 20 Year and 1 in 100 Year – 5 Minute Chicago Distribution – Hyetographs**

### *2.3.1 Impact of Climate Change on Rainfall*

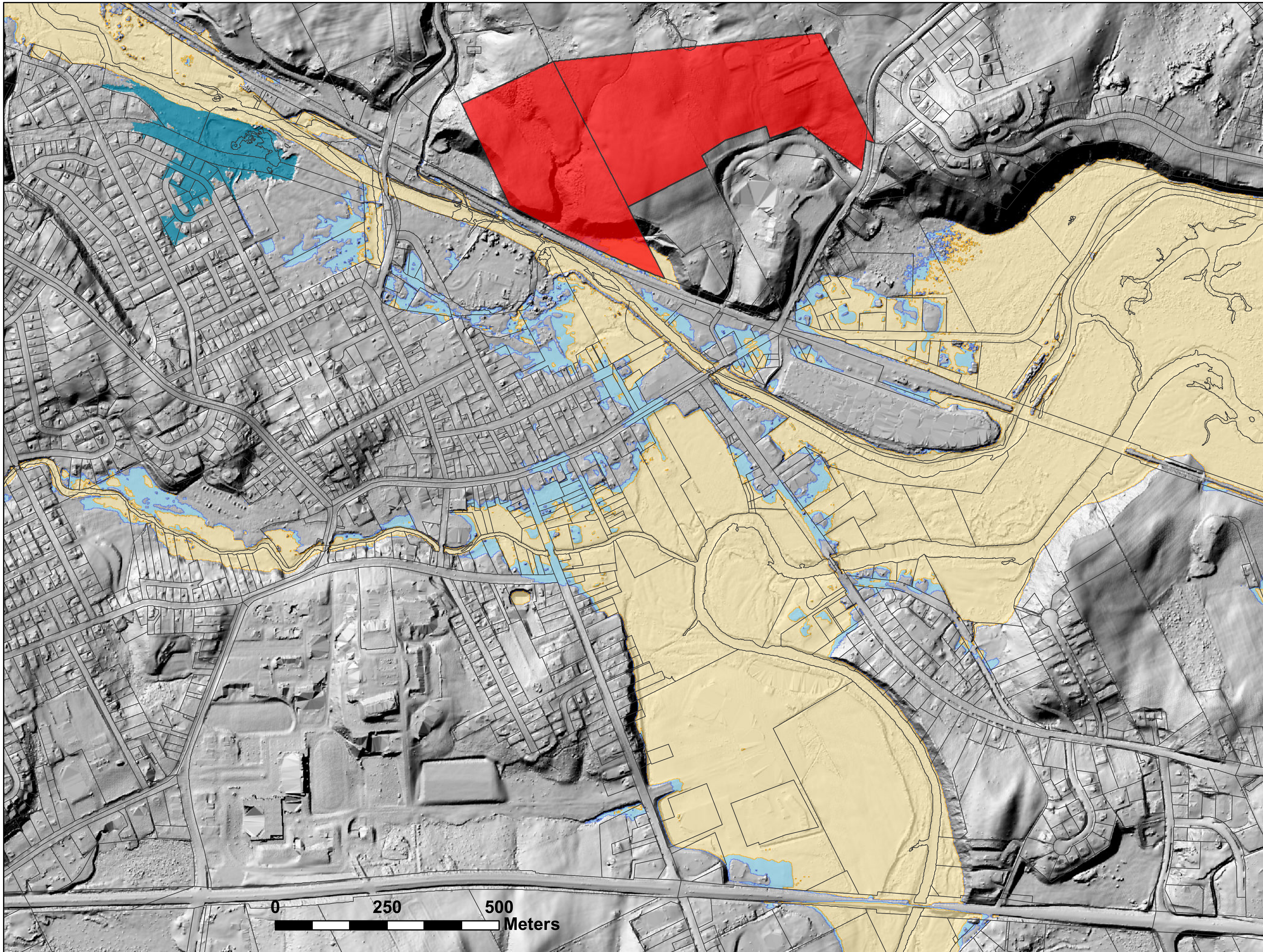
For this study, the worst-case climate change scenario, RCP8.5, as defined in the IPCC 5th Assessment Report (IPCC 2013)[1] was chosen. These estimates indicate that the most extreme future storms could increase rainfall intensity by 136%, whereas the minimum future increase could be as low as 14%[2]. Previous assessments in Halifax and Charlottetown found the percent increase in intensity to be between 8.59% and 52%, and between 18.85% and 46.3% respectively. These estimates are generally close to a 30% average increase by the year 2100. Therefore, to estimate the impact of climate change within the next 30 years (2050), a 15% increase in rainfall intensity was selected.

## 2.4 Hydrologic Modelling

The hydrologic model was developed using PCSWMM to estimate runoff flows from each sub-watershed for input into the hydraulic model. PCSWMM is a modelling platform developed by Computational Hydraulics International (CHI) that integrates Version 5 of the Storm Water Management Model (SWMM) with a GIS engine which is capable of performing 2D hydrodynamic simulations. SWMM is a hydrologic and one-dimensional hydraulic model developed by the United Stated Environmental Protection Agency to study semi-urban drainage systems and can perform unsteady flow calculations to simulate runoff flows based on soil types, slope, land uses, land cover and the shape of the watershed. Figure 8 shows the peak runoff flows calculated with the model, under current and future climate conditions, throughout the different subcatchments draining towards the West and Rights Rivers in the urban area. Map 1 shows the areas where potential additional development (outside of areas already developed) has been considered in the future runoff.

[1] IPCC. 2013. *IPCC 5th Assessment Report, Climate change 2007: The physical Science Basis. [Solomon S., D. Qin, M. Manning, Z., Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)].* Cambridge, UK, and New York, USA.: Cambridge University Press.

[2] Westra , S. , H. J. Fowler , J. P. Evans, J. V. Alexander, P. Berg, F. Johnson, E. J. Kendon, G. Lenderink, and N. M. Roberts. 2014. "Future Chances to the Intensity and Frequency of Short-duration Extreme Rainfall." Review of Geophysics 522-555.




THE TOWN OF
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Legend

- Property Lines
- Potential Development Parcels
- 1 in 20 year Flood Extent
- Water ponded behind berm
- 1 in 100 year Flood Extent

Map 1

**Future Climate**

February 7, 2019

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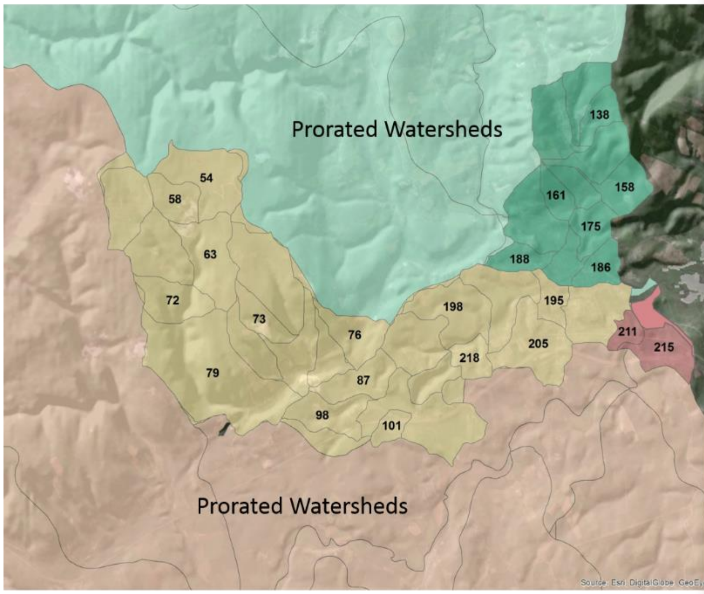



| Name | Present | | Projected | |
|---|---|---|---|---|
| | 1 in 20 year Flows ($m^3/s$) | 1 in 100 year Flows ($m^3/s$) | 1 in 20 year Flows ($m^3/s$) | 1 in 100 year Flows ($m^3/s$) |
| 101 | 0.49 | 0.7 | 0.66 | 0.93 |
| 129 | 1.52 | 2.16 | 2.04 | 2.87 |
| 133 | 3.18 | 4.44 | 4.19 | 5.76 |
| 138 | 1 | 1.44 | 1.35 | 1.91 |
| 152 | 2.39 | 3.38 | 3.19 | 4.45 |
| 158 | 1.65 | 2.36 | 2.22 | 3.13 |
| 159 | 1.48 | 2.07 | 1.95 | 2.68 |
| 161 | 1.3 | 1.83 | 1.72 | 2.4 |
| 164 | 2.95 | 4.07 | 3.87 | 5.23 |
| 175 | 1.88 | 2.63 | 2.48 | 3.42 |
| 180 | 5.24 | 6.66 | 6.29 | 8.08 |
| 186 | 3.41 | 4.43 | 4.2 | 5.43 |
| 188 | 5.06 | 6.46 | 6.12 | 7.79 |
| 194 | 2.34 | 3.27 | 3.11 | 4.27 |
| 195 | 4.74 | 5.99 | 5.68 | 7.17 |
| 198 | 0.81 | 1.2 | 1.13 | 1.65 |
| 200 | 5.25 | 6.66 | 6.39 | 8.09 |
| 205 | 5.58 | 7.16 | 6.86 | 8.76 |
| 211 | 2.26 | 2.95 | 2.79 | 3.61 |
| 214 | 1.35 | 1.95 | 1.83 | 2.62 |
| 215 | 2.62 | 3.63 | 3.44 | 4.7 |
| 218 | 0.81 | 1.14 | 1.08 | 1.5 |
| 226 | 3.72 | 7.12 | 6.56 | 11.46 |
| 54 | 0.9 | 1.33 | 1.25 | 1.82 |
| 57 | 1.03 | 1.5 | 1.41 | 2.03 |
| 58 | 0.67 | 0.97 | 0.91 | 1.31 |
| 61 | 1.7 | 2.5 | 2.36 | 3.42 |
| 63 | 1.93 | 2.9 | 2.73 | 4.02 |
| 64 | 1.58 | 2.3 | 2.17 | 3.12 |
| 72 | 2.81 | 4.49 | 4.21 | 6.48 |
| 73 | 0.94 | 1.35 | 1.27 | 1.8 |
| 75 | 0.92 | 1.32 | 1.24 | 1.77 |
| 76 | 1.06 | 1.53 | 1.44 | 2.06 |
| 78 | 5.42 | 8.65 | 8.11 | 12.45 |
| 79 | 3.7 | 5.54 | 5.22 | 7.79 |
| 84 | 5.85 | 9.03 | 8.49 | 12.75 |
| 87 | 5.43 | 8.98 | 8.4 | 13.18 |
| 92 | 4.28 | 7.72 | 7.17 | 11.96 |
| 98 | 0.95 | 1.38 | 1.3 | 1.87 |

**Figure 8: Modelled Extreme Runoff Flows**

## 3 HYDRAULIC MODEL DEVELOPMENT

Modelling of rainfall governed events requires the integration of runoff flow calculations from the hydrologic assessment with a hydraulic simulation of these flows through channels, culverts, bridges and floodplains. For this type of simulation, the PCSWM software conducts unsteady flow calculations to simulate water backup, pooling and culvert hydraulics by dynamically solving the continuity and momentum equations with a finite difference scheme. The hydraulic model included an analysis of the interaction between runoff flows and coastal water levels at Antigonish Harbour to provide a representative simulation of the flooding processes in the area.

