# Assessment of River Floodplains within Cumberland County

By

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Subcontracted to

Upland Urbans Planning + Design Studio

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# Executive Summary

The floodplain is an area of land adjacent to a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge. This report reviews previous studies that have examined inland flooding in the county. Given that the county is bordered to the north by the Northumberland Strait and to the south by the Bay of Fundy, most inland rivers drain to the coast and their discharge is strongly effected by a tidal influence. Therefore, any inland flood risk studies of the major rivers must take into account the tidal influence and interaction. Existing data in the form of primary, secondary and tertiary watersheds available from GeoNova have been highlighted. As well, data on the hydrology of some of the major river systems in the county in the form of historic water flows based on past hydrometric stations available from the Water Survey of Canada have been presented. NS Environment has collaborated with the Water Survey of Canada and has installed real-time water level gauges, from which flow can be inferred. The only real-time gauge in the county is located at Kelley's River presently. Given the historic flood problems for the area near Oxford on River Phillip, a recommendation is put forward that NS Environment be approached about installing a real-time water level gauge on River Phillip upstream of the town of Oxford. In addition to direct measurements of river flows, weather information can be used to estimate the possible return period of significant storm events that have caused flooding. Environment Canada has generated Intensity-Duration-Frequency IDF curves from some of their weather stations with long time-series of data that predict the return period of precipitation events of a certain duration and intensity. The closest IDF curves to Cumberland County include Truro and Caribou Point and have been described in this report.

An alternative approach to floodplain mapping is presented based on a study conducted by Kings County as part of their Kings 2050 vision. Kings County did not have the budget to conduct rigorous flood risk mapping studies for all the major watersheds and tributaries in the county but worked with researchers at NSCC to define a "geomorphic floodplain" based on the river gradient and a lidar DEM of the river system. This floodplain is a region surrounding the river that has flooded in the past and will flood again, given a high river discharge event, but does not have specific return period times associated with them. Examples of the output of a geomorphic floodplain have been generated for River Phillip and the Wallace River. The geomorphic floodplain near Oxford was favorably compared to the flood extent from a previous flood risk study that simulated the 1999 flood event. The accuracy of the floodplain extent is a function of the elevation data used regardless of the method used to calculate it (GIS or hydrodynamics), therefore the most accurate results are obtained in areas where lidar elevations are available. The latest lidar technology is discussed in the form of a topo-bathymetric lidar sensor that is capable of surveying the land topography and river channel simultaneously. This type of sensor allows a seamless DEM to be constructed that represents both the floodplain and the river channel and will facilitate further hydrologic modelling and better understanding the watershed and drainage characteristics of the rivers within the county. The coastal area of River Phillip and Pugwash was surveyed with this sensor in 2016 by NSCC as part of a project with Nova Scotia Department of Fisheries and Aquaculture.

# 1 Introduction

My role on the consulting team was to inform land use management policies with accurate and up-to-date science on sea level rise projections and floodway and floodway fringe delineation, with emphasis on inland flooding issues.

Taken from the Upland proposal, Appendix on the Detailed Methodology for Coastal Risk Analysis.

"The new MPS will address Item 6 in the Focus of Policy Review: Climate change mitigation and adaptation – Coastal vulnerability to storm surges and rising sea levels, Inland flooding. CBCL will provide updated data and recommend policies to address coastal flooding and erosion risks (including rising sea level, storm surges) along (1) the Northumberland Strait, (2) Chignecto Isthmus and (3) Bay of Fundy. Final mapping products will be produced by Upland.

*Disclaimer re. wave action and river flooding* - For areas exposed to wave action, an additional elevation allowance must be made for wave runup and overtopping. To our knowledge, wave action has not been included in any of the previous static flood modeling work. An accurate estimate can only be obtained by a site specific coastal engineering assessment, using hydrodynamic modeling with high resolution bathymetry as inputs (which is outside the present scope). Instead, CBCL proposes to flag exposed areas, give a cursory allowance (e.g. up to 0.5 m, 0.5 to 1 m) based on exposure, assumed shoreline type and shoreline slope (e.g. flat sand beaches are much better at limiting wave overtopping than rocky shorelines with a steep nearshore slope). Similarly, an accurate determination of river flood lines would require site-specific flood studies, with extensive field measurements and hydrologic/hydraulic modeling. As an example, part of that modeling work was done by Webster et al. for River Philip in Oxford/Pugwash, and Nappan. However, these studies do not provide flood lines to be used for legally binding purposes (e.g. 1 in 20 year floodway, and 1 in 100-year floodway fringe). **Given the size of the study area, a flood study for each watershed cannot realistically be included as part of this scope. Instead, we will use the existing data to its maximum applicability based on our experience in flood studies, and flag data gaps."**

Given these constraints on the scope of the study, I have concentrated on where previous studies have been conducted and where publically available data are available and where new data have been collected that may be obtained by the county or province for future studies.

## 1.1 Previous inland river flood risk studies.

### 1.1.1 The town of Oxford and the 1999 flood

Given Cumberland County is surrounded by two distinct ocean water bodies to the north and south, most of the rivers that drain the uplands transition into estuaries before emptying into either the Northumberland Strait or the Bay of Fundy. Thus in many cases the interaction of the tides, and possible storm surges, have a profound impact on the discharge of the upland rivers as they approach the coast. This fact is probably most pronounced for the town of Oxford which is approximately 18 km inland of the Northumberland Strait, yet the tide still has a significant impact on the discharge of the river at that location. Other rivers that drain into the Bay of Fundy can sometimes be impacted by anthropogenic structures such as aboiteau, which have been constructed to limit the impacts of estuarine flooding during high tide and storm surge events. These structures, which are designed to hold the higher water tidal-surge levels back from reaching the upstream areas, potentially cause problems during high discharge events on the rivers resulting from high precipitation or snow melt events by limiting the amount of discharge through the aboiteau. As a result of this interaction between inland river discharge and the interaction of the ocean tides-surge and potential anthropogenic alterations, this makes the hydrologic modelling of these systems complicated.

A study conducted by Stiff (2008) as part of his MSc thesis "Investigating Flood Risk in an Ungauged Watershed using LiDAR, GIS, and HEC Tools" at Acadia Geology Department used lidar to model the 1999 flood that affected Oxford. He used a similar size watershed (River John) to that of upstream of Oxford to estimate the discharge parameters for the 1999 flood event. His study did not factor in the tidal influence on river discharge.

Two studies have been conducted that examined the interaction of river discharge and ocean water level interaction within Cumberland County as part of the Atlantic Climate Adaptation Solutions (ACASA) project (https://atlanticadaptation.ca/en/home), previously known as the Regional Adaptation Collaboration (RAC) funded through Natural Resources Canada and administered locally by NS Environment. Webster et al. (2012, a) "Integrated River and Coastal Hydrodynamic Flood Risk Mapping" studied River Phillip and the potential flood risk for the town of Oxford and the LaHave River.

River Phillip report https://atlanticadaptation.ca/en/islandora/object/acasa%3A487

From Webster et al. (2012, a) Integrated River and Coastal Hydrodynamic Flood Risk Mapping.

"Only River Phillip had lidar coverage along the floodplain upstream to Oxford, which is prone to flooding, and local officials have indicated that the tide influences stage of the river there. As a result, the coupled river run-off watershed model was only applied to the River Phillip and Oxford area. The river flooding event of September, 1999 for Oxford was simulated in order to demonstrate the interaction of the river run-off and tide-surge. Due to the limited number of tide gauges in the region, specifically along the coast of the Northumberland Strait, a coastal boundary condition mimicking storm conditions of December 21, 2010, was used, with a record of the 1.5 m surge from that time. These two events were combined and demonstrate that the tide had an influence on river stage 18 km upstream, in Oxford. Daily rainfall and temperature data were used to model the 1999 event, and it is expected that results could be improved with better temporal environmental data. The results indicate this type of coupled river run-off and coastal model should be employed at other coastal communities in Nova Scotia to assess flood risk."

The Mike11 Hydrodynamic (HD) model required accurate stream and floodplain topography to simulate the flow of water through the system. Cross-sections were manually digitized across river branches and flood plains perpendicular to the direction of flow. Cross-sections were roughly spaced at 100 m intervals along river branches while ensuring that a cross-section was drawn at the start and end chainage of each river branch. Cross-section width was dependent on topography and was ensured to capture potential flood plains during significant flooding events. An integrated model was developed by linking the Mike11 rainfall-run-off and one-dimensional hydrodynamic model to the Mike21 shallow water two-dimensional hydrodynamic model using a coincident boundary. This linkage provided the ability to simulate flood events which were driven by precipitation events or tidal influence.

A long term simulation was developed to run from June 1 to September 30, 2011, to calibrate, validate and test the stability of model components. During the simulation period, discharge was observed for the gauged portion of River Phillip. Results of the simulation were used in an iterative process to adjust problematic bathymetry, calibrate rainfall-run-off module parameters, and validate the one-dimensional hydrodynamics.

A rainfall-based flood simulation was developed to model major flooding within the town of Oxford caused by the remnants of Hurricane Harvey, which deposited over 300 mm of rainfall between September 21 and 23, 1999. The simulation was run for September 1 to September 30, 1999. Flood results from the simulation were compared against previous modeling performed by Stiff (2008), and observational data obtained from press documents (The Oxford Journal, 1999).

The simulation was run for December 10, 2010 to January 6, 2011. A combined events simulation was created by artificially merging the rainfall observations from the September, 1999, flood simulation with tidal observations from the December, 2010, flood simulation. This methodology effectively simulated flooding extents caused by the hypothetical scenario of a major rainfall event occurring during a significant storm surge. Summary statistics were calculated for each of the event simulations and compared.

Coastal tidal-surge models and watershed river run-off models must be integrated to accurately model flood risk for communities such as Oxford, which are located along estuaries. It was confirmed that the discharge of the river during significant rainfall-run-off flooding events is influenced by the tide in the downstream estuary. To accurately model the flooding, the interaction between river discharge and the water level within the estuary must be taken into account. Models that simulate this interaction require accurate terrestrial and bathymetric topography.

### 1.1.2 The Village of Nappan

The report examining flood risk near Nappan by Webster et al. (2012, b) "River Flood Risk Study of the Nappan River Incorporating Climate Change" is summarized below.
https://atlanticadaptation.ca/en/islandora/object/acasa%3A688

This research examined the discharge of the Nappan River and the impact of sedimentation and the aboiteau that is operated by the Nova Scotia Department of Agriculture at the downstream location of the Nappan River. From Webster et al. (2012, b) "The aboiteau was constructed in the 1960's to control tidal influence upstream and reducing the problem of coastal flooding. The water in the Upper Bay of Fundy has a high degree of suspended sediment as a result of the clay rich soils that drain into the Cumberland Basin. This high level of suspended sediment has contributed to siltation of the river channel directly upstream of the aboiteau. This siltation has resulted in an increase of the elevation of the river bed and a widening of the river channel. The purpose of this ACAS project was to construct a model to simulate river flooding events, estimate the impacts of possible increased rainfall in the future under climate change, and to evaluate various adaptation strategies."

Webster et al. (2012, b) constructed a seamless elevation model (lidar + bathymetry) to facilitate the extraction of river cross-sections used in the 1-D hydraulic river model. They used the river stage information along with a local Environment Canada weather station to develop a watershed rain-fall run-off model. In order to control the function of the aboiteau in their model, they developed a 2-D hydrodynamic tide model for the Upper Bay of Fundy. They simulated past flooding events, such as from July 2010 and increased the rainfall two and three fold to simulate possible increases in precipitation with climate change. Atmospheric models predict a possible increase of the intensity of short term rainfall events of 16% by 2080 (Richardson and Daigle, 2011). However, these climate models are most reliable for predicting changes in the average of parameters and are not as accurate in their predictions of extremes, thus, Webster et al. (2012, b) increased the rainfall by two and three times for the July 2010 period to demonstrate the potential impacts of increased rainfall in the future.

To test different adaptation scenarios to possibly solve the flood problems that occur presently, they simulated blocking the drainage ditch to Smith Road (ie. equivalent of an aboiteau). The results indicate that this prevented the river from flooding the road for rain events that currently do cause flooding. They also simulated lowering the river bed in the area upstream of the aboiteau where there is significant silt build up. The results indicate this has the effect of raising the threshold of water necessary before flooding occurs. This study has implications for many estuaries in the province that have control structures (aboiteau) at their mouth. The problems of siltation, restricted drainage, and the prevention of river discharge during high tide events, make this issue of flooding upstream of these structures more problematic.

Since the discharge of the Nappan River is controlled by an aboiteau, which in turn is controlled by the state of the tide and thus stage of the water downstream from the aboiteau, they needed to establish an accurate model of the predicted tide so that they could model the action of the aboiteau. Dimensions for the Southampton Rd aboiteau (NS109-23), located at the mouth of the Nappan River, were provided in part by the Department of Agriculture. In places where design schematics were not complete for the Nappan aboiteau as supplied, dimensions for the sister aboiteau at Great Village (NS114) were used with the assumption of having a similar depth and width measurements. To supplement the topographic lidar elevation model which does not map under the water, the channel Nappan River was mapped using a canoe mounted with a sonar transducer (precise to 10 cm vertically) and a RTK (real time kinematic) survey grade GPS (global positioning system) receiver (accurate to 2.5 cm, three dimensionally). Such river channel depth data, combined with lidar data, is crucial for the accuracy of the resultant hydrodynamic model. Measurements were taken during several different river stage conditions over the course of several months. Flow measurements were recorded systematically along the stream profile at the location of the in situ river stage measuring device at the Lower Porter Road Bridge. River flow measurements were collected every 1 m to 2 m perpendicular to flow along with channel depth and a single water level. Unfortunately the closest station to where tidal prediction are available for Nova Scotia is at Joggins Wharf, which is a large distance away and would not accurately predict the local conditions up the Nappan River channel. To overcome this they developed a 2-D hydrodynamic model, Mike 21 from DHI, for the Upper Bay of Fundy and used a predicted tidal boundary condition from WebTide, a regional hydrodynamic model developed by the Department of Fisheries and Oceans (Dupont et al., 2005). This model was used to develop a time-series that controlled the river flow through the aboiteau. This hydrodynamic model for the Upper Bay of Fundy was also used in the examination of the Chignecto Isthmus by Webster, Kongwongthai and Crowell (2012).

They used the weather and watershed areas with a lumped rainfall-run-off model from DHI, called a NAM model. This model keeps track of antecedent conditions which is very important if you have had a stretch of wet weather and the ground is saturated. Additional rainfall may cause flooding during such conditions. They used a 1-D river hydraulic model in combination with the NAM model to determine the stage and flow of the river channel and floodplain, Mike 11 from DHI. Once the model was established and validated using field measurements, extreme precipitation events were imposed to determine the extent of flooding along the floodplain. Past flooding events were used to qualitatively validate the model, since no accurate records were available of the spatial extent and depth of flooding.

The main information that drives the watershed run-off model is the precipitate and temperature atmospheric conditions. These are typically obtained from a weather station in the area. However, for large watersheds, ca. greater than 50 square kilometers, the amount of precipitation can vary within them and should be adequately represented in the model. In this study they had to rely on a single weather station located near the mouth of the Nappan River to represent precipitation throughout the entire watershed. This can result in missing a precipitation event, since the weather station is located near the outlet of the watershed and a rain event could occur in the upper watershed that is not captured by the weather station although the river stage and discharge will capture the event by increased levels. To potentially overcome this problem, they examined the use of deriving precipitation estimates from the Environment Canada Radar Precipitation maps. Detailed validation of this method as compared to weather station data was beyond the scope of thier project and these data were not used in the modeling. Therefore it was recommended that for river run-off studies, additional weather stations be distributed throughout the watershed to ensure significant rain events are captured. An alternative to this is to further explore other potential sources of distributed rainfall data such as those derived from the radar maps, although these data require validation.