### 3.1 Coastal Water Levels Analysis

Local water levels result from the combined effects of tides, storm surge and sea level rise (SLR). Tides at Antigonish Harbour are semi-diurnal in character, with a maximum range of 1.6 m (source: DFO 2019 Canadian Tide and Current Tables). Storm surges are the result of meteorological effects on sea level, such as wind set-up[3] and low atmospheric pressure, and can be defined as the difference between the observed water level during a storm and the predicted astronomical tide. Table 3 shows the total extreme still water levels[4] assumed for Antigonish Harbour based on the occurrence of extreme storm surges at higher high water

[3] Wind set-up refers to the increase in mean water level along the coast due to shoreward wind stresses on the water surface.

[4] "Still Water Level" refers to water levels (tidal or extreme storm surge) without wave run-up.

large tide and storm surge modeling by Bernier[5]. The Canadian Hydrographic Service very recently updated their Chart Datum measurements, and it was recommended that a value of 0.52 m be used to convert the Chart Datum measurements to Canadian Geodetic Datum (CGD).

**Table 3: Extreme Water Levels at Antigonish Harbour**

| Extreme Values by Return Period [years] | Meters above Chart Datum (CD) | Meters above CGVD28 |
|---|---|---|
| 100-yr | 2.8 | 2.3 |
| 50-yr | 2.7 | 2.2 |
| 10-yr | 2.5 | 1.9 |
| 5-yr | 2.4 | 1.8 |
| 2-yr | 2.3 | 1.7 |
| **2019 Tidal Elevations** | | |
| Higher High Water Large Tide | 1.5 | 1.0 |
| Higher High Water Mean Tide | 1.4 | 0.9 |
| Mean Water Level | 0.9 | 0.4 |
| Lower Low Water Mean Tide | 0.5 | 0.0 |
| Lower Low Water Large Tide | 0.4 | -0.1 |

### *3.1.1 Impact of Climate Change on Sea Level*

The Department of Fisheries and Ocean (DFO) developed the online Canadian Extreme Water Level Adaptation tool, based on the study by Zhai et al. (2014) accounting for local factors impacting sea level. CAN-EWLAT is a science-based planning tool for climate change adaptation of coastal infrastructure related to future water-level extremes. It was developed to provide SLR allowances for DFO harbours across Canada. Allowances are estimates of changes in the elevation of a site that would maintain the same frequency of inundation that the site has experienced historically. The CAN-EWLAT tool was used as a benchmark to forecast relative SLR at Antigonish Harbour. For the year 2060, the tool estimates an upper-bound relative SLR of approximately 0.42 m for the IPCC 2013 RCP8.5 scenario, as defined in 2013.

[5] Bernier, N. B. , and K. R. Thompson. 2006. "Predicting the frequency of storm surges and extreme sea levels in the northwest Atlantic." J. Geophys. Res., C10009.

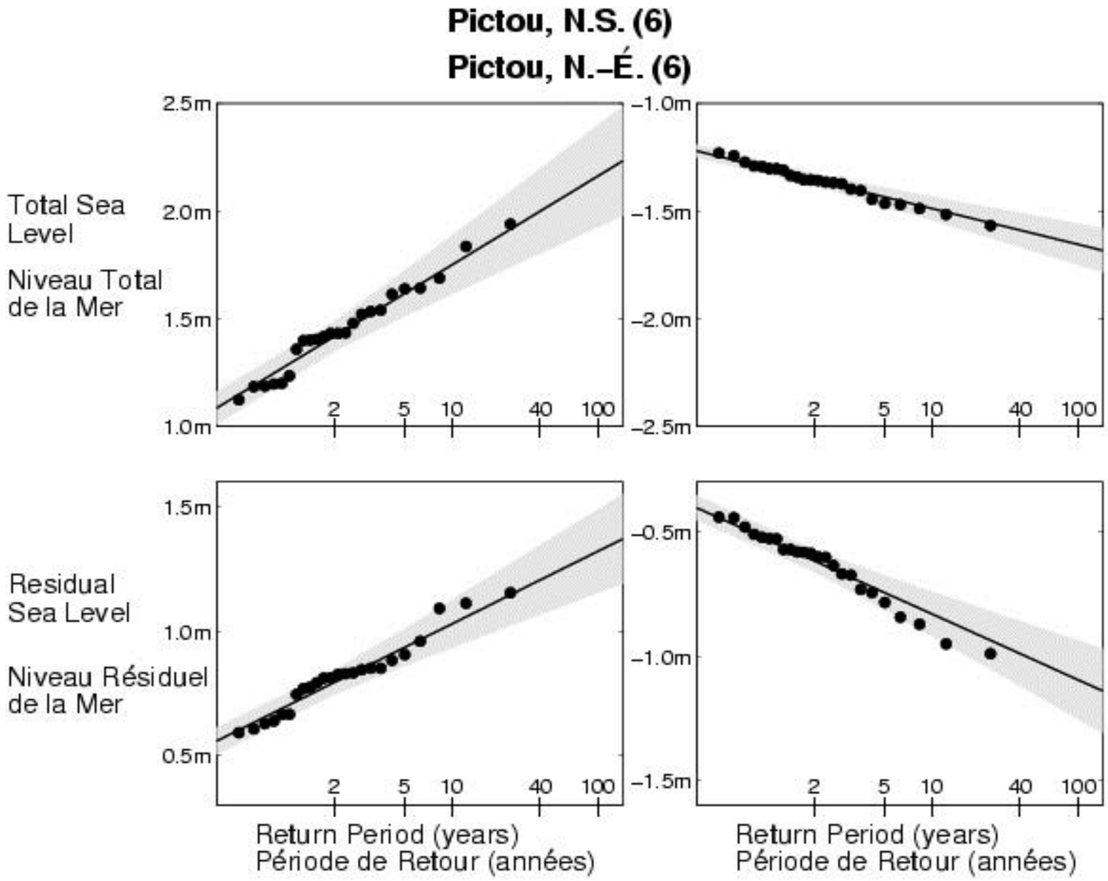



**Figure 9: Storm Surge Return Period at Pictou, NS**

## 3.2 Model Calibration

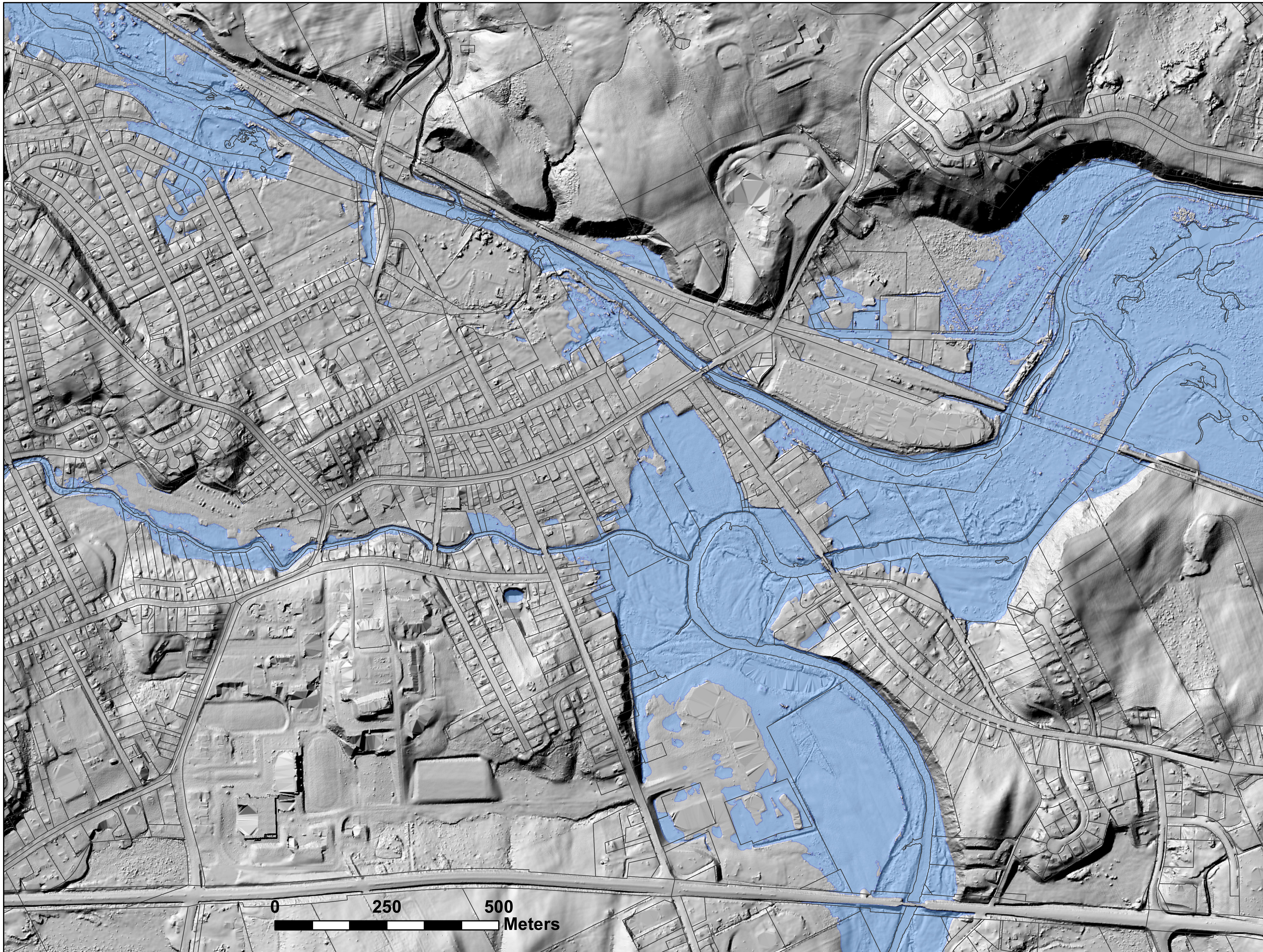
The Town of Antigonish provided CBCL with anecdotal and photographic records of the flood events listed in Table 4. The table shows estimated average daily flows at the Rights and West River for each event.

**Table 4: Summary of Past Flood Events Observed at the Town of Antigonish**

| Event Date | Record | Type of Event | Prorated Average Daily Flows at the Lower Reach ($m^3/s$) | |
|---|---|---|---|---|
| | | | Rights | West |
| March 31, 2003 | Notes on floodmap | Rainfall and snowmelt | 59.4 | 158.9 |
| December 14, 2010 | Photographic Records | Rainfall | 31.7 | 84.9 |
| March 8, 2011 | | Ice Jam | 18.5 | 49.4 |
| January 12, 2014 | | Rainfall and Snowmelt | 45.2 | 120.9 |
| March 3, 2014 | | Rainfall and Snowmelt | 22.8 | 60.9 |
| October 11,2016 | | Rainfall (Hurricane Mathew) | 36.6 | 98.0 |
| January 24, 2018 | | Snowmelt and Ice Jam | 44.7 | 119.5 |
| February 2, 2018 | | Snowmelt | 35.4 | 94.9 |

The highest rate calculated corresponds to the 2003 flood and for this event the Town of Antigonish provided information on flood extents throughout the study area in the form of handwritten annotations on a flood map of Antigonish. Therefore, CBCL selected the 2003 flood as the calibration event for the hydraulic model. The calibration process consisted of using rainfall observations from Shearwater, the 2003 prorated flows and the tide prediction for the event date plus a 0.75 storm surge as input into the model to calculate water levels and flood extent throughout the Town. The storm surge was estimated assuming a 1 in 2 year return period. The model results were used to create an interpolated water surface using GIS.

Initially, the model flow inputs included the instantaneous peak flows observed on March 31 2003 at the EC station in the South River, prorated to the Rights and West River. The resulting floodmap indicated flooding in areas shown as dry in the information provided by the Town. This suggested that prorating the instantaneous peak flows from the South River may overestimate the flows in the Rights and West Rivers. Calculations based on the daily average resulted in flood extents consistent with those observed during the event (Figure ***10***).




THE TOWN OF ANTIGONISH

**Legend**

Property Lines

2003 Flood Extent

Figure 10

**2003 Flood Event**

February 7, 2019

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### 3.3 Modelling Approach

Based on flow adjustments conducted during the calibration process, the maximum daily average records were selected to conduct the extreme flow calculations. CBCL used the following boundary conditions to simulate 1 in 20 year and 1 in 100 year flood extents in the study area under current and projected climate change conditions.

| Return Period | Climate Conditions | Rights River Flow ($m^3/s$) | West River Flow ($m^3/s$) | Peak Rainfall Intensity (mm/hr) | Water Level at Antigonish Harbour (m CGVD28) |
|---|---|---|---|---|---|
| 20 year | Present | 72.53 | 194.10 | 123 | 1.7 |
| 100 year | | 106.82 | 285.85 | 149 | 1.7 |
| 20 year | Future | 94.289 | 252.33 | 159.9 | 2.1 |
| 100 year | | 138.866 | 371.605 | 193.7 | 2.1 |

### 3.4 Extreme Flow Model Results

Figure 11 shows a series of profiles along Brierly Brook and the Rights and West Rivers indicating the calculated water levels for each extreme scenario, in areas with high risks of flooding. The profiles corresponding to Main Street, Highway 104 and St Andrew bridges show a significant drop in water levels as flows pass through each bridge, indicating a limited hydraulic capacity for conveying extreme flow rates. The increased water levels on the upstream side of each structure increases the risk of flooding in the adjacent areas. The model results indicate bridge overtopping at the Church Street Bridge during the 1 in 20 year event with climate change and the 100 year event under current and future conditions.

As shown in Figure 12, water level calculations around the industrial park located along Adam St indicate that flooding risks in the area are associated with high water levels in the Harbour. These calculations are based on a 2 year storm surge; therefore flood extents are anticipated to increase with more extreme storm surges.

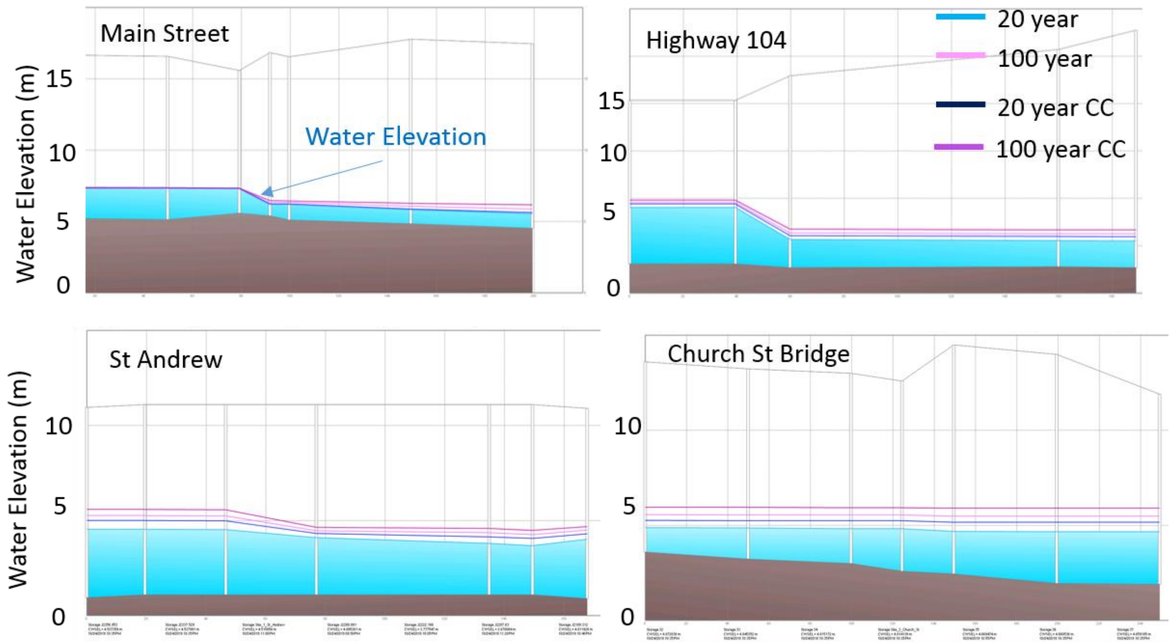



**Figure 11: Extreme Water Level Profiles at Bridges in Proximity to Flooding Areas**

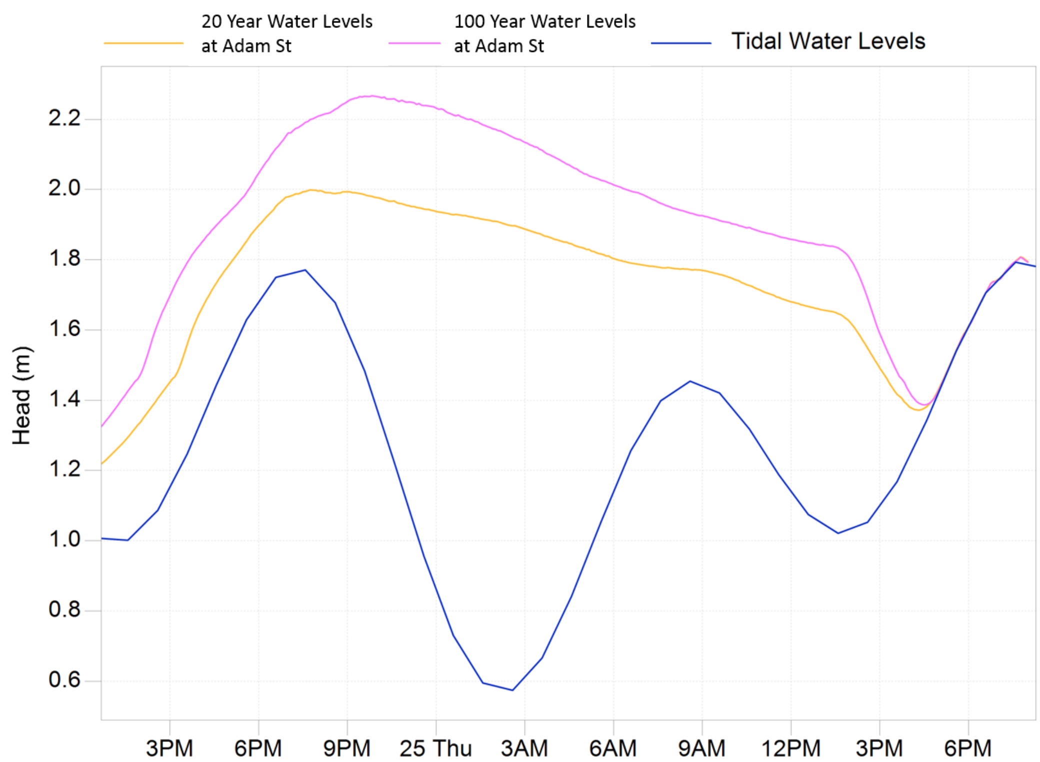



**Figure 12: Water Levels at Adam St. and Antigonish Harbour**

# 4 Ice Jam Analysis

## 4.1 HEC-RAS Hydraulic Model Development

A simplified steady state HEC-RAS model of the Rights and West Rivers was developed to carry out the ice jam and encroachment analyses. The calibrated PCSWMM hydraulic model was therefore converted to a steady state HEC-RAS model by converting and importing the cross sections and hydraulic structure characteristics from the PCSWMM model. Peak flows inputs for the HEC-RAS model were estimated from the PCSWMM model for the representative design storm, and downstream boundary conditions were set as fixed depths for the respective design sea levels. A three-dimensional view of the cross sections used for the HEC-RAS model is presented in Figure 13 with an example flood simulation.

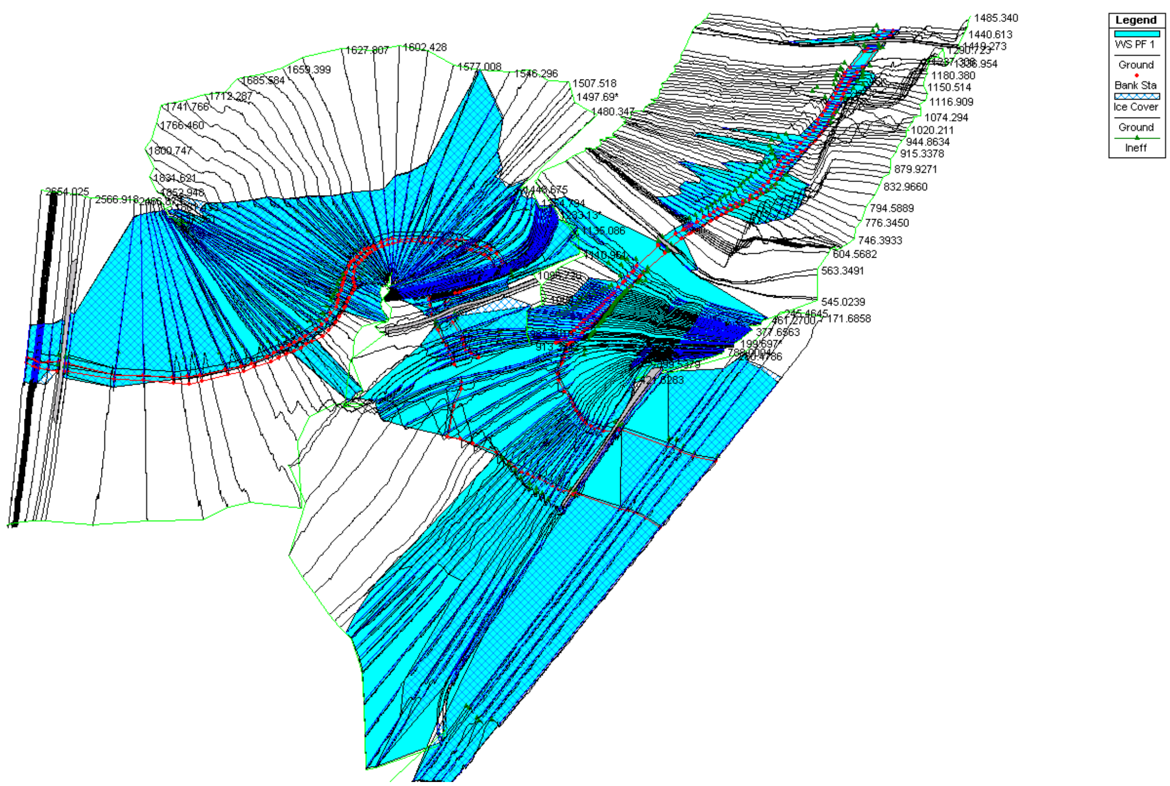



**Figure 13: Three-Dimensional View of HEC-RAS Hydraulic Model**

### *4.1.1 Design Ice Accumulation Event*

#### 4.1.1.1 Ice Jam Formation Characteristics

Ice jam formation can occur during the freeze-up period at the beginning of winter, or during the break-up period in spring. During the freeze-up period, ice forms on the river surface beginning at the banks. Ice crystals may also develop within the river as frazil ice, which is very common in rapids. The ice crystals tend to coalesce and accumulate, and may become attached to the underside of the ice cover or to the river bed as anchor ice.