### 1.1.3 Summary of past studies

The comments made in the proposal Upland that these previous studies do not identify the 1 in 20 year floodplain or the 1 in 100 year floodplain and thus cannot be used for legal definitions is true in that these studies were focusing on replication past events and linking the interaction of river run-off with tidal influences and in the case of Nappan anthropogenic influences with the aboiteau. One of the big challenges for defining a floodplain with a specific flooding return period such as the 1:20 or 1:100 year event, is that you need observational data in order to calculate the statistical extreme analysis to determine the water levels and associated return periods. For example, Webster et al. (2012, c) did this for the five coastal areas that they surveyed with lidar and provide flood inundation maps by analyzing tide gauge records of observed total water levels. They conducted extreme analysis on the annual maximum for the nearest tide gauge observations, to their lidar survey areas. In the case of river floodplains there are two approached that are taken to conduct the statistical extreme analysis: 1) use the time-series of the river discharge measurements directly, or 2) use the time-series of precipitation as a surrogate for river discharge. McGuigan, Webster and Collins (2015) used the time-series of the LaHave River flow measurements to calculate return periods and simulated the 1 in 50 year and 1 in 100 year return periods for peak flow. Rivers are not directly measured for discharge (cubic metre of flow per second), but rather stage or water level. A “rating curve” is established by measuring the river cross-section and flow and relating the stage and flow at different times of the year at different flows and stage levels. This rating curve then is used to translate the stage measurement into flow. In the case of extremely high flow flood events which typically exceed the area of the curve supported by observational data, there is an increased level of uncertainty. In the following section, I have examined what rivers have been gauged in Cumberland County in the past and report on those locations. As well, the province of Nova Scotia Department of Environment has established several new rea—time gauges throughout the province. Kelley’s River is currently the only real-time gauged river in Cumberland County, however given the frequent flooding in Oxford, one would hope the area upstream of Oxford on River Phillip is in their future plans. In the case of precipitation return periods, Environment Canada has developed IDF (Intensity Duration Frequency) curves for some locations to assist engineers in understanding the return period of such events for infrastructure planning. There does not appear to be any IDF curves generated for Cumberland County and the nearest most representative curves appear to be for Truro and Caribou Point on the Northumberland Strait. These are discussed in the next section on Environmental Data.

# 2. Environmental Data

If data representing the floodplain topography exists at sufficent resolution and if river channel geometry is known (river bathymetry), then one can begin to construct a hydraulic model for the system. The boundary conditions to simulate the volume of water passing through the system are typically derived through two possible data sources: 1) direct measurement of river discharge, or 2) estimating through a rainfall-run-off model that accepts distributed rainfall across the watershed or drainage area upstream of the area in question.

## 2.1 River Discharge Measurements

Data for rivers that have been gauged in the past or are presently being gauged and some in real-time are available at the Water Services Branch of Environment Canada.

NS Environment and Water Services manage the present gauged stations and the real-time stations. As previously mentioned Kelley's River is the only current station in Cumberland County (Figure 1).

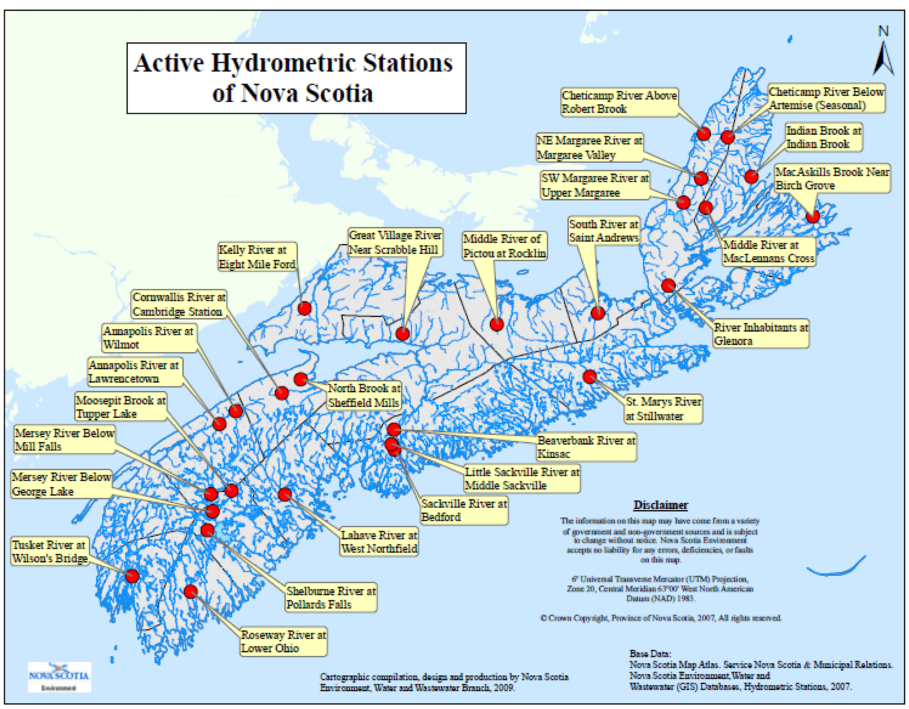



*Figure 1 Real-time hydrometric stations in Nova Scotia (source NS Environment).*

The following website and query were constructed to obtain historic water flow records in the county.

https://wateroffice.ec.gc.ca/search/historical_results_e.html?search_type=coordinate&north_degrees=46&north_minutes=02&north_seconds=26&south_degrees=45&south_minutes=30&south_seconds=0&east_degrees=63&east_minutes=10&east_seconds=0&west_degrees=64&west_minutes=54&west_seconds=35&start_year=1850&end_year=2017&minimum_years

The following information was obtained from the Water Survey of Canada site for past water level and flow gauging stations in the county:

Station 01DL001 Kelley's River drains to River Herbet in the Upper Bay of Fundy.

Station 01DL002 MacCan River drains to Nappan area in the Upper Bay of Fundy.

Station 01DN004 Wallace River drains to Wallace on the Northumberland Strait.

Station 01DN005 Wallace River drains to Wallace on the Northumberland Strait.

Station 01DN006 Roaring River at Westchester drains to Wallace on the Northumberland Strait.

Station 01DN007 Collingwood drains to River Phillip on the Northumberland Strait.

Station 01DN008 Collingwood Corner drains to River Phillip on the Northumberland Strait.

The locations of the stations were plotted since they also report their latitude and longitude of the station. Figure 2 shows the provincial 1:50,000 scale watersheds in addition to the location of the previous gauging stations. The watersheds are coded at the primary, secondary and tertiary levels (Figure 2). Primary watershed IDK and a small part of IDJ drain into the Bay of Fundy along the south shore of the county and IDL drains northwestward to the Chignecto Basin and contained stations 01DL001 and 01DL002 (Figure 2). Primary watersheds IBT and IDM appear to drain to both the Bay of Fundy and Northumberland Strait, although that appears to contradict the definition of a primary watershed (Figure 2). Primary watershed IDN drains both River Phillip and the Wallace River to the Northumberland Strait from the Cobequid Highlands and contained the location of stations 01DN004, 5, 6, 7 and 8 (Figure 2). A small section of the eastern county is drained by primary watershed IDO for Malagash point.

The ability to separate the primary and secondary watersheds is possible and figure 3 shows the separation between the Maccan River and River Herbert secondary watersheds and the tertiary watershed boundaries (Figure 3).

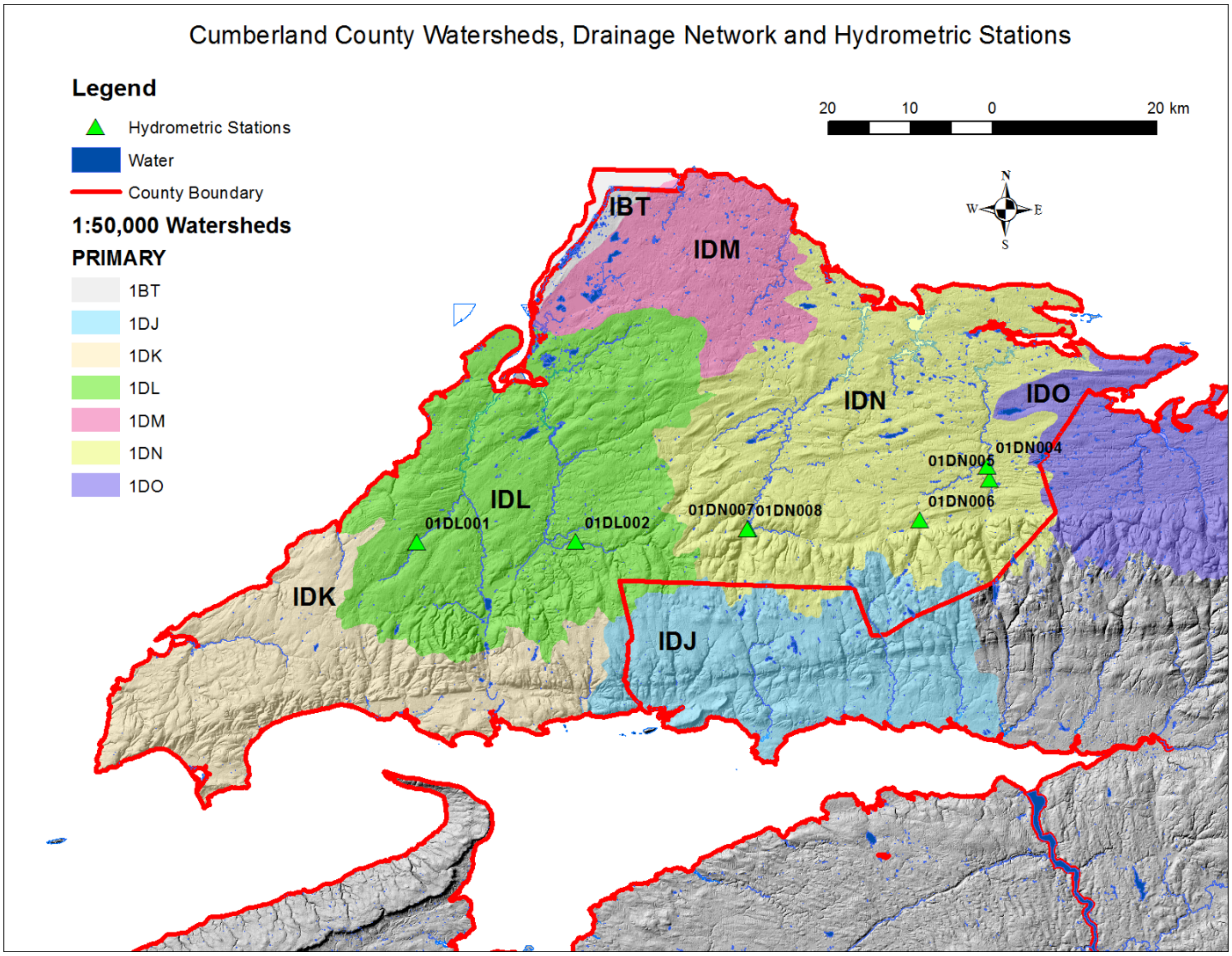



Figure 2 Past Gauging stations and primary watersheds in Cumberland County (source Water Survey of Canada and GeoNova).

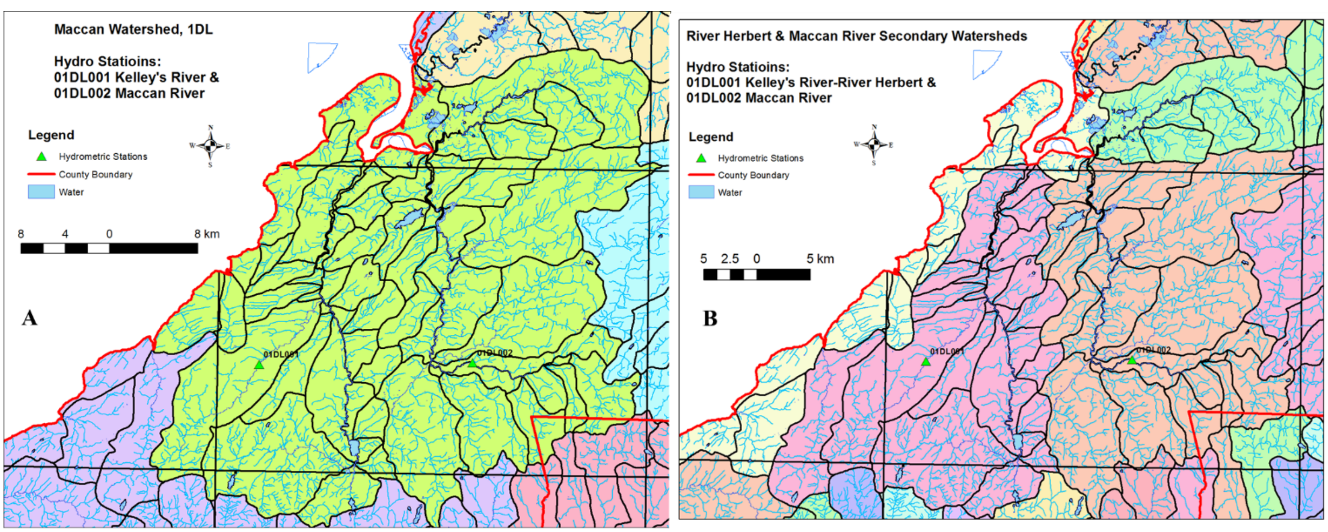



Figure 3 A. Maccan primary watershed with tertiary boundaries. B. Maccan and River Herbert secondary watersheds colour coded (Source Water Survey of Canada and GeoNova).

The historic daily discharge record for station 01DL001 at Kelley's River along River Herbert is plotted below for the years 1969-2015. Water Survey of Canada indicated this station recorded from a drainage area of 63.2 sqkm. The maximum flow occurred in Nov. 13, 1975 reaching 47.3 cubic metres/second with the next largest event occurring in Dec. 9, 2014 reaching 45 cubic metres/second (Figure 1Figure 4). The annual maximum and minimum has also been calculated for some of the stations including Kelley's River on River Herbert by Water Survey of Canada (Figure 5). The annual maxima is typically used in the extreme analysis statistics to calculate the return periods of flows and thus the 1 in 20 year and 1 in 100 year flow events.

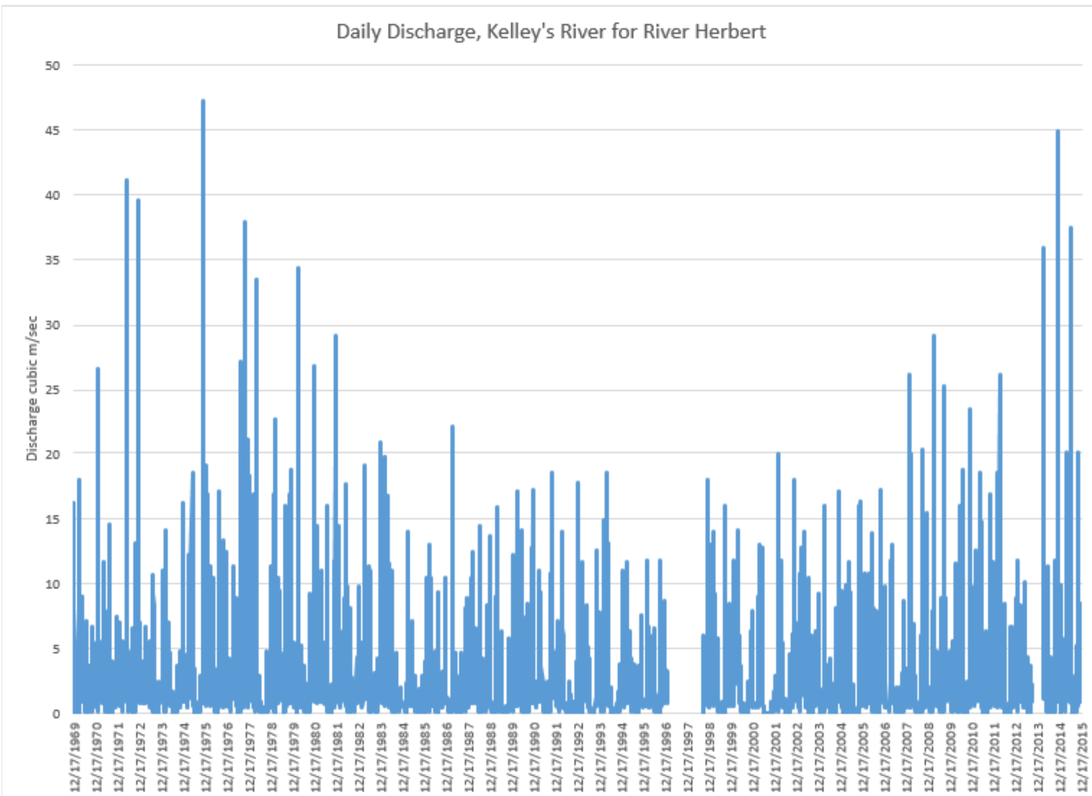



*Figure 4 Daily discharge for Kelley's River station 1969-2015 (Source Water Survey of Canada).*