Frazil pans and floes are major components in the formation of a river's initial ice cover. In tranquil reaches, this cover is a mere surface layer of ice floes and pans, but elsewhere it can be several layers thick.

Ice jams during the freeze-up period usually form where floating ice slush or blocks encounter a stable ice cover. There are, however, certain features that, in conjunction with ice cover, enhance the probability of ice jam formation: bridge piers, islands, bends, shallows, slope reductions, and constrictions.

During breakup in the spring, or during winter thaws, an ice jam results from the accumulation of ice from the breakup of the upstream ice cover. A rise in water levels may result from the spring snowmelt, or a sudden midwinter thaw, common in Atlantic Canada. Midwinter thaws are often accompanied by substantial rainfall, resulting in a rapid increase in water levels and severe ice jams. Compared to other flood events, ice jams can occur when minor rainfall events occur, or can even be due to flow caused by ordinary spring thaw, making them difficult to predict.

There are two main features of ice jams that can cause flooding. First, ice jam thickness can be considerable, amounting to several metres. Secondly, the underside of the ice cover is usually very rough. Under open water conditions, the only frictional resistance retarding the flow of the water is the streambed. The rougher the streambed, the greater the depth required to pass a given discharge. With an ice jam in place, the additional ice and very rough lower surface retard flow. Therefore, the flow depth has to be much greater than for open water.

An important factor to the level of ice build-up is the amount of ice existing on the banks just prior to the jam occurring. This amount is dependent on many factors, such as the variation in temperature and water levels in the entire winter period leading to the ice jam.

#### 4.1.1.2 Ice Jam Accumulation

To evaluate the potential ice thickness that can be reached in the Rights and the West Rivers, a statistical analysis was carried out using the US Army Corps of Engineers' Ice Engineering publication: "Method to Estimate River Ice Thickness Based on Meteorological Data". This publication describes a formalised approach to estimating maximum potential ice thicknesses based on climate data and heat transfer processes, using the concept of "Accumulated Freezing Degree Days". The methodology included calibration against actual ice thickness measurements carried out by the Canadian Ice Service, the closest location being in Caraquet, NB. Figure 14 shows the available ice thickness measurements at this location, from 1974 to 1986.

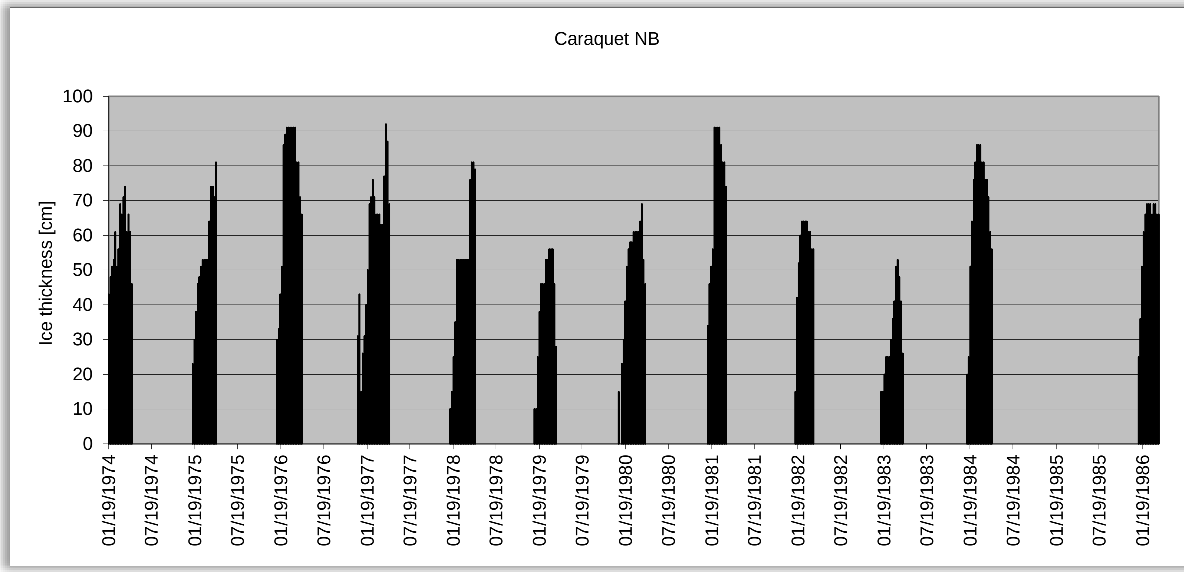



**Figure 14: Ice Thickness Measurements in Caraquet, NB**

Long term temperature data was obtained from the climate station at Shearwater Airport (longest record in the province), and the maximum annual ice thicknesses for each year was then compiled and analysed with statistical distributions. The results from this analysis are presented in Figure 15.

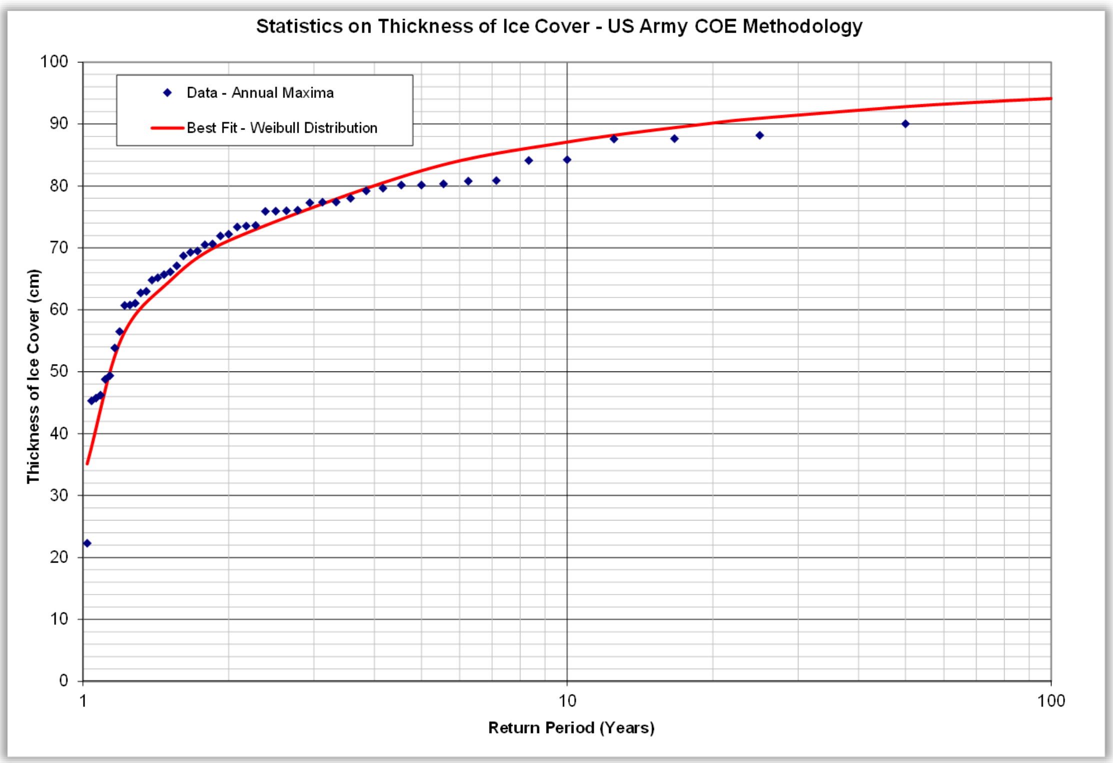



**Figure 15: Estimation of 1 in 100 Year Ice Thickness Based on Statistical Analysis**

Based on this method, the 1 in 100 year ice accumulation was estimated to 94 cm. The Town of Antigonish has conducted several ice monitoring studies since 1995. The studies available between 1995 and 2011 conducted by CJMac were reviewed to better understand the potential thickness of ice formation, as well as typical locations of ice jamming. Summary notes on the ice thickness measurements available in the ice studies are attached at the end of this report. In 2008, ice thicknesses in the order of 500mm were noted in one of the ice studies. Photo from this report are reproduced here for illustration, taken at the Main Street Bridge:

Based on this information, and seeing that over 15 years, the maximum ice thickness was in the range of 500mm, the above assessment showing a potential ice thickness reaching 950mm during a 1 in 100 year ice formation event, seems to be consistent with the information available.

This value was therefore input into the HEC-RAS model as the initial ice accumulation parameter to simulate the ice jam flood. The ice jam flood was simulated by also inputting peak flows and sea levels corresponding to the average of the annual maximum events. Including a larger rainfall event (such as the 1 in 100 year rainfall event) at the same time as the 1 in 100 year ice accumulation would change the return period of this occurrence to a value significantly greater than 1 in 100 years.

It is noted that while the most accepted methods were used in this study to conduct simulations of ice jam processes, the results are still highly uncertain. The first reason is that there was no ice jam thickness data available for the Rights River or the West River to calibrate the model on. Secondly, the results are still highly uncertain, and too variable to produce flood lines that can be relied upon with confidence. The results are therefore presented for information, and should be reviewed when any work in the river, including bridge repairs or upgrades, is conducted, to lessen potential risks.

The ice jam model results are presented in Figure 16a below:

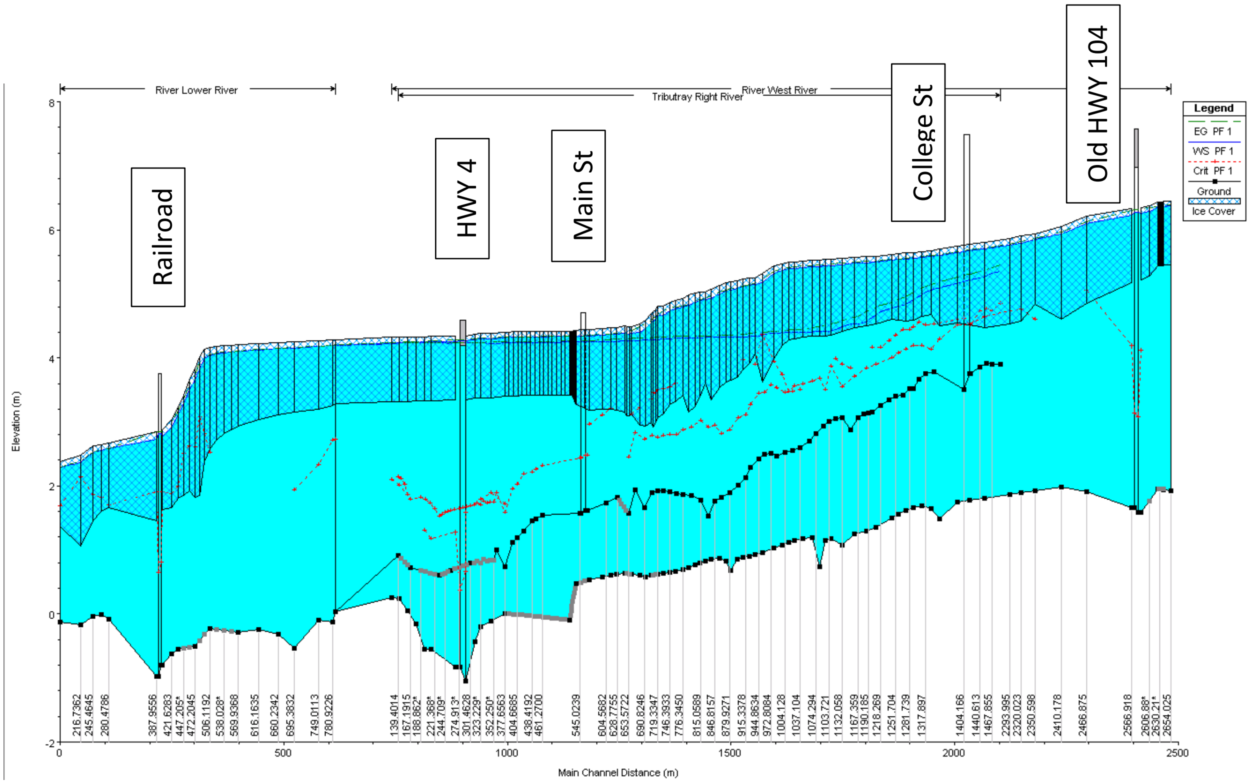



**Figure 16a: Rights and West River Ice Jam Model Output**

In general terms, the flood lines generated by ice jams are of a similar order of magnitude of width to the 1 in 100 year flood lines generated by rainfall and sea level. The model does not seem to show any significant increase in ice thickness beyond the 1 m thickness input in the initial conditions, except in two main areas: just upstream of the railway line (by the downstream tidal area, where it crosses the two rivers), and approximately 500m upstream of highway 4 on the West River, by the Antigonish Market Square, as shown on Figure 16b below. Both areas are in wide, flat, low-lying ground, which, as described above, tend to be the most likely places for ice jams to develop. In addition, they are both just upstream of constrictions, which also increase the potential for ice to jam.

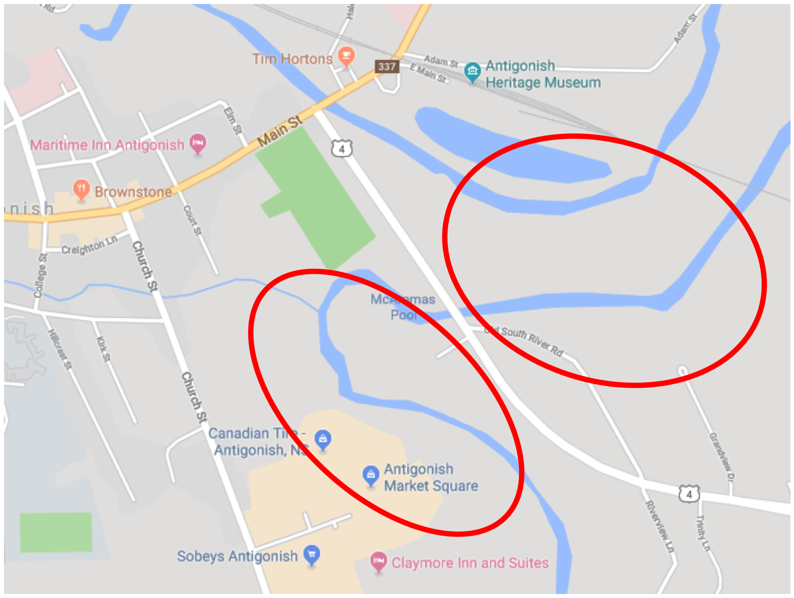



**Figure *16b*: *Areas at Risk of Increased Ice Jam Thickness***

Very little potential for ice jamming was identified on the Rights River, which is consistent with the anecdotal information received at the start-up meeting, which included the fact that river training work (narrowing and deepening the river) had been successful in reducing the risks of ice jams. In the lower Rights River, there is an ice park used infrequently, which may help store some of the volume of ice flowing down the river.
In general, compared with the previous analysis results (1 in 100 year rainfall, no ice jams), the model results indicate that there is a slightly increased risk of flooding in the downstream areas of both the Rights and the West Rivers, caused by ice accumulation. Other than those areas, the ice jam model does not seem to highlight any significant additional risk of flooding that is not present in the hydrologic and hydraulic model (based on the rainfall and sea level analysis).

## 5 FLOODPLAIN AND FLOODING RISKS ANALYSIS

Figure 17 shows the flood extents calculated for the 1 in 20 and 1 in 100 year events under current climatic conditions. The model results indicate that under a 1 in 20 year event, areas at risk along the Rights River only include the surroundings of Carter Crescent. This is a result of water ponding behind the berms constructed along the river banks in this area and the east side of College St, which may affect access to Maclellan St.

Along Briery Brook, areas at risk of flooding include the south side of the Whidden Park Campground and Cottages and the adjacent commercial properties, as well as the east parking lot of the Main St. business park.

Along the West River, areas at risk include the Church Street business park, the Antigonish Highland Games field, the parking lot of the adjacent business park, and the industrial properties located along Adam Street.

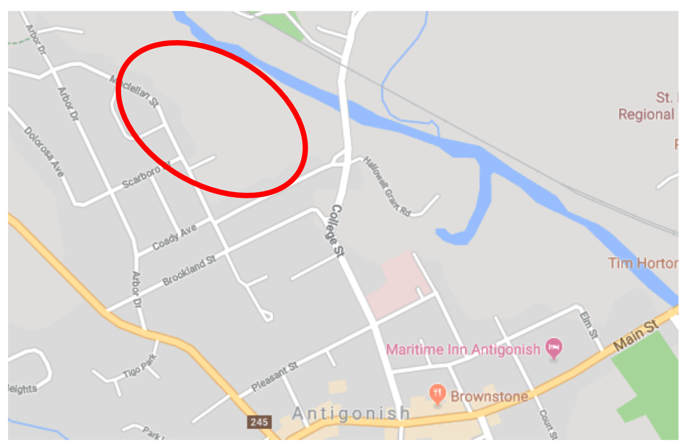
For the 1 in 100 year event, the flood extents increase along most areas including overtopping of Church St along the Brierly River and the Sunrise Trail along the West River.

Figure 18 shows 1 in 20 and 1 in 100 year events under future climatic conditions. For the 1 in 20 year event, the flood extents increase from that shown in the previous figure and includes overtopping at Church Street. The 1 in 100 year event increases the flood extents to include additional areas of the Whidden Park Campground Cottages, overtopping of Church Street and Main Street, overtopping of the Old Highway 104 Bridge along the West River, the Sunrise Trail and the adjacent business park.