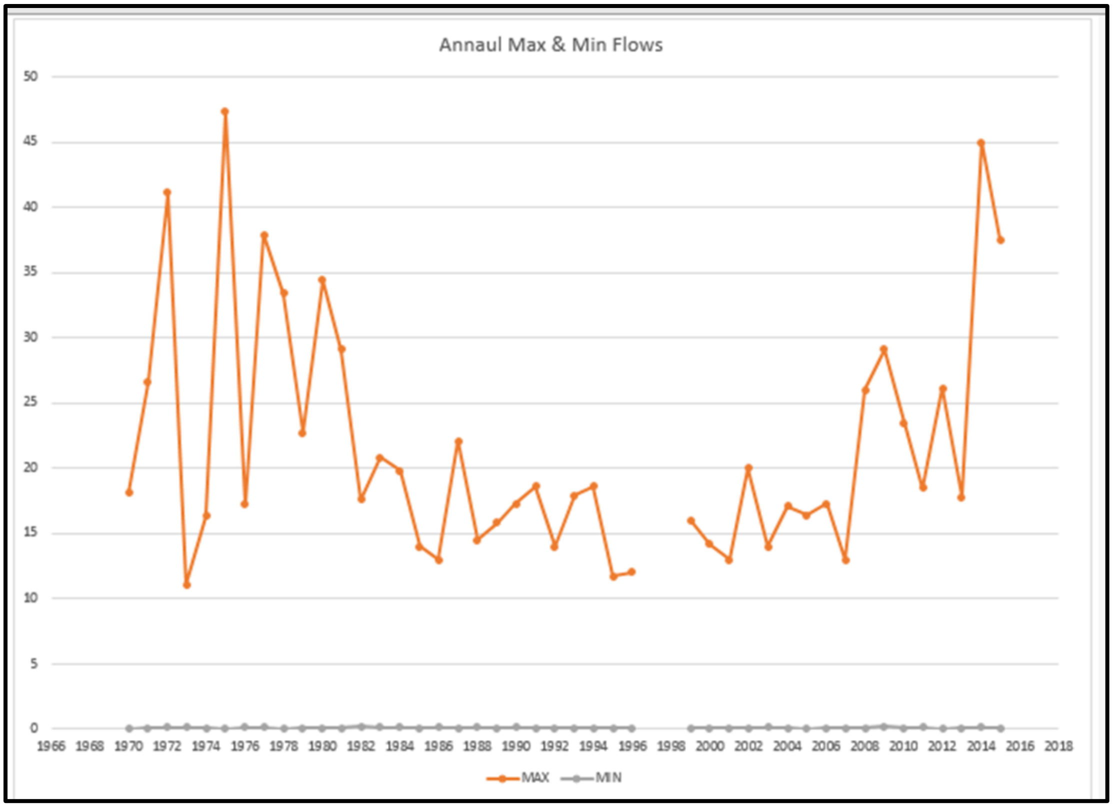



*Figure 5 Annual maxima and minima for Kelley's River station on River Herbert (source Water Survey of Canada).*

The Maccan River gauging record from 1977-1979 shows a peak flow of 28.3 cubic metres/second on Jan. 14, 1978 (Figure 6). Water Survey of Canada indicated this station recorded from a drainage area of 98.4 sqkm. The annual maxima and minima only consist of 1 record since the gauge was only in place for a short period of time. This time-series is considered too short to be able to accurately build a reliable estimate of return periods of flow using the extreme analysis method, many authors consider 30 years of data to be the minimum time-series length required.

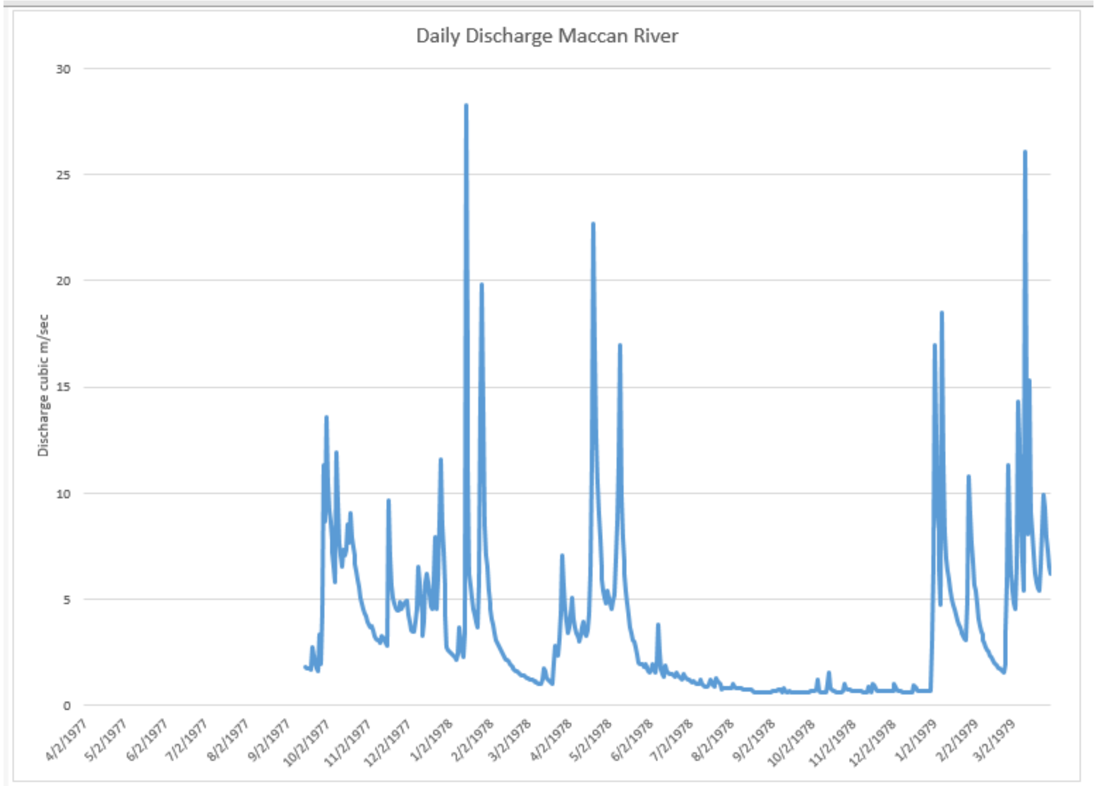



*Figure 6 Maccan River gauge record from 1977-1979 (Source Water Survey of Canada).*

River Phillip and the Wallace River watersheds can be divided at the secondary level from the primary watershed IDN (Figure 7). River Phillip had two gauging stations both at Collingwood Corner at slightly different locations 01DN007 and 01DN008 (Figure 7) with both operating between 1977 and 1979. It is unclear if this is an error in the Water Survey of Canada database but seems unlikely two stations so close would be operated for the same amount of time. Closer inspection of the two records from the Water Survey of Canada shows that 01DN007 operated briefly from Jan. 2 1977 until Jan. 6$^{th}$ 1977 then a gap until operating between Oct. 7, 1977 and March 31, 1979 while 01DN008 operated from Oct. 7, 1977 until March 31, 1979.

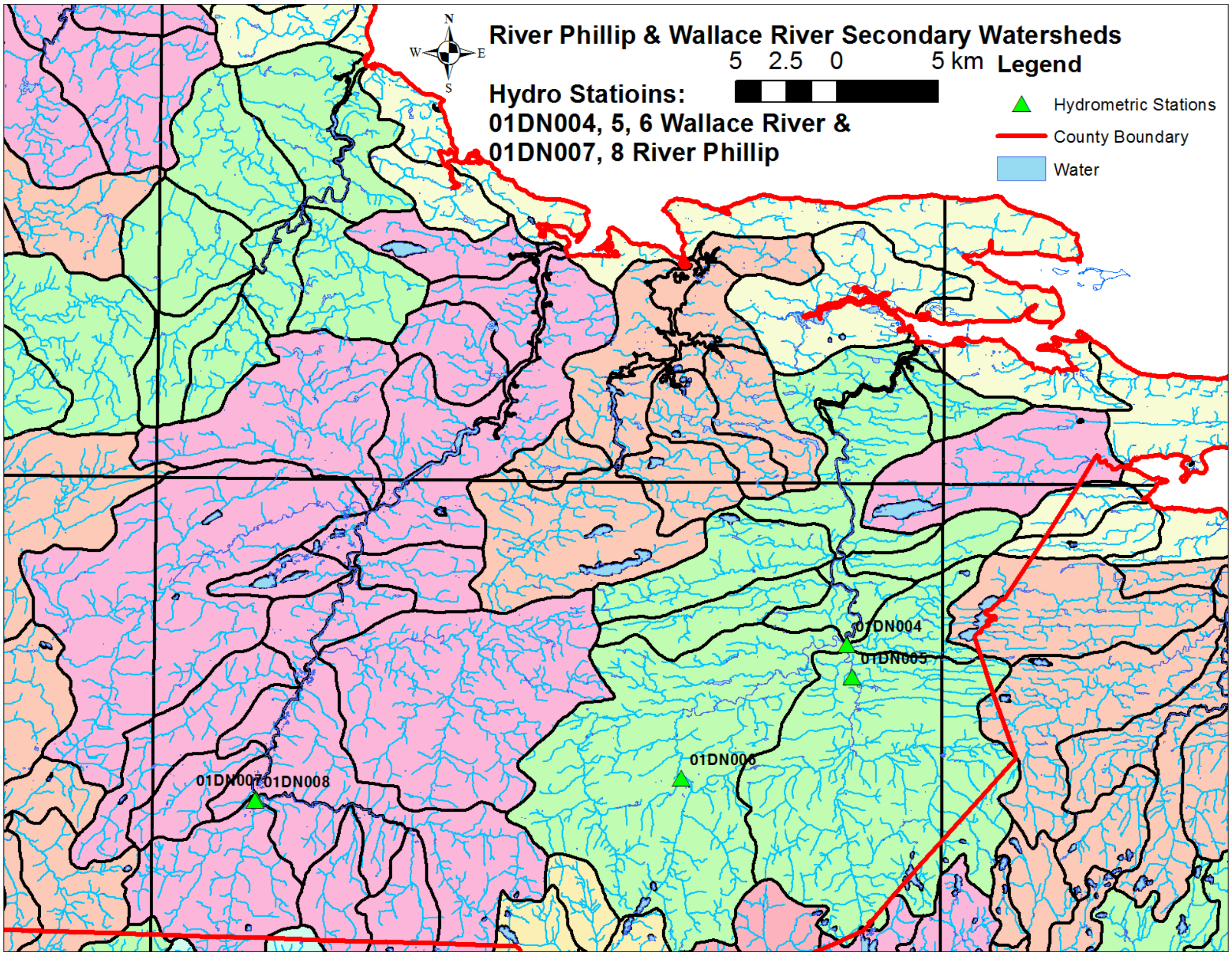



*Figure 7 Secondary watersheds for River Phillip (pink) and the Wallace River (green), the Pugwash River secondary watershed is shown in brown-tan colour (Source GeoNova).*

The data records for each daily flow sometimes have an alphabetical code associated with them (Table 1).

*Table 1 Table of codes associated with the historic flow records (source Water Survey of Canada).*

| **Code** | **Definition** |
|---|---|
| A | Partial Day |
| D | Dry |
| R | Revised within the last two years |
| B | Ice Conditions |
| E | Estimated |
| P | Partial dry |

Examining the common flow period of stations 01DN007 and 01DN008 indicated the flows followed an identical pattern of peaks, however the values were significantly different with 01DN007 having a much higher flow rate (Figure 8). The records for station 01DN008 have an associated “E” with them indicating they are estimated flows (Table 1). Therefore, it appears as though station 01DN007 is the official flow record for River Phillip at Collingwood (Figure 9). Water Survey of Canada indicated this station recorded from a drainage area of 105 sqkm.

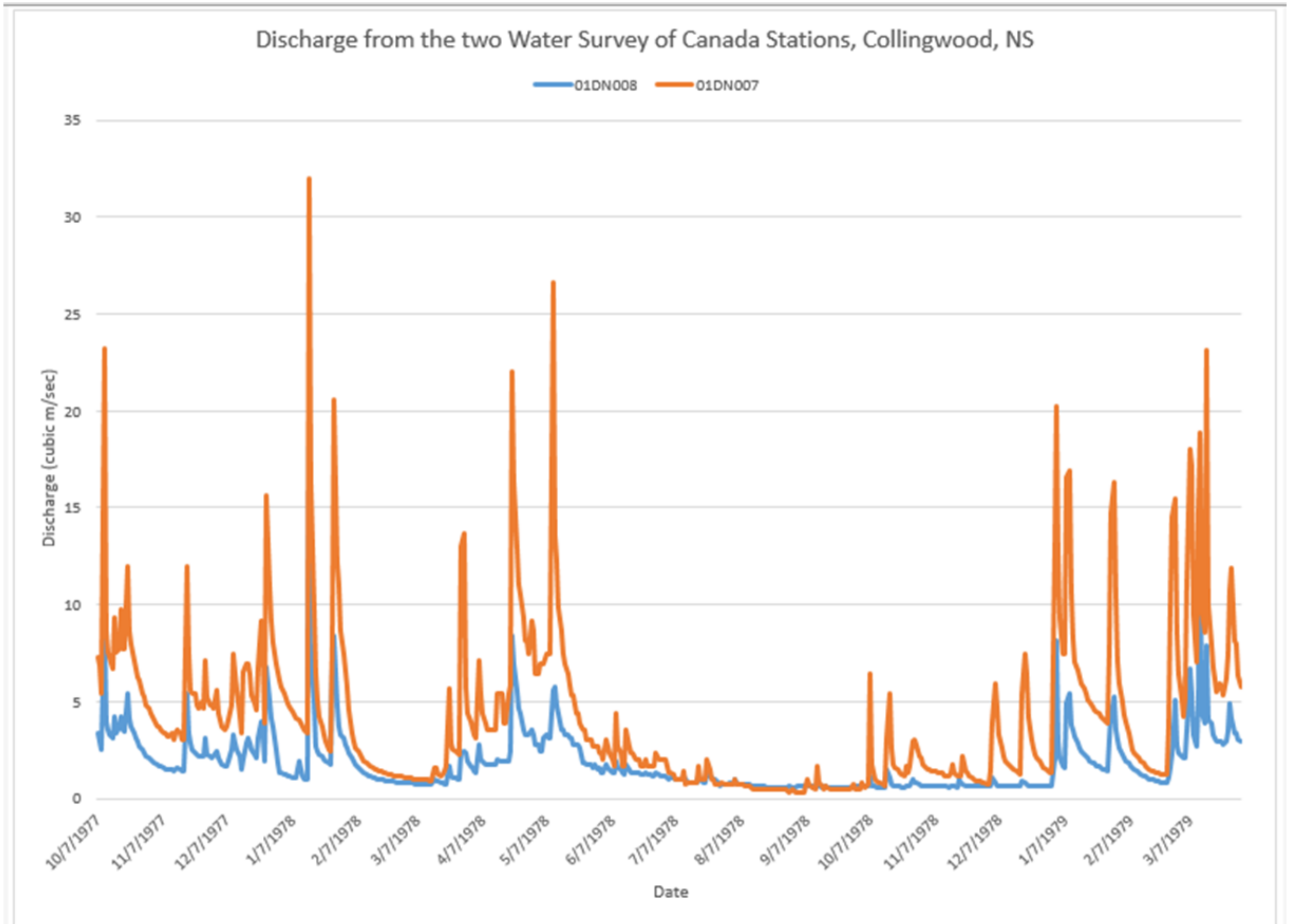



*Figure 8 Comparison between Collingwood water flow stations 01DN008 (blue) and 01DN007 (orange) (source Water Survey of Canada).*