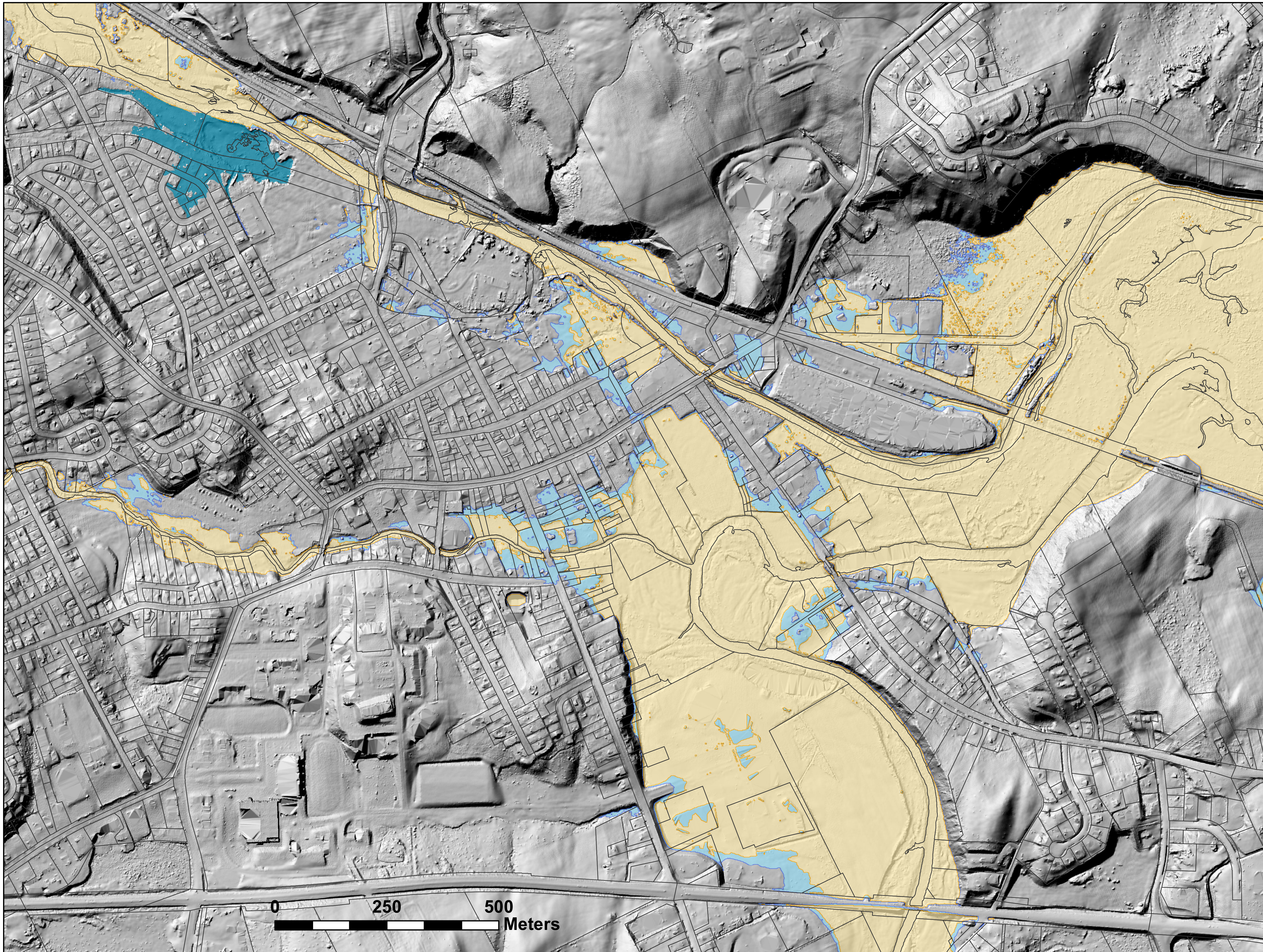
## 6 CONCLUSIONS

CBCL conducted an assessment of flooding risks throughout the Town of Antigonish based on a hydrological and hydraulic analysis of Brierly Brooks and the Rights and West Rivers. The analysis included calculations of high flows through the Rights and West Rivers using prorated data from the South River and the development of hydrologic model to calculate runoff flows through the Brierly Brook and the downtown area of the Town of Antigonish. The identification of suitable gauged flow data was made with the support of a field measurement campaign of water levels at 3 sites, one on each watercourse, for 2 months. To calculate water levels and flood extents throughout the study area, CBCL developed a hydraulic model including survey information of the bridges crossing each major stream. This model was calibrated using anecdotal information of flood extents observed in 2003 and provided by the Town on a map. The analysis also included a statistical analysis of historical runoff flows for the calculation of extreme values and an assessment the potential impact of climate change on sea level at Antigonish Harbour, rainfall intensity and stream flows.

The calibrated model was used to calculate the extent of flooding under extreme events under present and future climatic conditions within a time frame of 30 years, as requested by the Town. The resulting flood maps indicate that in general, areas at risk include the Church Street business park, the Sunrise trail and the adjacent business park, the Antigonish Highland Games field, the south side of the Whidden Park Campground Cottages. The flood delineation also indicates that the residential area along Maclellan St is vulnerable to flooding (see adjacent map), potentially caused by water ponding behind the berms that run along the Rights River. An analysis of the hydraulic model results suggests that flooding risks may be related to limited hydraulic capacity at the Main Street, Highway 104, and St Andrew bridges. The results also indicate that flooding risks in the industrial park adjacent to Adam Street are associated with tidal water levels in the Harbour, therefore the vulnerability of this area is likely to increase with extreme water levels in the harbour.




Regarding ice jam risks, a modelling analysis was carried out using the HEC-RAS model, supported by a methodology from the Cold Regions Research and Engineering Laboratory of the USACE. In general terms, the flood lines generated by ice jams are of a similar order of magnitude of width to the 1 in 100 year flood lines generated by rainfall and sea level. The model does not seem to show any significant increase in ice thickness beyond the 1 m thickness input in the initial conditions, except in two main areas: just upstream of the railway line (by the downstream tidal area, where it crosses the two rivers), and approximately 500m upstream of highway 4 on the West River, by the Antigonish Market




THE TOWN OF ANTIGONISH

Figure 17

**Present Climate**

February 7, 2019

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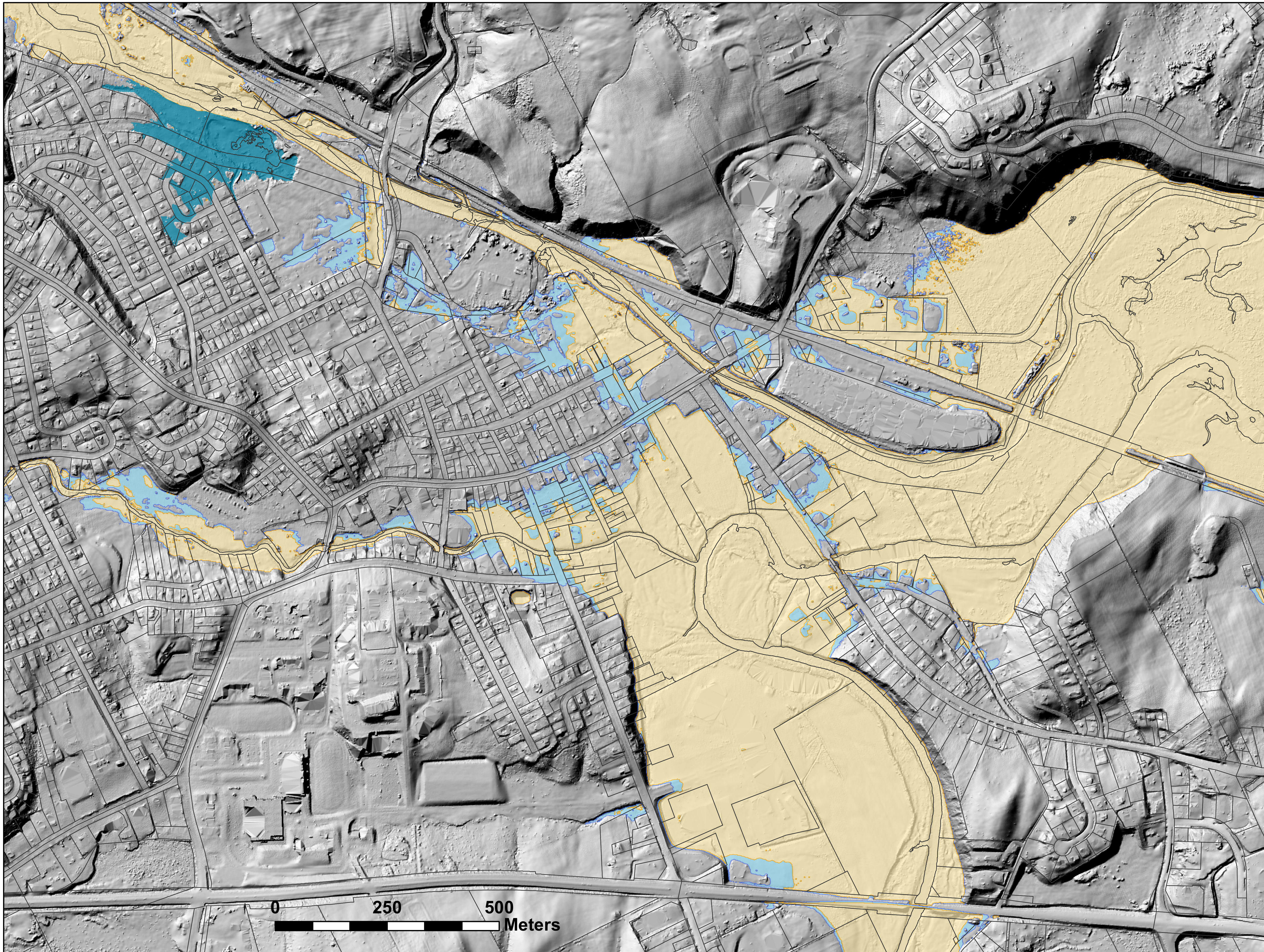


THE TOWN OF
ANTIGONISH

Legend

Property Lines
1 in 20 year Flood Extent
Water ponded behind berm
1 in 100 year Flood Extent

Figure 18

**Future Climate**

February 7, 2019

CBCL LIMITED
Consulting Engineers

Square. Both areas are in wide, flat, low-lying ground, which, as described above, tend to be the most likely places for ice jams to develop. In addition, they are both just upstream of constrictions, which also increase the potential for ice to jam.

Very little potential for ice jamming was identified on the Rights River, which is consistent with the anecdotal information received at the start-up meeting, which included the fact that river training work (narrowing and deepening the river) had been successful in reducing the risks of ice jams. In general, compared with the previous analysis results (1 in 100 year rainfall, no ice jams), the model results indicate that there is a slightly increased risk of flooding in the downstream areas of both the Rights and the West Rivers, caused by ice accumulation. Other than those areas, the ice jam model does not seem to highlight any significant additional risk of flooding that is not present in the hydrologic and hydraulic model (based on the rainfall and sea level analysis).

We would like to thank you again for allowing us this opportunity to conduct this very interesting analysis.

Yours truly,

CBCL Limited

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Project No: 181105.00

# 7 References

Conestoga-Rovers & Associates, Mr. Roger LeBlanc. *Floodplain Delineation Study Prepared for the Town of Antigonish*, January 4, 2014.

Bernier, N. B. , and K. R. Thompson. 2006. "Predicting the frequency of storm surges and extreme sea levels in the northwest Atlantic." *J. Geophys. Res.,* C10009.

Castellano, Christopher, and Arthur DeGaetano. 2017. *Extreme Precipitation Analysis for Atlantic Canada.* Technical Document, Cornell University.

IPCC. 2013. *IPCC 5th Assessment Report, Climate change 2007: The physical Science Basis. [Solomon S., D. Qin, M. Manning, Z., Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)].* Cambridge, UK, and New York, USA.: Cambridge University Press.

McCuen, R. 1996. *Hydrology FHWA-SA-96-067.* Washington: Federal Highway Administration.

Pacific Climate Impacts Consortium, University of Victoria. 2015. *Statistically Downscaled Climate Scenarios. GCMS.* Accessed 03 15, 2018. https://pacificclimate.org/data/statistically-downscaled-climate-scenarios.

Rawls, W. J. 1983. *ASCE J. Hyd. Engr* 109:1316.

Schardong, Andre, Gaur Abhishek, Slobodan Simonovic, and Dan Sandink. 2018. *Computerized Tool for the Development of Intensity-Duration-Frequency Curves Under a Changing Climate.* Manual, London, Ontario: Western University.

Vincanne, Adams, Sharon R. Kaufman, and Van Hattum Taslim . 2011. "Aging Disaster: Mortality, Vulnerability, and Long-Term Recovery Among Katrina Survivors." *Med Anthropol.* 247–27.

Westra , S. , H. J. Fowler , J. P. Evans, J. V. Alexander, P. Berg, F. Johnson, E. J. Kendon, G. Lenderink, and N. M. Roberts. 2014. "Future Chances to the Intensity and Frequency of Short-duration Extreme Rainfall." *Review of Geophysics* 522-555.

William, Richards, and Réal Daigle. 2011. *Scenarios and guidance for adaptation to climate change and sea level rise – NS and PEI municipalities.* ACASA.

**Notes on CJMac ice studies conducted by the Town of Antigonish between 1995 and 2011:**

1995 CJMac study:

- Comments on a range of ice jam events, with regular locations of jams. – recommendation to adjust the river cross section, and to leave room in the downstream ice park, to be maintained regularly.