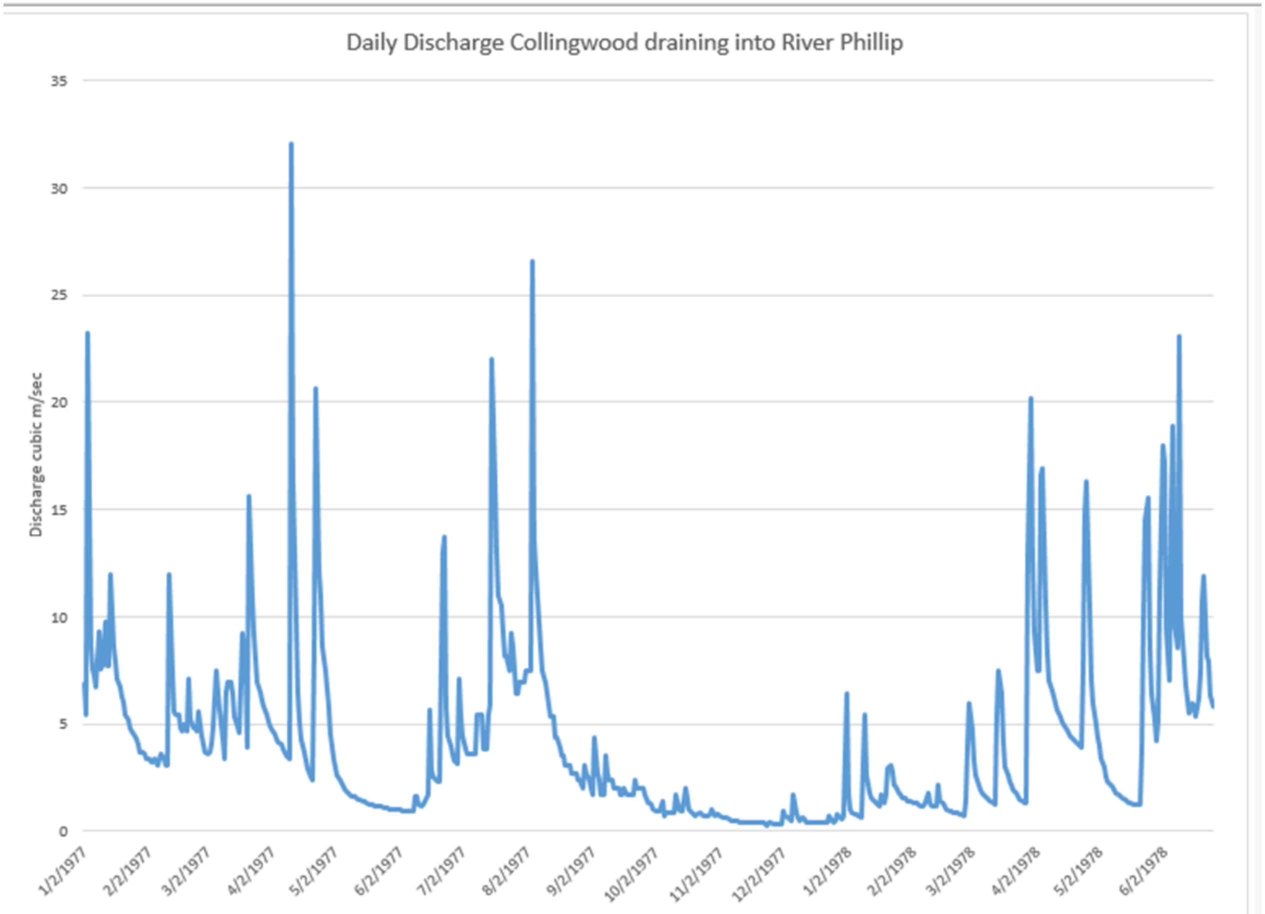



*Figure 9 Daily flow at Collingwood station 01DN007 for River Phillip (source Water Survey of Canada).*

Water Survey of Canada has not reported the annual maximum values for this station and since it only operated for 2 years it does not have a long enough time-series to be used for accurate estimations using extreme value analysis.

The Wallace River is reported to have three gauging stations 01DN004, 01DN005 and 01DN006. Station 01DN004 at Wentworth Centre operated from Aug. 21, 1964 until Sept. 1, 1999. Water Survey of Canada indicated this station recorded daily discharge from a drainage area of 298 sqkm. The daily discharge for 01DN004 covers over 30 years of time and is plotted (Figure 10). The annual maxima and minima are also reported by the Water Survey of Canada and have been plotted (Figure 11).

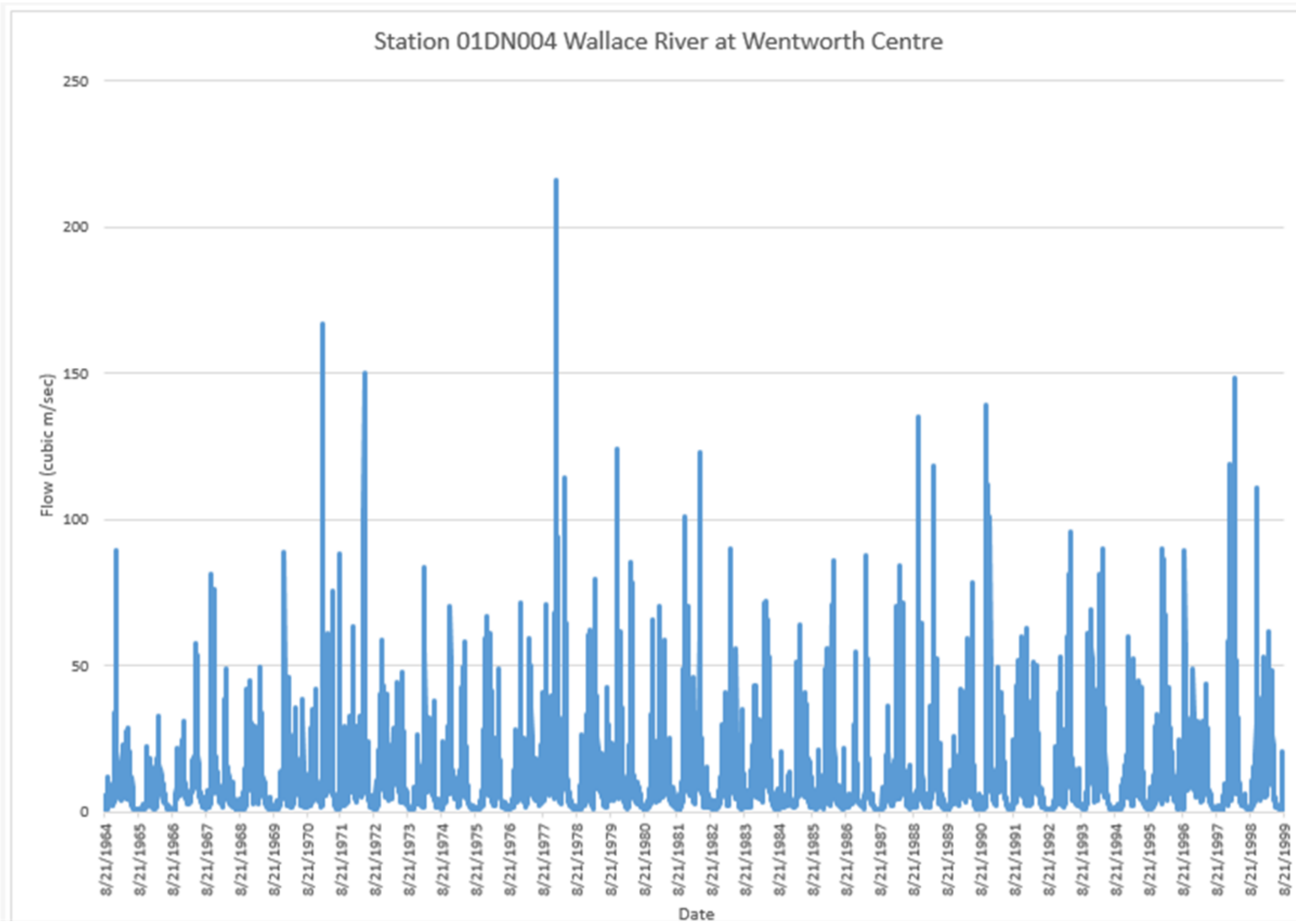



*Figure 10 Daily discharge for station 01DN004 for the Wallace River at Wentworth Centre (source Water Survey of Canada).*

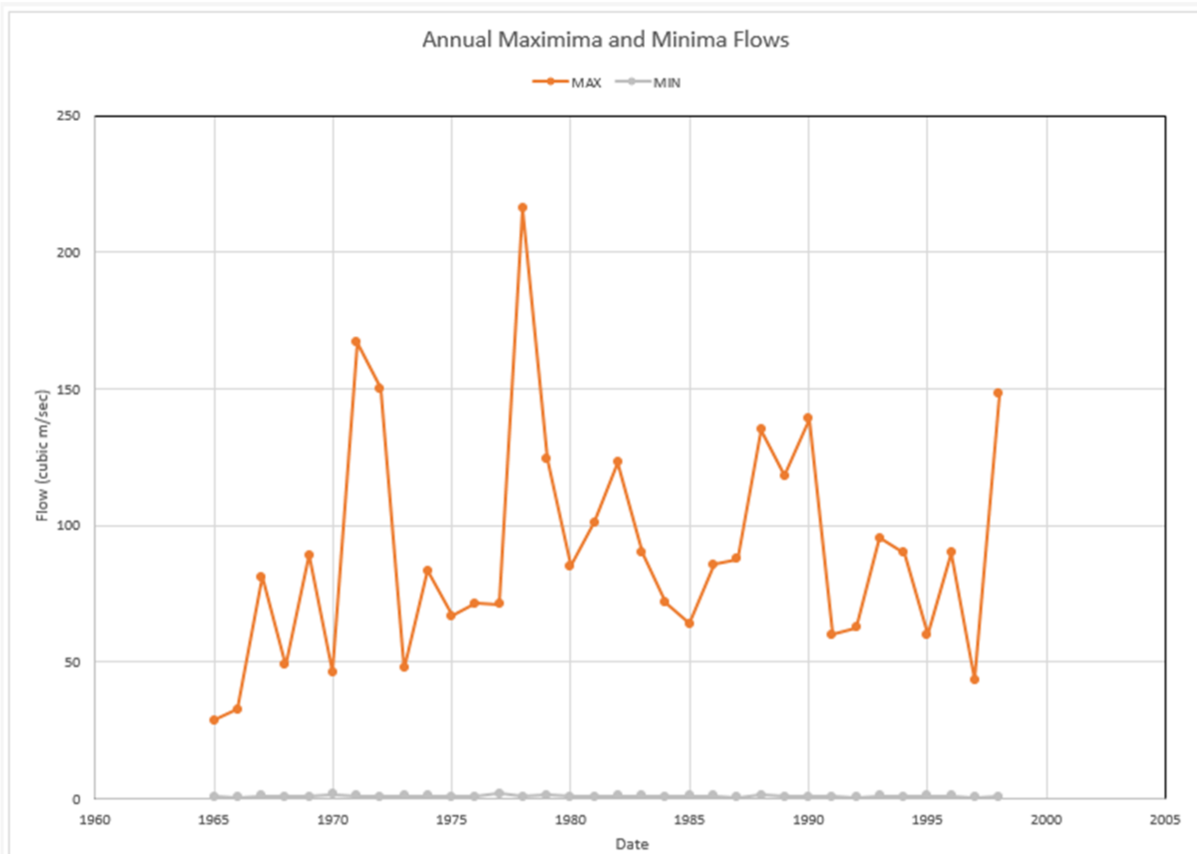



*Figure 11 Annual maxima and minima for station 01DN004 for the Wallace River at Wentworth Centre (source Water Survey of Canada).*

There are two additional stations associated with the Wallace River, station 01DN005 at Wentworth is reported to have recorded flow from a drainage area of 114 sqkm. This station operated from Oct. 21, 1977 to March 31, 1979 and the daily flows have been plotted (Figure 12). Since this station did not operate longer than 2 years, it does not have a long enough time-series to be used for accurate estimates using extreme value analysis.

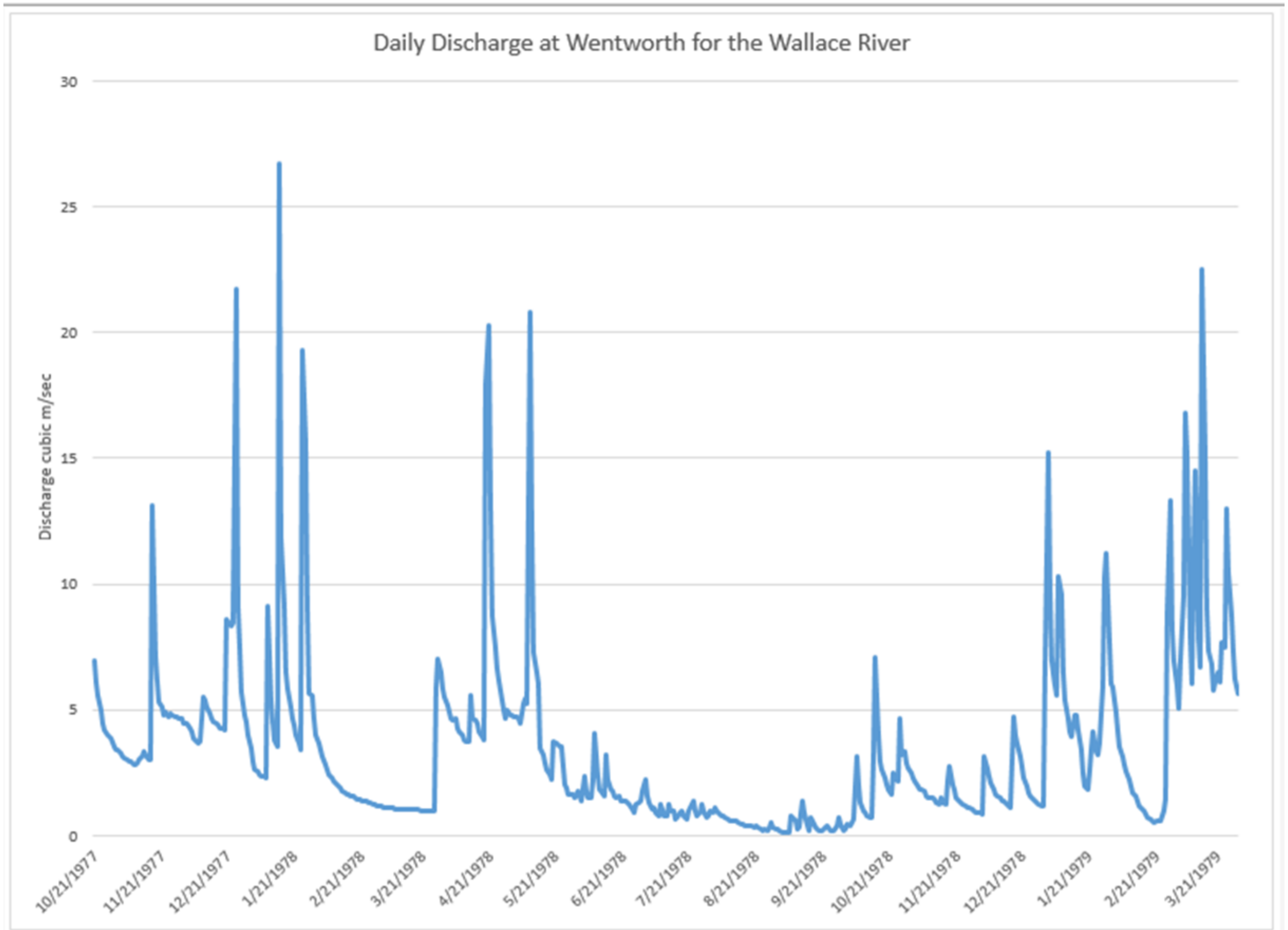



*Figure 12 Daily discharge from station 01DN005 for the Wallace River at Wentworth (source Water Survey of Canada).*

An additional station, 01DN006, for the Wallace River was also placed at the Roaring River at Westchester Station and is reported to measure daily flows for a drainage area of 43 sqkm. This station operated from Oct 1, 1977 until March 31, 1979. The daily flows for station 01DN006 have been plotted (Figure 13). Since this station did not operate longer than 2 years, it does not have a long enough time-series to be used for accurate estimates using extreme value analysis.

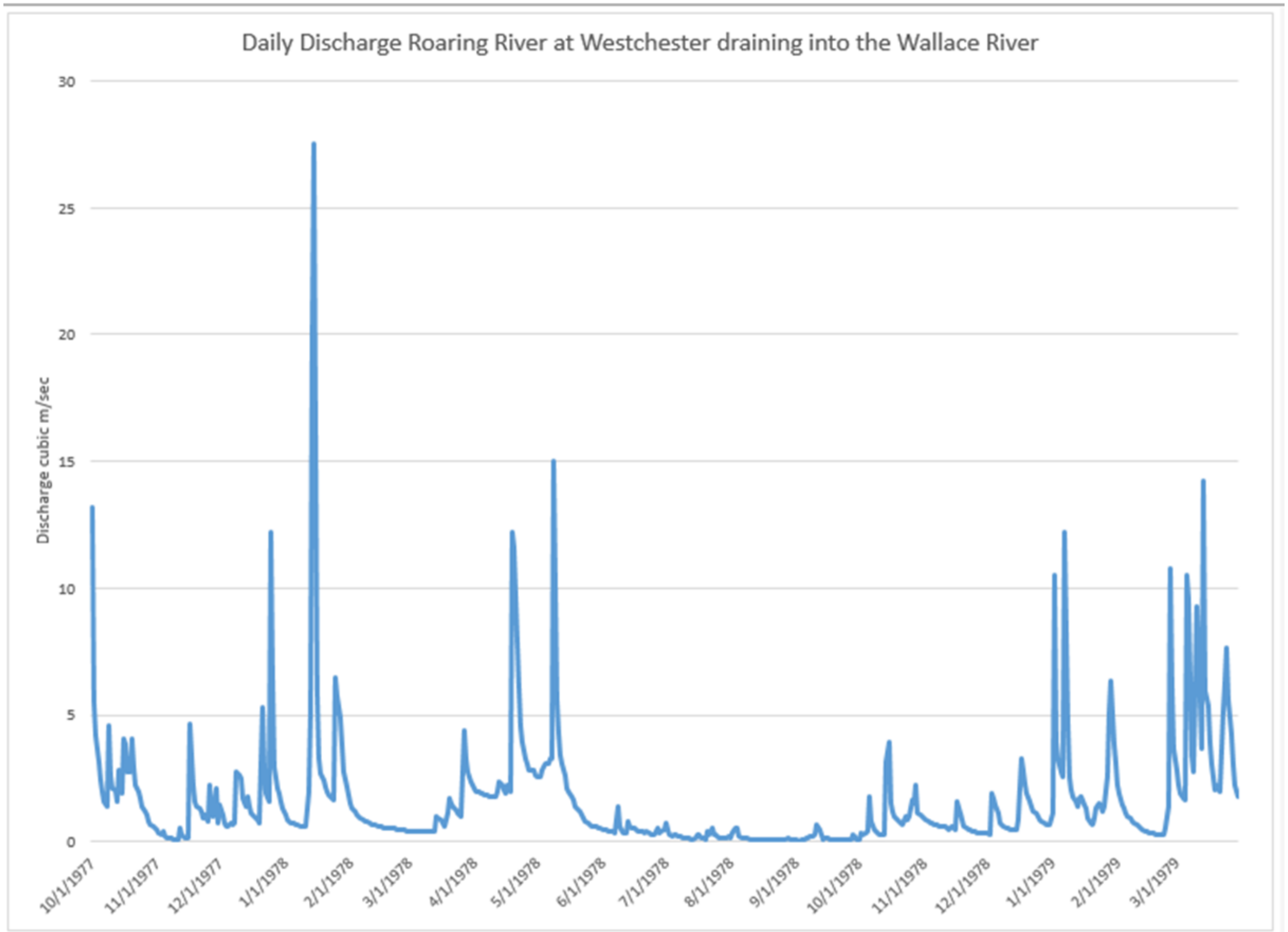



*Figure 13 Daily discharge for station 01DN006 at Roaring River Westchester Station (source Water Survey of Canada).*

In summary, Kelley's River has a long time series of flow information where the annual maxima could be used for extreme value analysis as well has a real-time gauging station currently active. Station 01DN001 at Wentworth Centre has a long time series of flow information for the Wallace River where the annual maxima could be used for extreme value analysis, although it is quite old (1964-1999) and the watershed has undoubtedly changed in its hydrological characteristics since then. River Phillip has not been gauged long enough to produce a suitable time-series for extreme value analysis to be conducted, although a short 2 year record exists in Collingwood for the system. Given the flood problems that have and continue to occur in Oxford and along the River Phillip and its tributaries, one would expect this system to have more attention paid to it and have better data. Perhaps the provincial Department of Environment could be approached about installing a real-time water gauge on this system to aid in times of high flows when flooding may be a potential.

Two other significant watersheds were identified within Cumberland County for Parrsboro and for Advocate. Unfortunately, neither of these watersheds have any information related to surface water flows. The watersheds associated with these two communities have been plotted for Parrsboro (Figure 14) and Advocate (Figure 15).

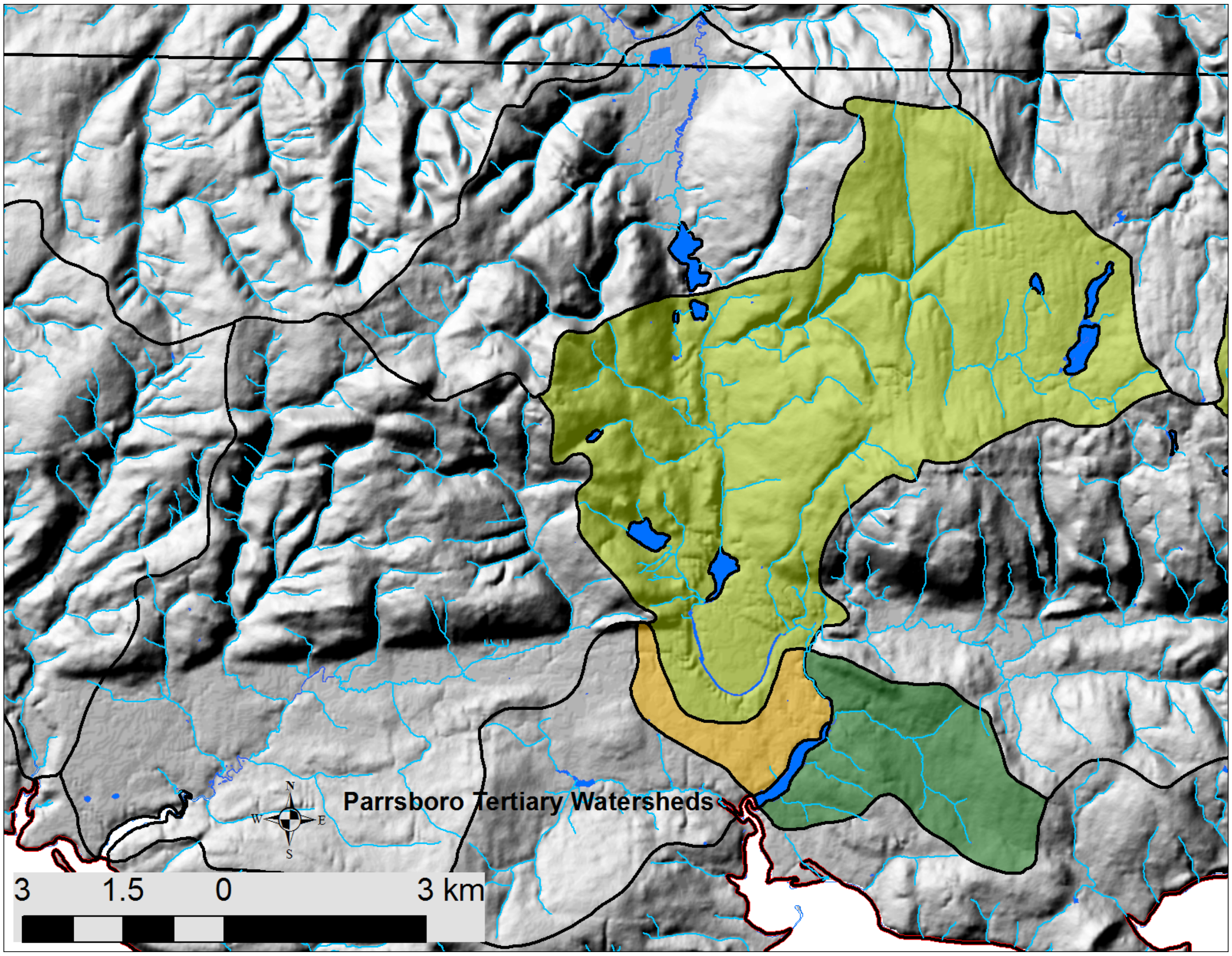



*Figure 14 Watersheds associated with drainage for the community of Parrsboro (source GeoNova).*

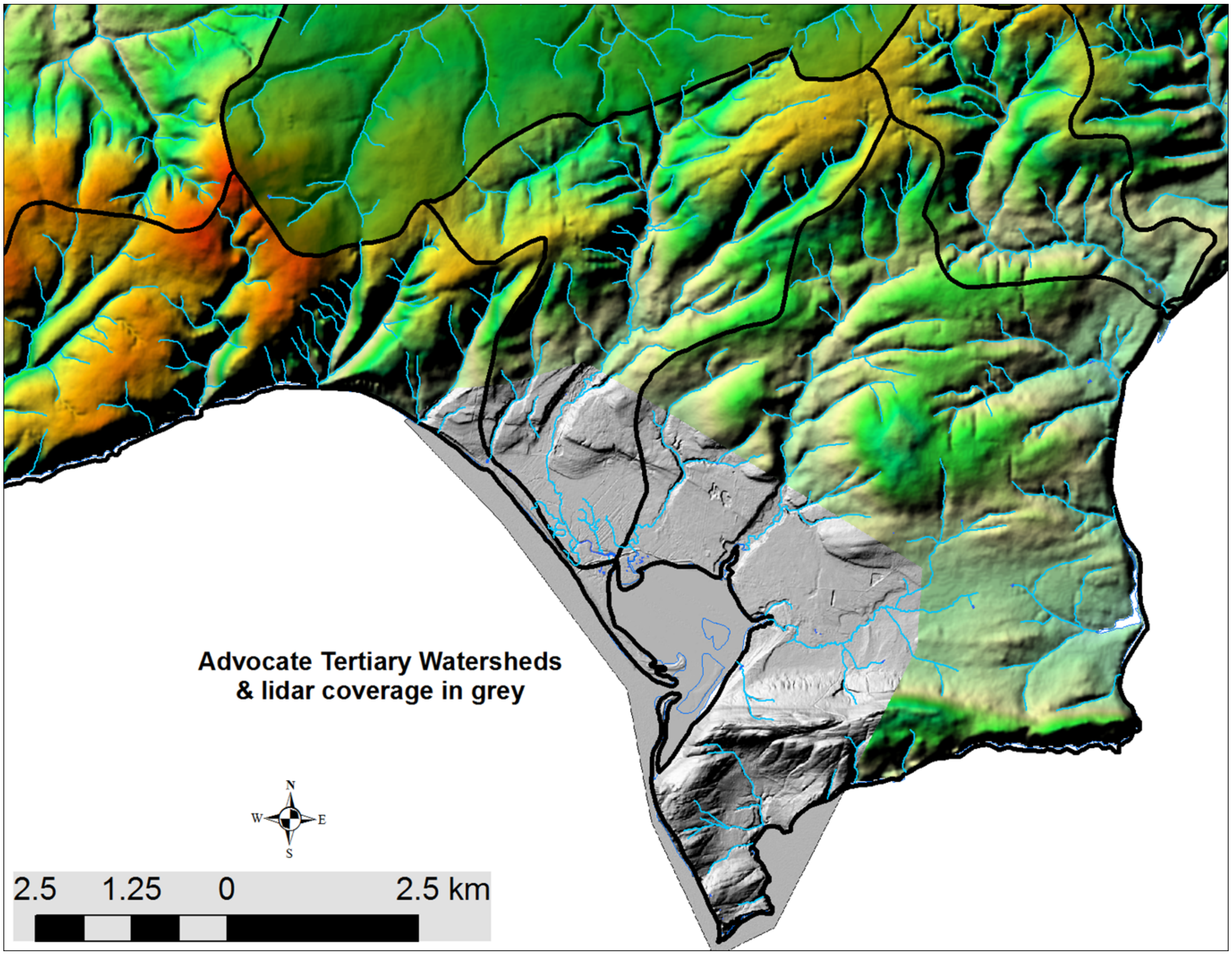



*Figure 15 Watersheds associated with the community of Advocate (source GeoNova).*

## 2.2 Rainfall and temperature

If one is not able to measure the stage and flow of a river system directly, the next available data to provide insights into the hydrological cycle and how it relates to the watershed characteristics and floodplains and potential flood risk is weather data, specifically precipitation and temperature. Webster et al. (2012, a) used hourly temperature (°C) and precipitation (mm) observations that were retrieved from the Weather Underground Inc. website ((http://www.wunderground.com/) for an Environment Canada meteorological station in Nappan from June 20, 2004, to December 31, 2011 in their study of flood risk for the Nappan River. Daily precipitation and minimum/maximum temperature values were retrieved for the same observation station from the Environment Canada website from January 1, 1998, to December 4, 2003, because these historical observations were unavailable from Weather Underground Inc. Precipitation data were used as a Mike11 rainfall-run-off model input, and temperature data were used to calculate evapotranspiration for catchments within the study area. As mentioned previously, they used the weather and watershed areas with a lumped rainfall-run-off model from DHI, called a NAM model. This model has precipitation and temperature as inputs and keeps track of antecedent conditions which determines things like if the ground is saturated or not which can have an impact on the hydrologic characteristics of the watershed for a given rainfall event. They used a 1-D river hydraulic model in combination with the NAM model to determine the stage and flow of the river channel and floodplain and validated the model using field measurements. Extreme precipitation events were then imposed on the model to determine the extent of flooding along the floodplain.

High or intense precipitation can be defined using Environment Canada's Rainfall Warning Criteria, wherein warnings are issued when 25 mm of rain or more is expected in one hour, when 50 mm or more is expected within 24 hour or 75 mm or more within 48 hours during the summer, or when 25 mm or more is expected within 24 hours during the winter (Environment Canada, 2011). Environment Canada has produced short duration rainfall Intensity-Duration-Frequency (IDF) curves for selected areas in Canada.

## 2.3 Intensity-Duration-Frequency (IDF) Curves

An Intensity-Duration-Frequency curve (IDF Curve) is a graphical representation of the probability that a given average rainfall intensity will occur. The IDF curves produced by Environment Canada are from an extreme value statistical analysis of at least ten years of rate-of-rainfall observations. It includes the frequency of extreme rainfall rates and amounts corresponding to the following durations: 5, 10, 15, 30 and 60 minutes, and 2, 6, 12, and 24 hours. Return periods are used as the measure of frequency of occurrence and are expressed in years. Estimates of the rates and amounts for the durations noted above and their confidence intervals for the rates are provided for return periods of 2, 5, 10, 25, 50 and 100 years.

More information on IDFs can be found here:

ftp://ftp.tor.ec.gc.ca/Pub/Engineering_Climate_Dataset/IDF/Whats_New_EC_IDF.pdf

Unfortunately there are no IDF curves calculated for Environment Canada weather stations within Cumberland County, the closest representative IDF curves for the county are Truro (Bay of Fundy region) and Caribou Point, Pictou County (east along the Northumberland Strait).

http://climate.weather.gc.ca/prods_servs/engineering_e.html

Quantile-Quantile graphs plot the empirical probability of each of the annual maximum observations vs. the probability calculated for each observation from the fitted extreme value distribution. These graphs are useful in assessing the fit of the extreme value distribution to the observations and identifying statistical outliers. The Quantile-Quantile plot for the annual maximum observations and the extreme value model shows a good fit for Truro (Figure 16).