1996 follow up study

- Description of ice jam events, noting the ice park was effective, and planning for river training was under way. Water levels were measured, but only after the event. Notes that because of the efficiency of the ice park, there is no longer a need to lower the adjacent shoreline elevation. 8" max thin

1997 follow up study

- Similar observations, less severe ice jams, ice park effective, perhaps some siltation below East Main Bridge – 8" max thickness

1998 follow up study

- High rain event (50mm), but not much for ice jamming, that event (25th February) cleared most of the ice

2001 follow up study

- Little ice buildup, warmer temperatures, frequent small breakups

2002 follow up study

- Not enough rain to allow ice to go into ice park. No flooding that year. No ice thickness measured.

2003 follow up study

- 3 ice jams: low temperatures combined with large rainfall events. On March 3rd, Water rose to 12" below Church St bridge. Almost no clearance at East Main Bridge. Excavator used to successfully remove some of the ice jams. No ice thickness measured but photos show overturned ice close to 1m thickness.

2005 follow up study

- Conditions favourable to formation of thick layer of ice: 18" thickness measured at Main, 16" at Court St. On March 9th, ice sheets hitting the soffit of Main St Bridge.

2006 follow up study

- No significant ice events. 10" thickness measured downstream of Mian Street Bridge

2007 Follow up study

- No significant ice jamming, but ice thickness development  was described as 100% river cover, and "significant" thickness – 2.9m from ice to underside of Main st Bridger, and 200mm thick.

2008 Follow up study

- January 29th Ice Jam at Court St and “significant” ice buildup at Church St. Photos show ice jam under Main St, 250mm-500mm thickness of ice.
- 


2009 update

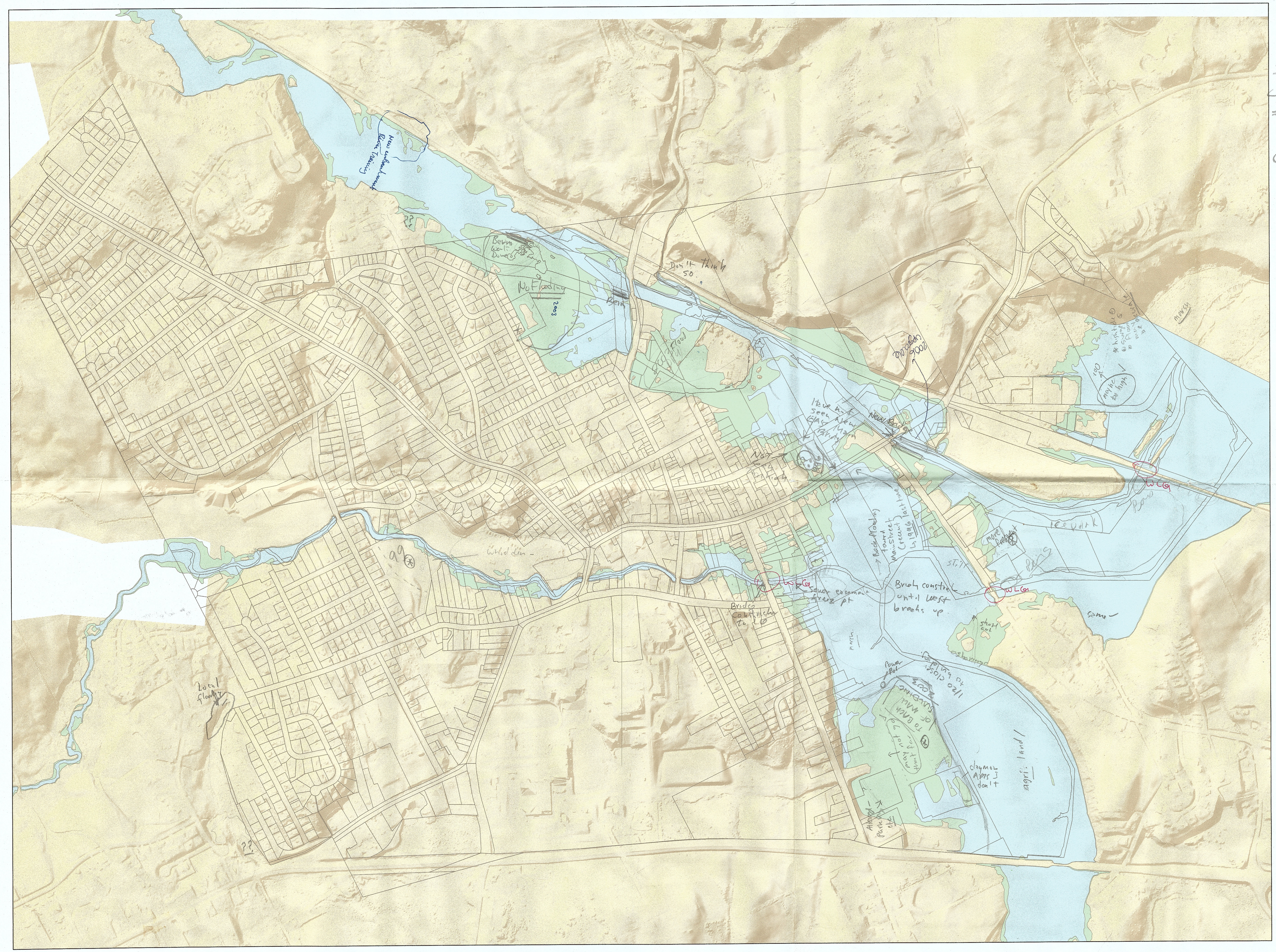
- No significant ice jam. Max thickness of 170mm.

2010 update

- No significant ice jam or ice buildup

2011 update

- February 28, Major ice “chunks” under Court St (Brierly Brk). No measurements




overall fairly accurate

does not show properties w/ fill

need to 'proof' properties

data based on future

is increasing intensity?