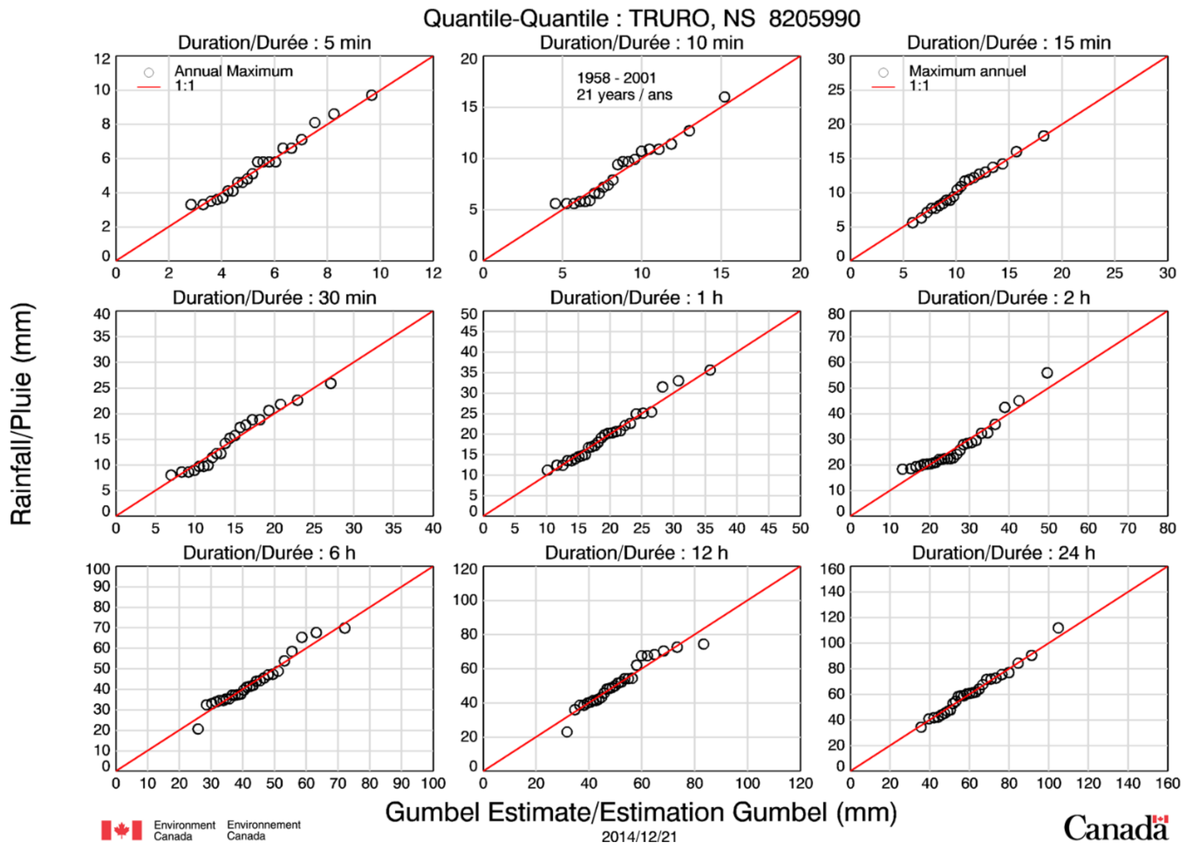



*Figure 16 Truro extreme annual maximum rainfall plots for durations: 5 min to 24 hrs (source Environment Canada).*

The Return Level graph for each rainfall duration plots the fitted extreme value (Gumbel) distribution and the corresponding confidence interval with the corresponding annual maximum observations (Figure 17). These graphs are useful to estimate rainfall amounts for return periods other than those presented in the standard IDF curve file. The graphs are also useful to visually identify statistical outliers, and assess both the fit of the extreme value distribution to the observations and the level of uncertainty from the confidence intervals

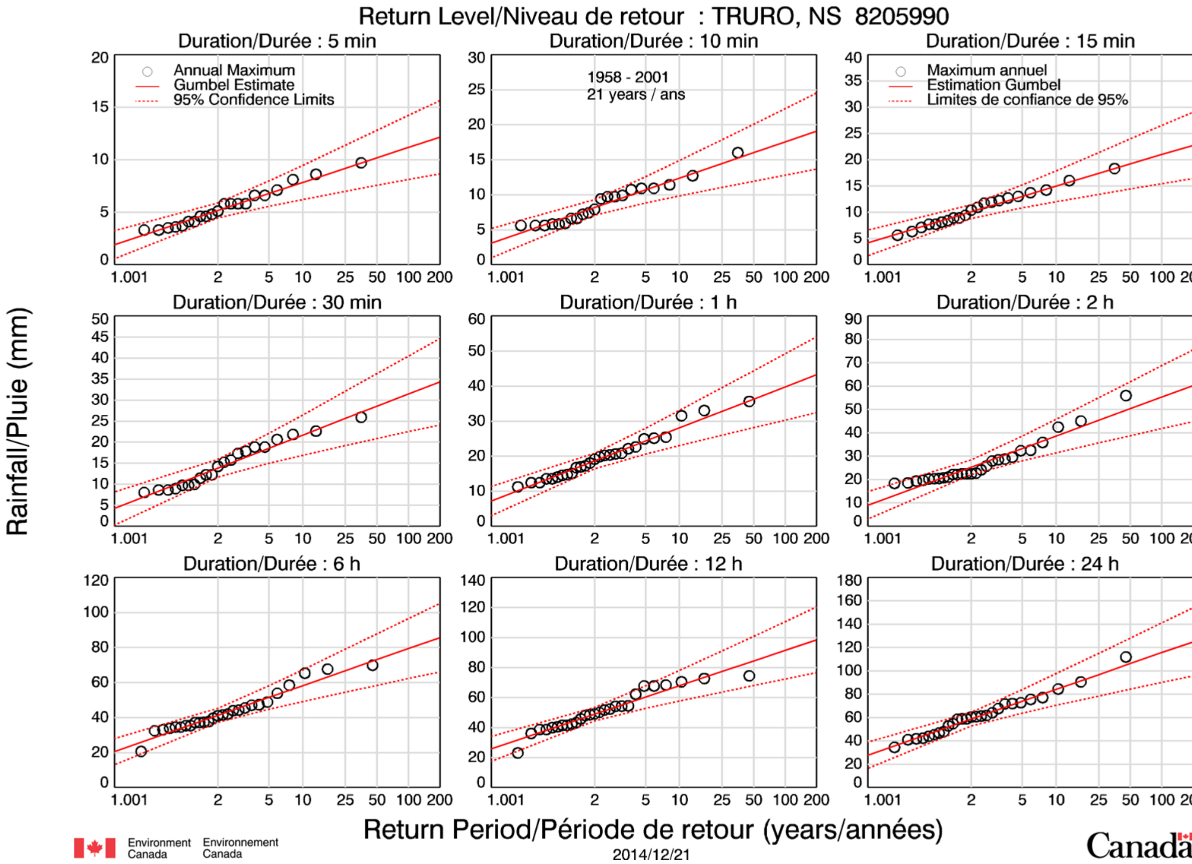



*Figure 17 Return period estimates from extreme value analysis for rainfall intensity and durations from 5 min to 24 hrs (source Environment Canada).*

Rainfall Intensity (mm/hr), Rainfall Duration (how many hours it rained at that intensity) and Rainfall Frequency (how often that rain storm repeats itself) are the parameters that make up the axes of the graph of IDF curves. An IDF curve is created from the extreme value model which is derived from the long term rainfall records collected at a rainfall monitoring station. Rainfall intensity in the IDF Curve is the average rainfall depth that falls per specific time duration.

The nearly parallel lines on the IDF Curve represent probability, or frequency. The 10-year Return Period line would represent rainfall events that have a probability of occurring once every 10 years. Another way to put it is that the probability of a 10-year magnitude storm (or greater) occurring in any given year is 1/10 or 10%, and of a 50-year storm occurring 1/50 or 2%. Each plotted line on the graph represents rainfall events with the same probability of occurrence, in a range of durations (durations are shown on the x-axis). A 10-year storm can therefore be of any duration - a 10-year 30-min storm, a 10-year 2-hour storm or a 10-year 12-hour storm (Figure 18).

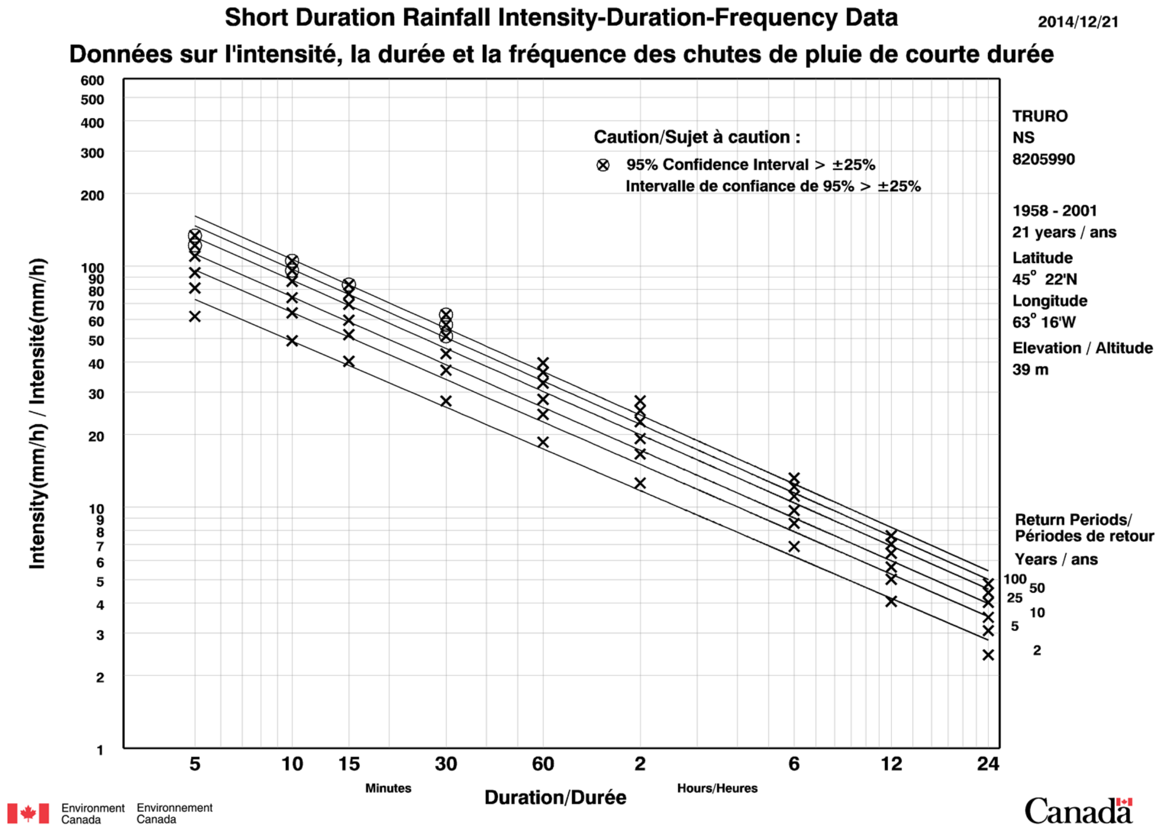



*Figure 18 IDF curves for Truro for return periods 2, 5, 10, 25, 50 and 100 year events (source Environment Canada).*

Similar plots are available for Caribou, NS along the Northumberland Strait. Figure 19 shows the observed annual maximum rainfall (open circles) compared to the extreme value model using the Gumbel distribution to fit the data. Note the return period (x-axis) is on a logarithmic scale for the model (straight solid line bounded by curved confidence intervals of 5 and 95%) to be represented as a straight line to predict the rainfall amounts (y-axis) (Figure 20Figure 19). This type of plot is similar to the extreme value analysis conducted by Bernier (2005) for various tide gauges in the region to calculate the return periods of storm surges. Webster et al. (2012, c) did a similar analysis using the Gumbel distribution for the extreme value analysis of the total water level observed tide gauges to calculate return periods of high water events for the five communities surveyed by lidar and flood risk maps constructed.

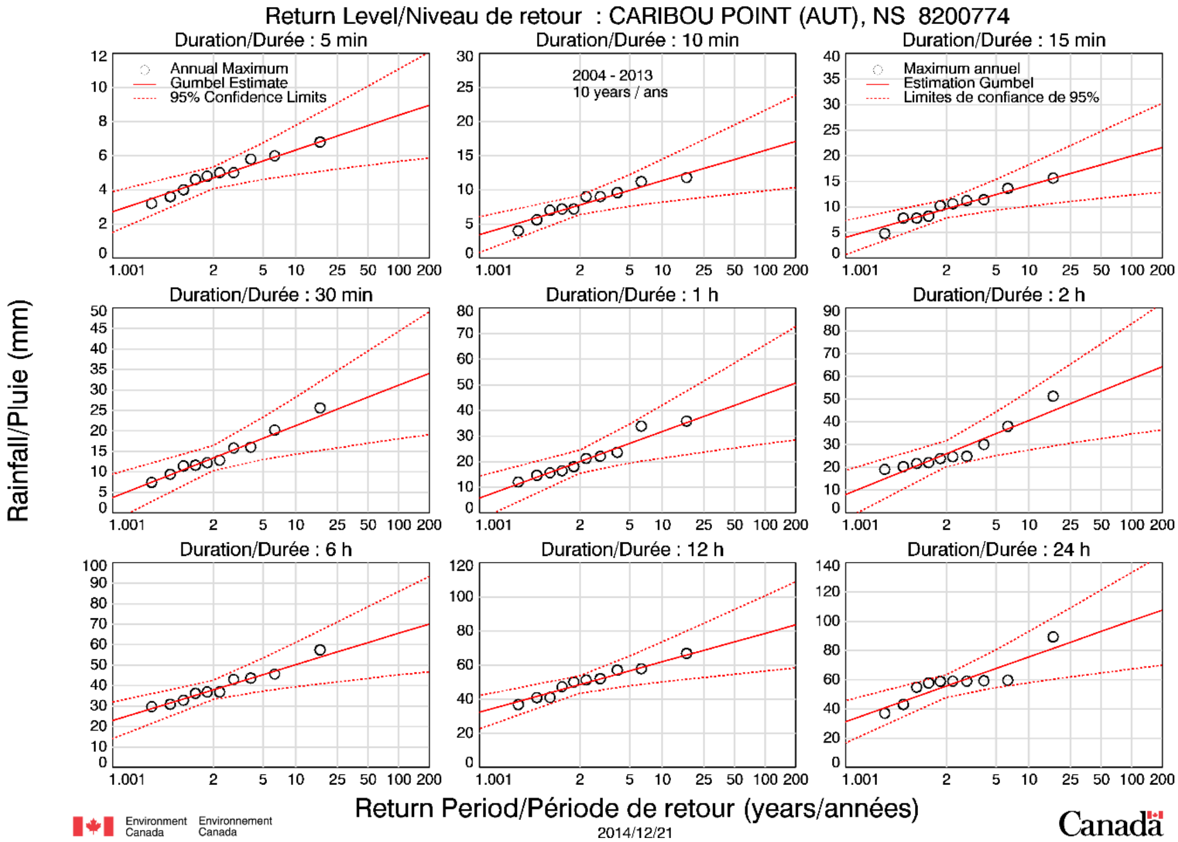



*Figure 19 Return period estimates from extreme value analysis for rainfall intensity and durations from 5 min to 24 hrs (source Environment Canada).*

The IDF curves for Caribou Point appear to have a slight arc (Figure 20) compared to those of Truro (Figure 18). The IDF curve is plotted on a log-log scale with the x-axis representing duration of rainfall and the y-axis representing the intensity of rainfall or rate in mm/hr.

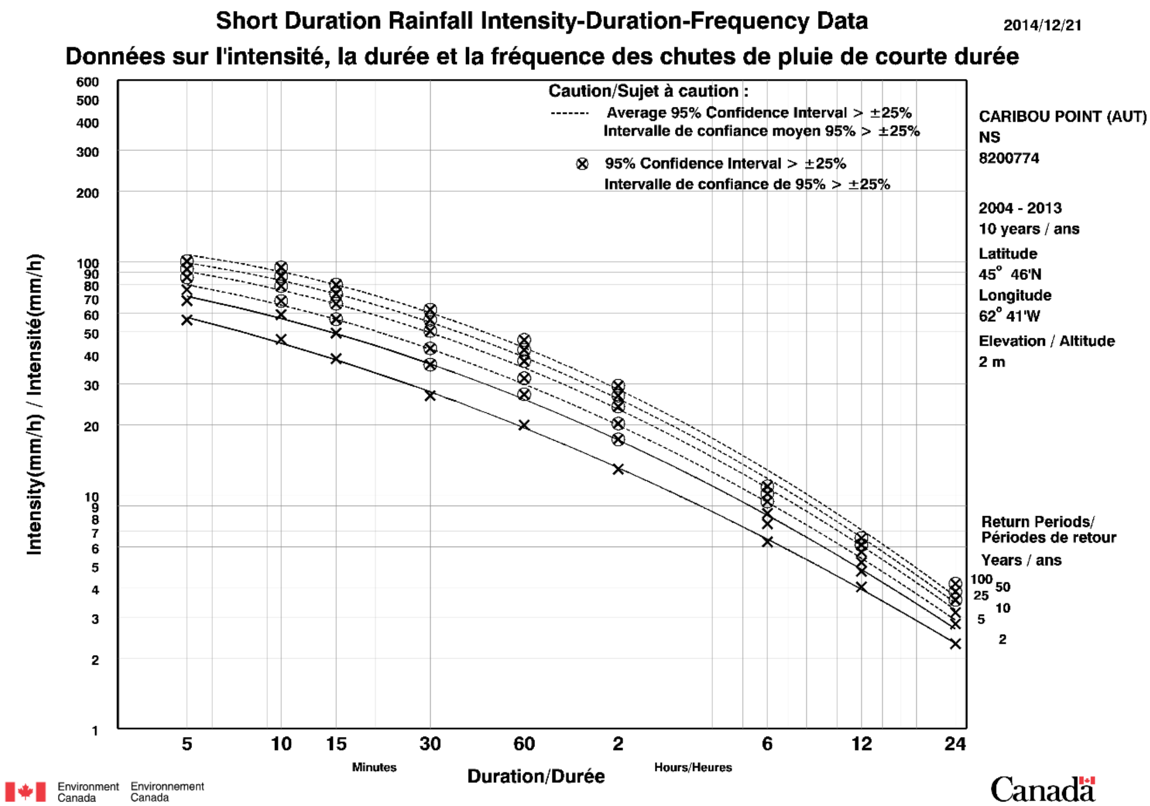



*Figure 20 IDF curve for caribou Point, NS for return periods 2, 5, 10, 25, 50 and 100 year events (source Environment Canada).*

The information derived from an IDF curve is specific for that site where the weather station observations were made. Although engineers have used these IDF curves to design structures to pass water, for example culverts and bridges. The IDF curve does not describe the hydrology of a watershed, which involves both precipitation and evapotranspiration, but also the permeability of the soils, the relief, landcover and other factors that influence how that precipitation is routed through the watershed.