## Legend

14.01_20yr

14.01_100yr

## Hillshade

## Value

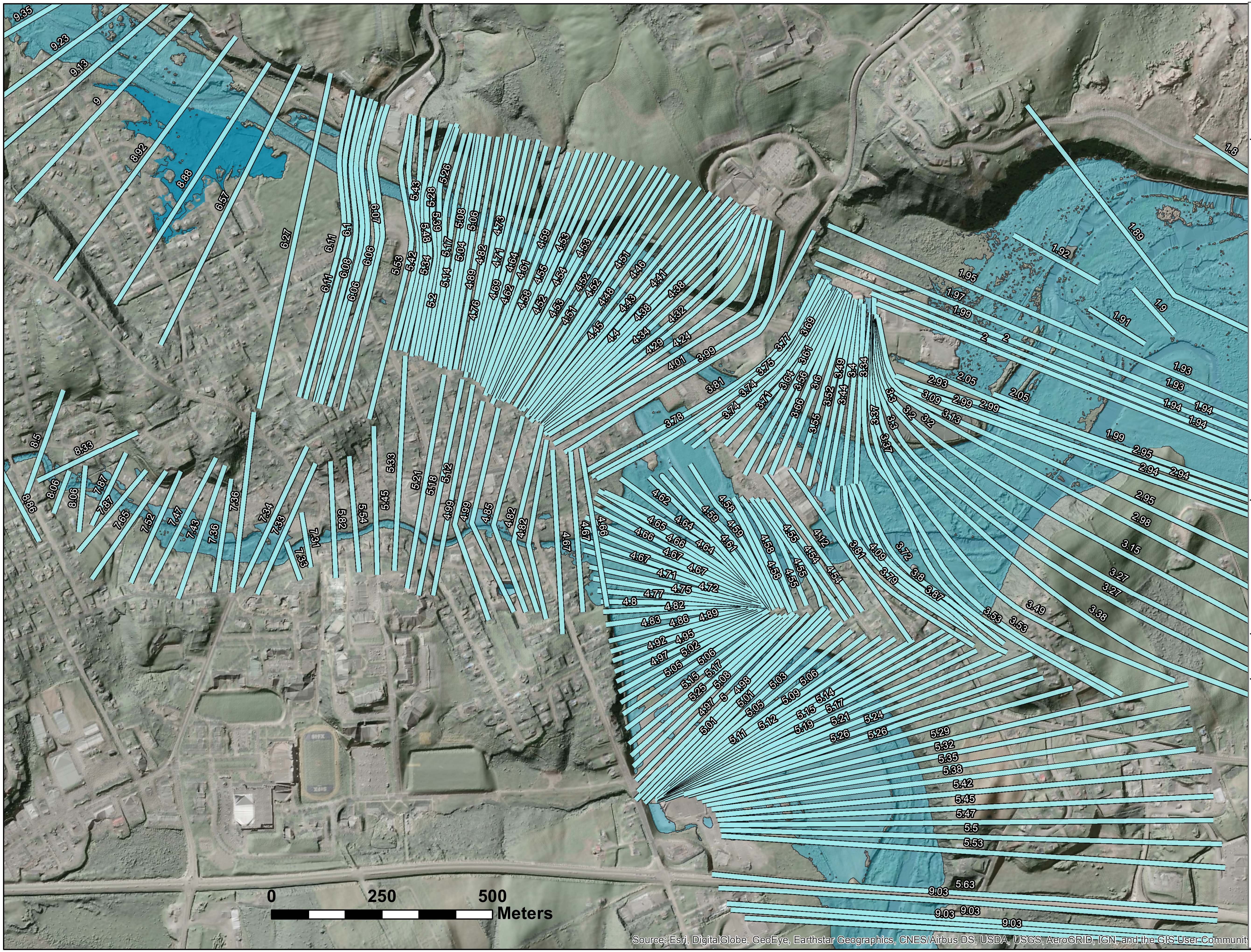
254

127

0

1 inch = 0.08 miles

2014 Conestoga Rovers




THE TOWN OF ANTIGONISH

**Legend**

- 1 in 20 year Transect Level
- Floodline extent
- Water ponded behind berm

Note: Water Levels in CGVD28

Transect Set 1

**Max Water Elevation (m)**
**1 in 20 year event**
**Present Climate**

August 5th, 2019

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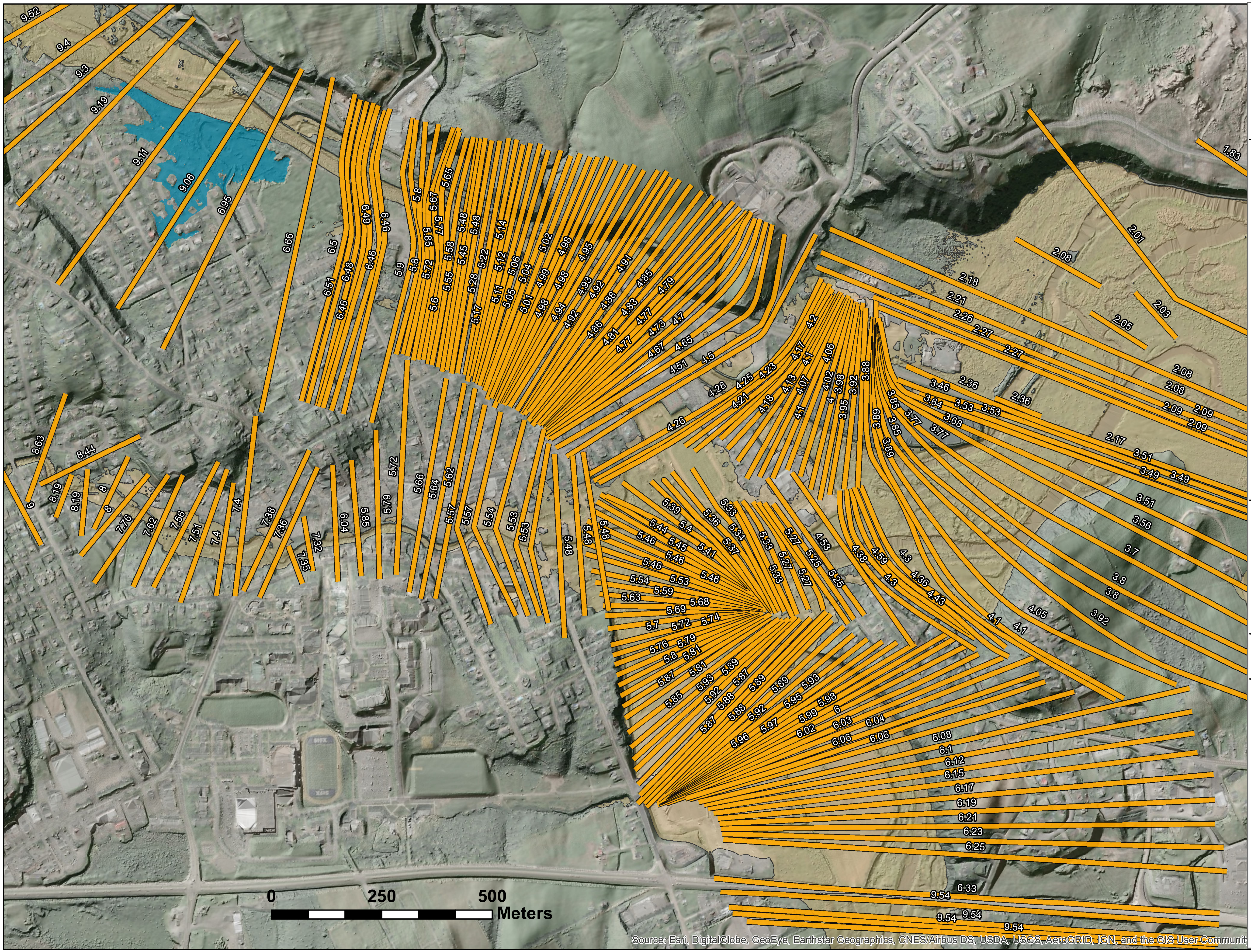


THE TOWN OF
ANTIGONISH

**Legend**

- 1 in 100 year Transect
- Floodline
- Water ponded behind berm

Transect Set 2

**Max Water Elevation (m)**
**1 in 100 year**
**Present**

April 25th, 2019

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THE TOWN OF ANTIGONISH

## Legend

- 1 in 20 year Transect
- Floodline
- Water ponded behind berm

Transect Set 3

**Max Water Elevation (m)**
**1 in 20 year**
**Projected Climate**

April 25th, 2019

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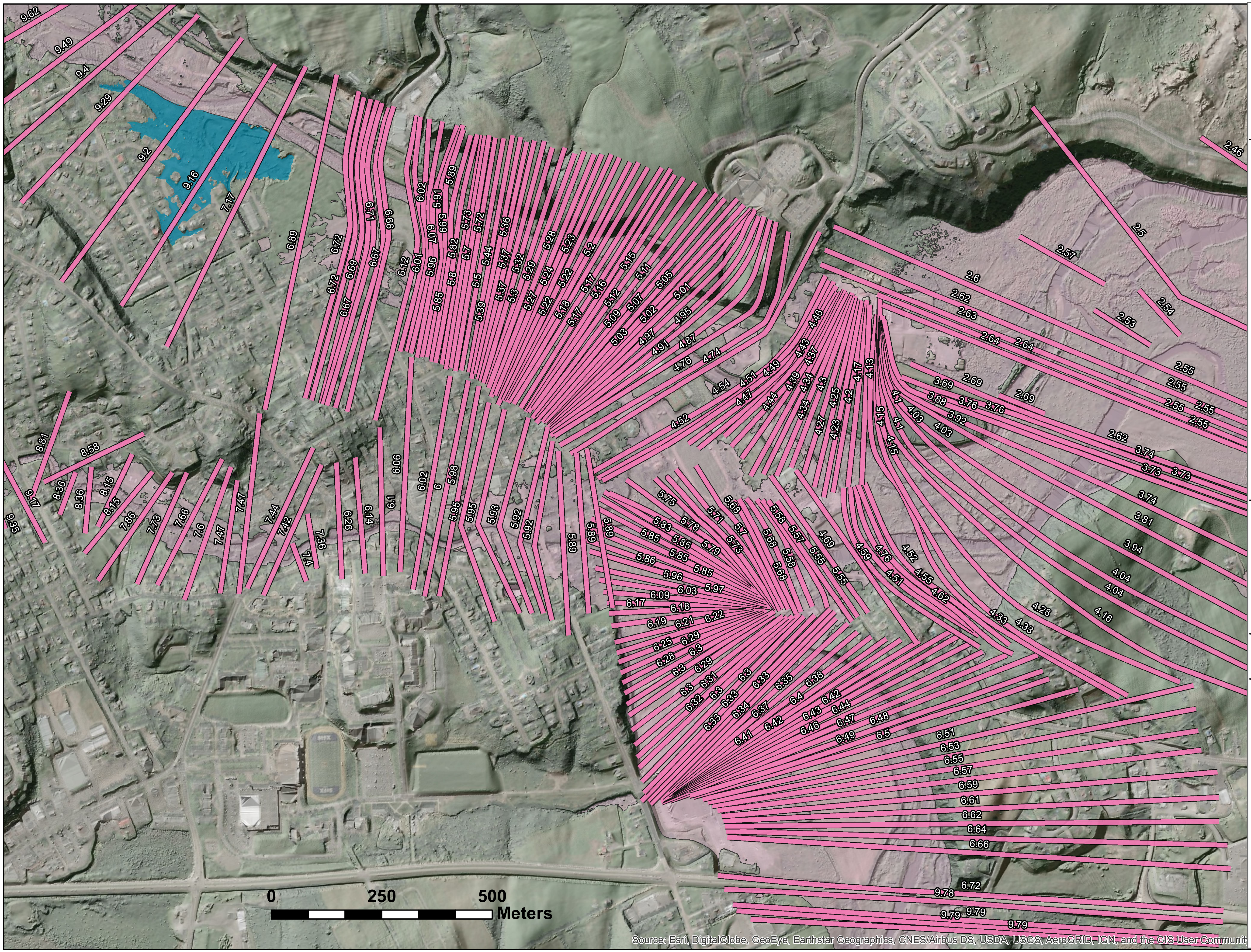


THE TOWN OF
ANTIGONISH

## Legend

- 1 in 100 year
- Floodline
- Water ponded behind berm

Transect Set 4

**Max Water Elevation (m)**
**1 in 100 year**
**Projected Climate**

April 25th, 2019

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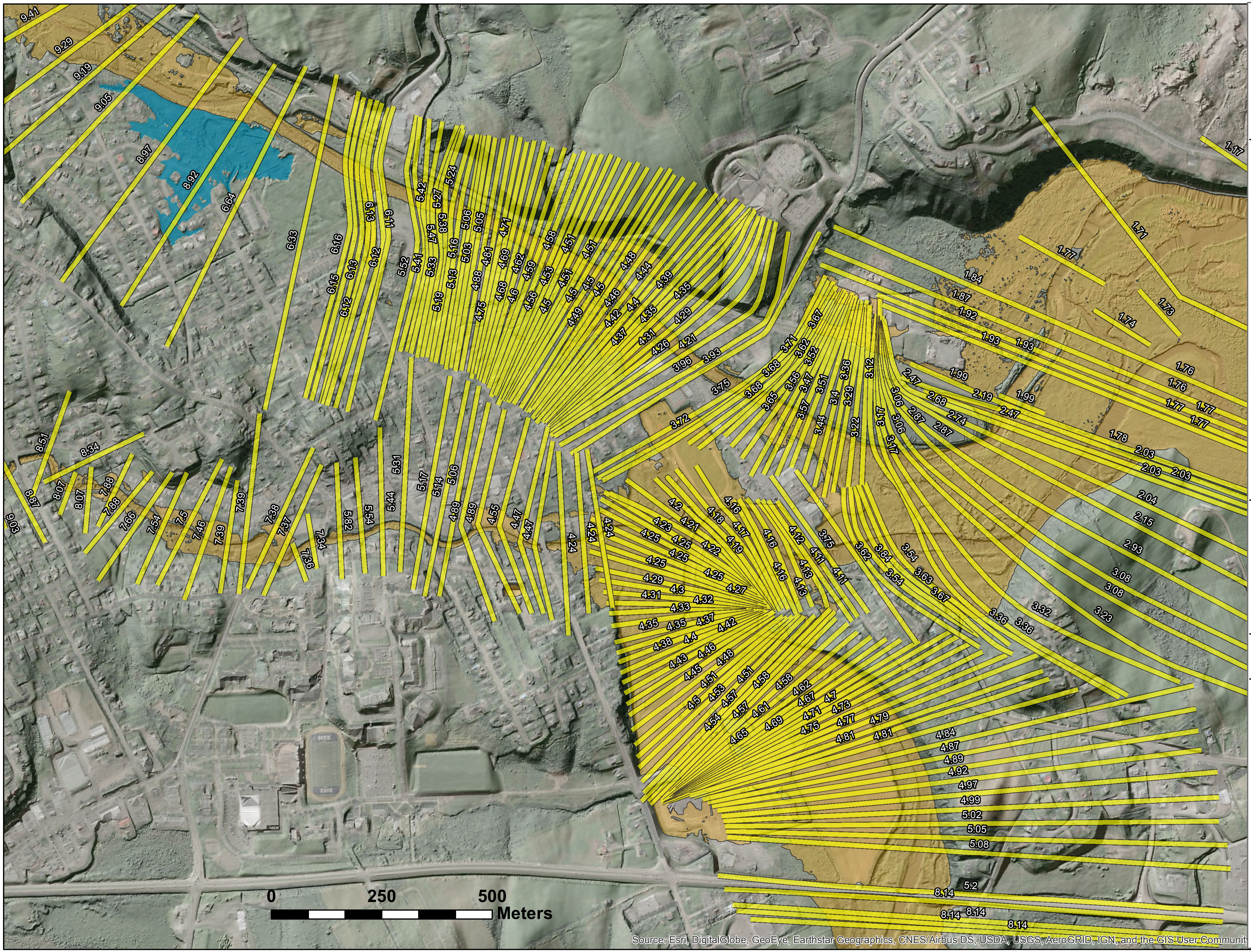


THE TOWN OF
ANTIGONISH

**Legend**

- 2003_high_Transects
- Floodline
- Water ponded behind berm

Transect Set 5

**Max Water Elevation (m)**
**2003**
**Flood**

April 25th, 2019

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