It is very challenging and data intensive to predict the return period of river or fluvial flooding events and map the associated floodplain extents as highlighted in this report. The permeability of the land affects the ability of the land to absorb water and contributes to the severity of a fluvial flood. Frozen or saturated land could have temporary low permeability, while developed land or rocks such as shale and unfractured granite have permanently low permeability. Land cover such as pavement, ditched farmland, and deforested areas contribute to the amount of run-off entering a river, and can worsen the severity of fluvial flooding. Evapotranspiration is the total amount of moisture removed from the drainage basin by evaporation and plant transpiration. Researchers at the NSCC have constructed an impervious surface layer maps that can be downloaded at:

http://agrg.cogs.nscc.ca/data_for_download/impervious_surfaces_nova_scotia

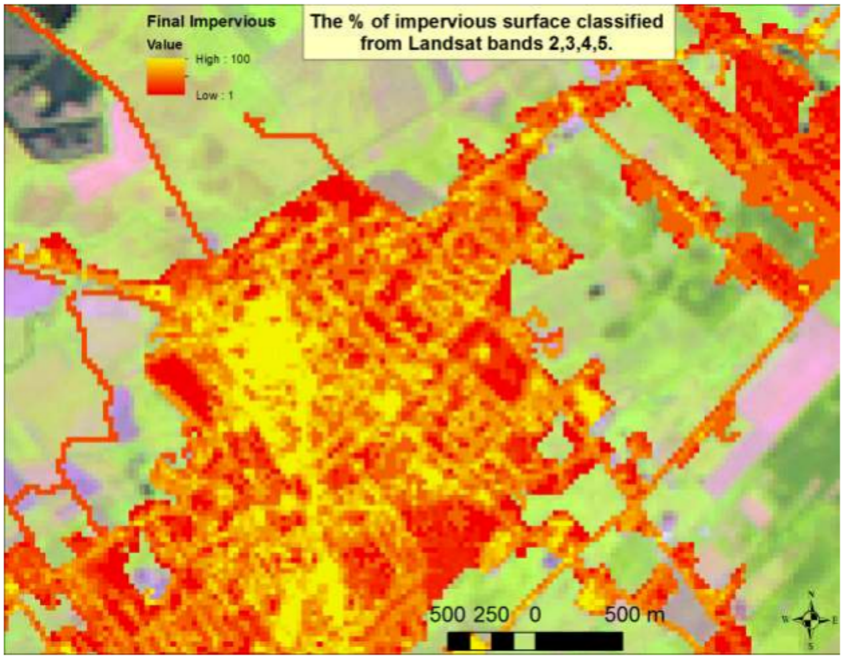


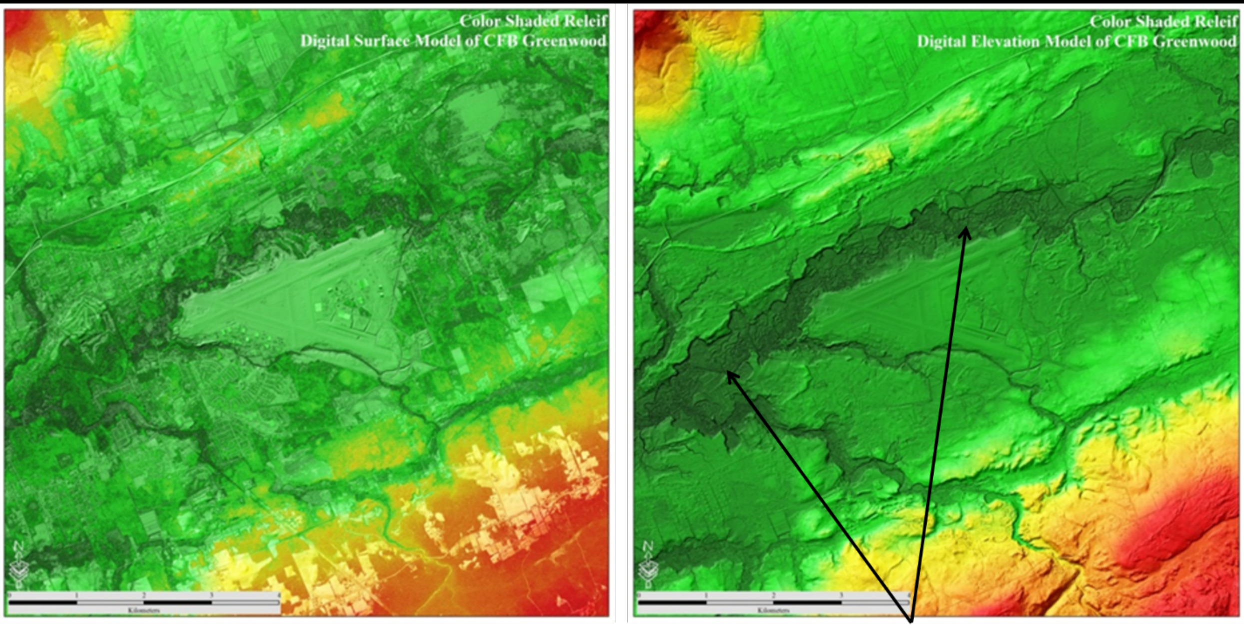

*Figure 21 Example of the percent impervious material near Amherst (source AGRG-NSCC).*

# 3. An alternative approach to Floodplain Mapping

The floodplain is an area of land adjacent to a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge. It includes the floodway, which consists of the stream channel and adjacent areas that actively carry flood flows downstream, and the flood fringe, which are areas inundated by the flood, but which do not experience a strong current. The floodplain is an area near a river or a stream which floods when the water level reaches flood stage.

## 3.1 The "Geomorphic Floodplain" defined in the Kings 2050 study

Kings County, NS had a map representing the floodplain that was manually derived by approximately adding 1 m to the elevation of the bank of the river and plotting that extent (D. Poole, per. Comm.). For their Kings 2050 project, the county was interested in refining this information and utilizing lidar elevation data acquired by the Applied Geomatics Research Group, NSCC that now covers the entire Annapolis Valley. The county did not have the budget to conduct rigorous flood risk mapping studies for all the major watersheds and tributaries in the county of which most of them are not gauged and limited data exists regarding their hydrological characteristics. A river has a distinct gradient in elevation, which facilitates its flow from the headwaters to the ocean. This gradient must be accounted for when calculating the floodplain extent once the water level exceeds the river channel. When examining a lidar DEM of the river system, the "geomorphic floodplain" is often visible as a low relief area of land adjacent to the river (Figure 22). This low relief area adjacent to the river channel is a result of years of the river spilling over its channel banks and through a process of erosion and deposition forming the land into a natural floodplain. Researchers at AGRG-NSCC conducted a research project with Kings County to develop a method to delineate geomorphic foodplains for the major tributaries in Kings County (Webster et al., 2012, d). The geomorphic floodplain is a region surrounding the river that has flooded in the past and will flood again, given a high river discharge event, but does not have specific return period times associated with them.




**Example of lidar elevation of the Annapolis and Fales rivers with trees**

**With trees removed, the geomorphic flood plain is visible**

*Figure 22Left map is an example of a lidar digital surface model (contains trees) of the Annapolis and Fales River. Right map is a lidar DEM that reveals the extent of the geomorphic floodplain for the Annapolis and Fales River.*

A suitable approach to determine maximum water for floodplain delineation was developed in the GIS environment that follows a similar methodology as is implemented with the DHI Mike 11 1-dimension river model. In this GIS method to delineate the geomorphic floodplain, each river system was processed individually to calculate the floodplain. Riverbed levels were first determined from the intersection of river cross-sections, and river reach lines were derived. Maximum and minimum bed levels for each river dataset were then used to determine a logarithmic function such that the highest river bed level was assigned a water depth of 0 m (dry) and the lowest bed level (the river mouth) could be assigned a water depth of some value input determined by inspecting the DEM (Webster et al., 2012, d). All other river bed values where then assigned a suitable water depth based on the derived stretch function (Figure 23).

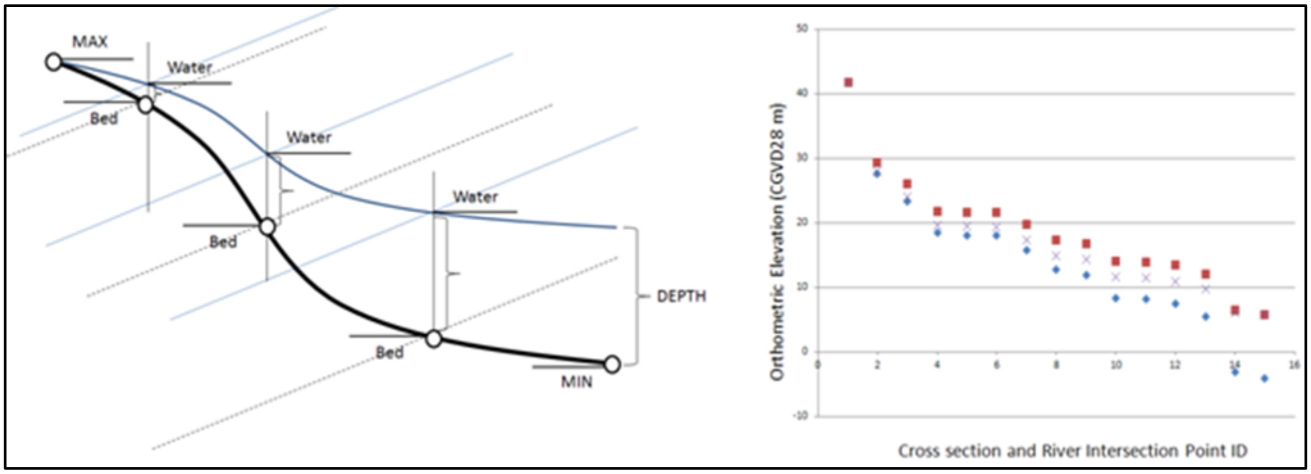



*Figure 23 Left image is an example of the longitudinal profile of the riverbed and water elevation used in this method. Right graph shows the actual elevation data used derived from the lidar DEM (from Webster et al., 2012, d).*

The water depths at each intersection point were converted to water levels (CGVD28), interpolated between river cross-sections and intersected with the hydrologically prepared DEM to produce cohesive floodplain polygons. Webster et al. (2012, d) then compared the results using this GIS based method of floodplain delineation to the floodplain output to that of Mike 11 model where large discharge values were input. The validity of any floodplain derived using the GIS method depends heavily upon the input depth of the outlet (minimum bed elevation). Overall, the accuracy of the GIS approach was deemed quite good with regard to the general adherence spatially to the Mike 11 approach whereby water level maxima were output from the hydrodynamic model with a simulation period of one year (Figure 24). The accuracy of the GIS method does, however, hinge greatly upon the choice of input water depth for the outlet, which must be estimated by the user. This approach, however, does not replace or imitate in any way the hydrodynamic systems ability to model and replicate the flooding effect of a particular storm event but rather delineates the natural geomorphic floodplain.

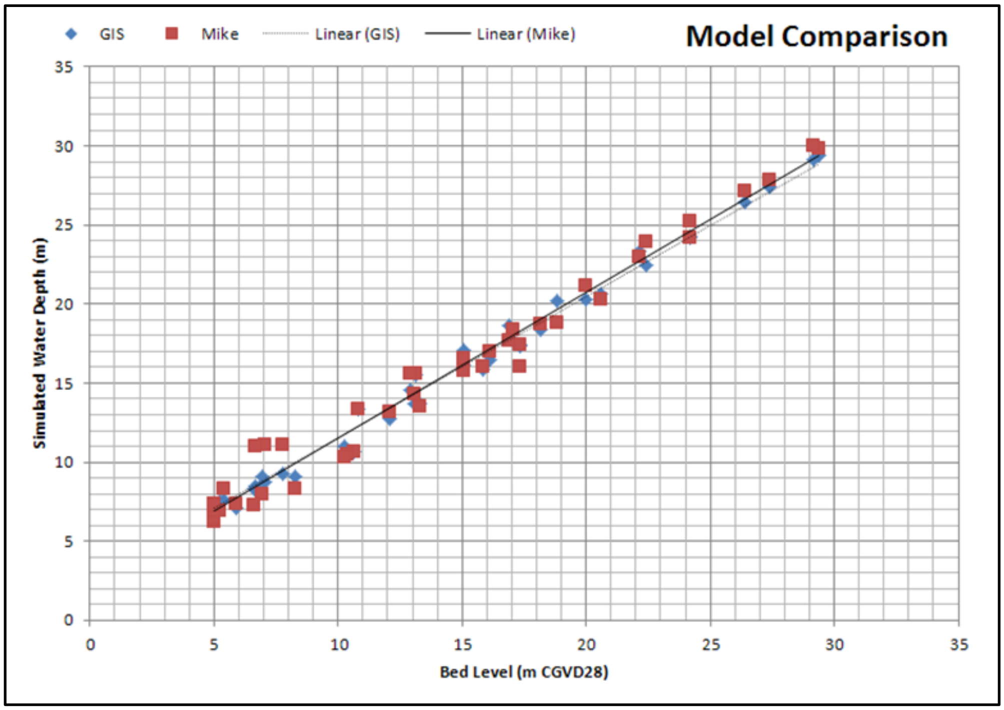



*Figure 24 Comparison of water depths for Kings County rivers using the GIS method and the Mike 11 method (source Webster et al., 2012d).*

The requirement of the floodplain to have accurate elevation data is critical and thus is limited to areas where lidar data are available. The GIS and Mike 11 method both require riverbed elevations to be determined and cross-sections calculated that include the river channel and floodplain elevations. The determination of the riverbed channel can be a challenge and expensive to acquire. The water surface of the river can be used as rough estimate of the river channel and used for a first estimation of the geomorphic floodplain.

Researchers at the AGRG-NSCC were approached to user their GIS-based method to derive the geomorphic floodplain for River Phillip and the Wallace River utilizing available elevation data (lidar and the provincial 20 m DEM). A single vector representing each river and associated tributary was digitized and a water depth of 5 m was assigned to the river mouth for the generation of the geomorphic floodplain. It is this outlet value that the user can modify to control the extent of the floodplain. The River Phillip geomorphic floodplain was calculated utilizing the lidar data collected in 2009 and used in the Webster et al. (2012c) coastal flood risk project merged with the 20 m DEM. Regional cross-sections were derived for the extent of the river. The floodplain is defined by the intersection of the terrain (DEM) with the water level along the cross-section and then the floodplain extent is interpolated between cross-sections using the DEM. Therefore more detail can be defined for a given tributary by increasing the density of cross-sections. The River Phillip geomorphic floodplain highlights the flood prone area near Oxford (Figure 25). The Wallace River watershed does not have lidar data along the river floodplain, so the 20 m DEM was used. The resultant geomorphic floodplain is thus limited by the resolution of the input data (Figure 26).

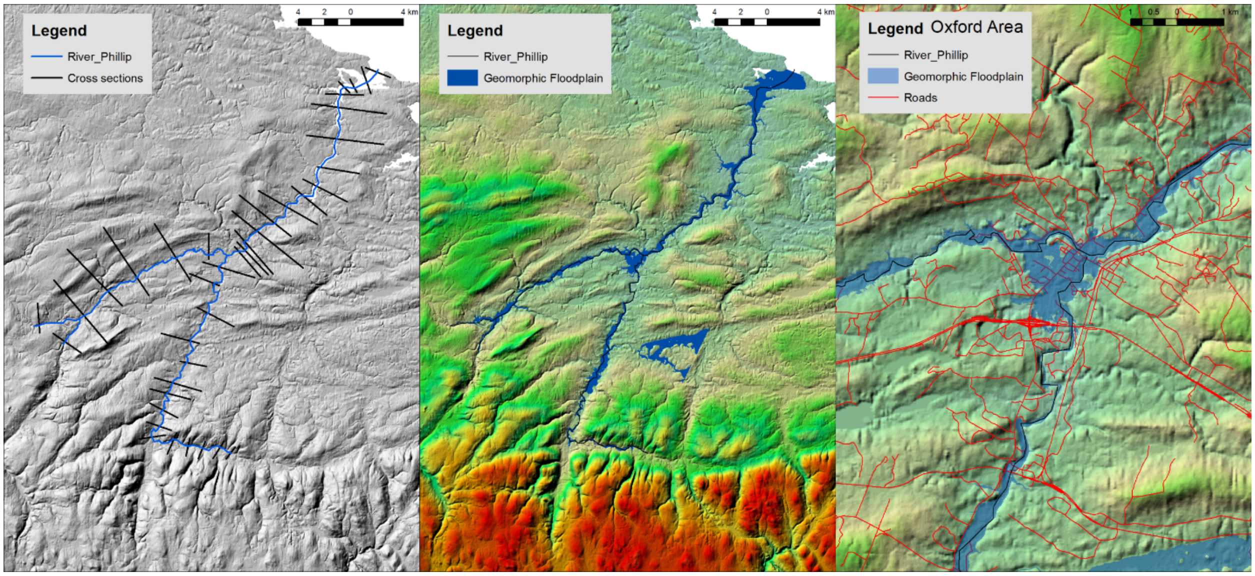



*Figure 25 Left map shows the centre of River Phillip and tributary and cross-sections. Middle map shows the extent of the geomorphic floodplain. The right map shows the floodplain for the Oxford area with roads.*

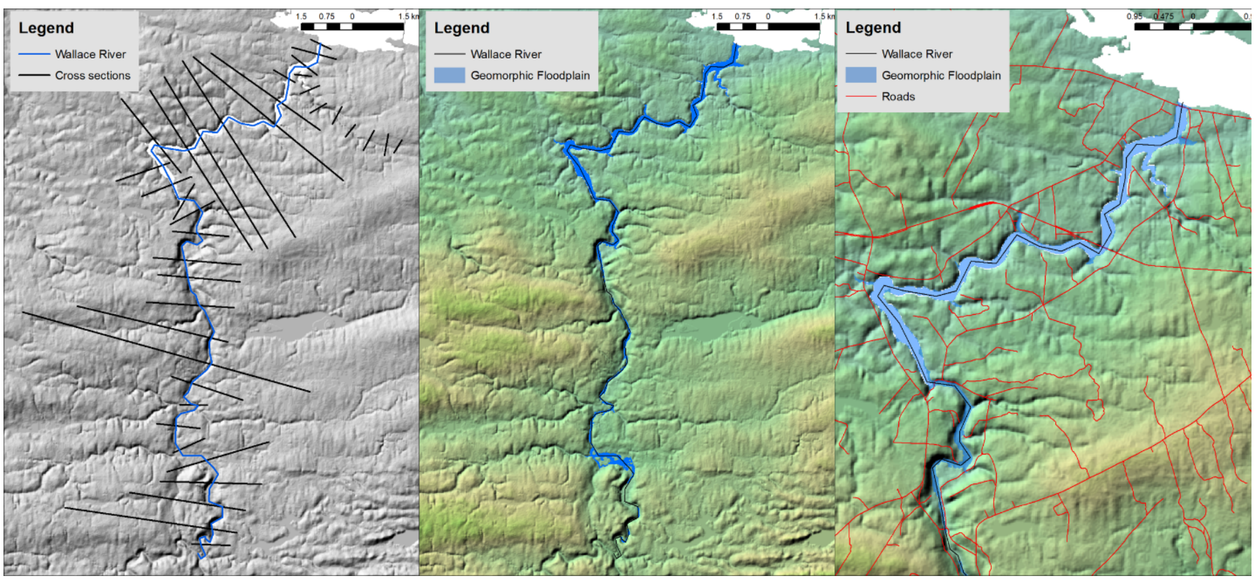



*Figure 26 Left map shows the centre of the Wallace River and cross-sections. Middle map shows the extent of the geomorphic floodplain. The right map shows the floodplain for the Wallace area with roads.*

The extent of the geomorphic floodplain for the area near Oxford was compared to the maximum flood extent derived by Stiff (2008) for the 1999 flood that affected the town of Oxford (Figure 27). In general the geopmorphic floodplain agrees very closely to the maximum extent of Stiff (2008) which simulated the flooding associated with tropical storm Harvey that occurred in Sept. 1999. The geomorphic floodplain has a larger extent than the flood extent from Stiff (2008). This can be controlled by altering the water depth at the mouth of the river when the GIS method is applied. Thus this method appears to produce satisfactory results to define the geomorphic floodplain extent.

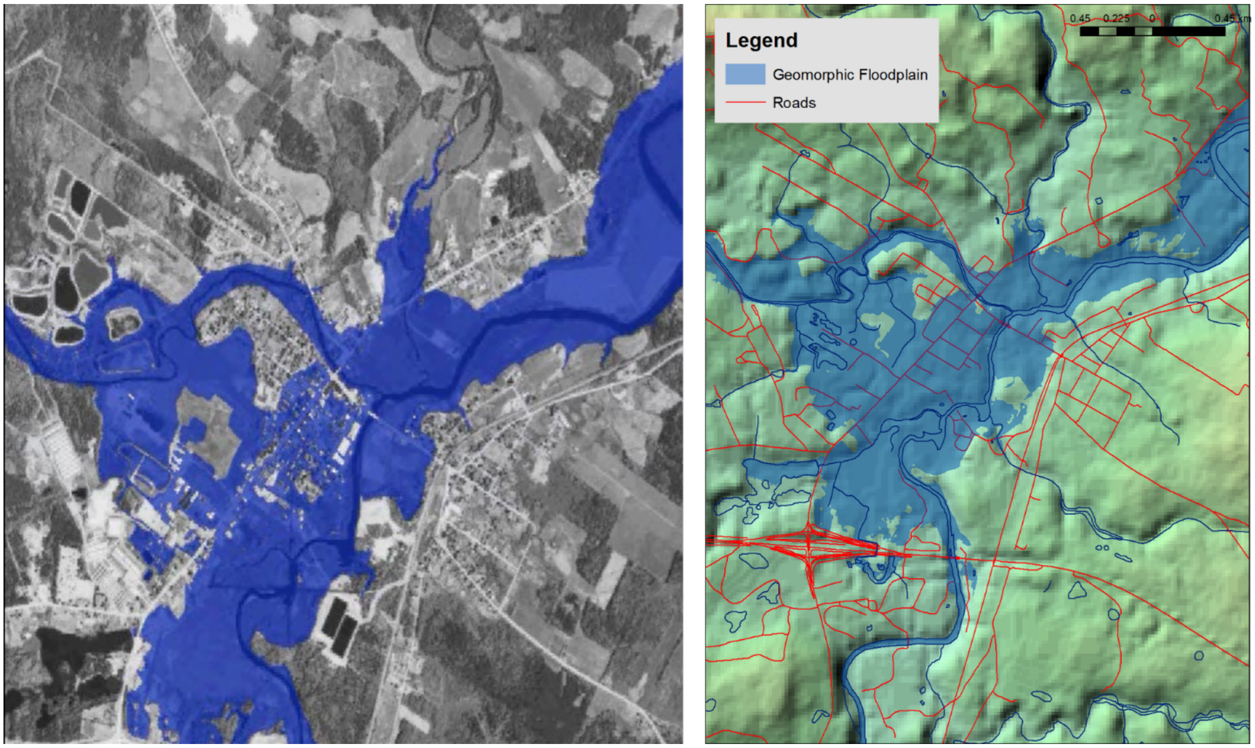



*Figure 27 The left map is the maximum flood extent from Stiff (2008). The right map is the geomorphic floodplain. Maps are not at the same scale.*

## 3.2 Current research in mapping to advance coastal and fluvial flood risk studies

As described earlier in this report, one of the biggest challenges for delineating flood risk areas along the coast, estuaries, and rivers is the ability to survey the bathymetry and river channel geometry. Researchers at AGRG-NSCC  have acquired a topo-bathymetric lidar sensor that can both acquired detailed elevation data on land and also under water. The sensor has two lasers: a near infrared laser for topographic mapping and a green laser for mapping the submerged topography (bathymetry) (Figure 28). The limiting factor for utilizing this technology is water clarity. The sensor specifications indicate it will penetrate 1.5 m times the Secchi disc depth. Researchers at AGRG-NSCC have used the sensor to conduct surveys around the Martitmes since 2014. Topo-bathymetric survey areas in the Northumberland Strait can be challenging because of the high levels of silt that can be stirred up from wave action and degrade the water clarity. In general, depths achieved with the sensor along the strait have varied between 6 m and 9 m. The speed of light in water is not significantly influenced by temperate and salinity like the speed of sound is with echosounders. Because of this, this sensor is ideal for surveying estuaries with mixed salt and fresh water and river channels. AGRG-NSCC is in the midst of an NSERC funded research project with CBCL Consulting "Evaluating a topo-bathymetric lidar sensor to map river channels for improved hydrodynamic flood risk mapping" where they used the sensor to survey Rights River in Antigonish County.

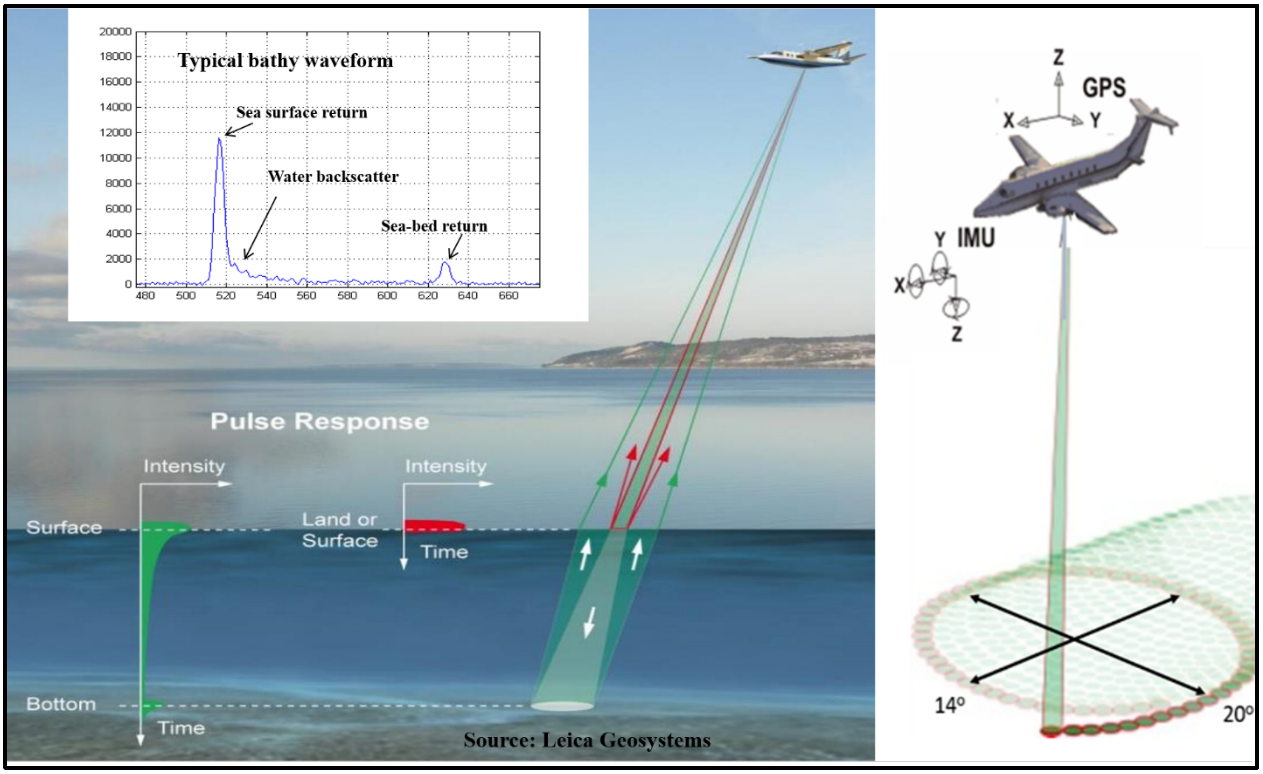



*Figure 28 Schematic of the Chiroptera II topo-bathymetric lidar sensor. it is equipped with two lasers: a NIR and green laser that scan in elliptical pattern.*

In July of 2016 AGRG-NSCC surveyed the River-Phillip and Pugwash areas including the outer harbor area and up the river channels. The system did not obtain depths for the main channel that were greater than 6 m depth, but did obtain complete coverage of the seabed and land to build a seamless DEM (Figure 29). These deeper channels can be surveyed safely with a boat using echosounding technology.

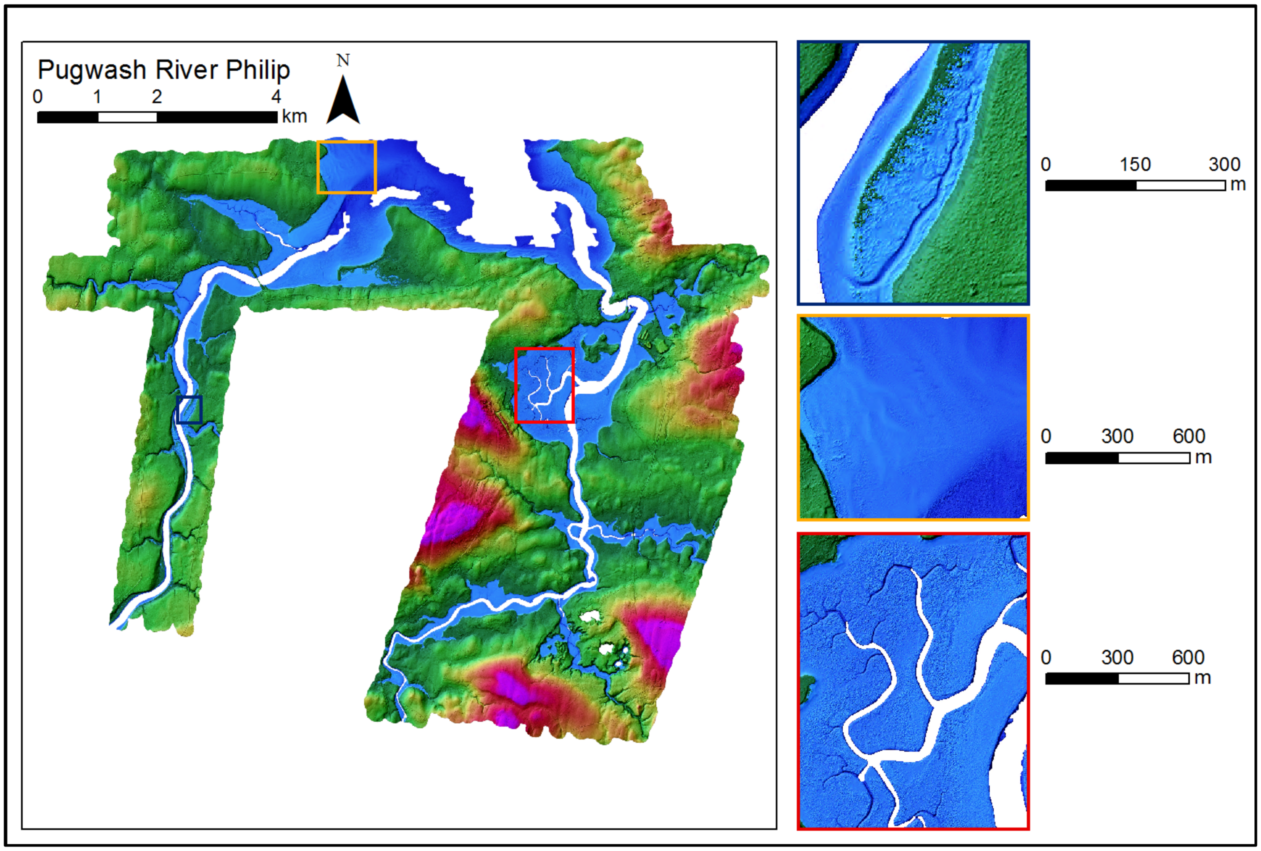



*Figure 29 Example of seamless DEM collected by the NSCC topo-bathymetric lidar for River Phillip & Pugwash River (source AGRG-NSCC, 2016).*

The areas where the topo-bathymetric lidar sensor did not penetrate to the seabed where infilled using a combination of chart soundings and previous depth soundings using an echosounder (Webster et al. 2012, a). A coastal hydrodynamic model was constructed from the seamless DEM and sampled up from 1 m to 3 and 9 m for modelling purposes (Figure 30). This type of sensor could be used to acquire a seamless DEM of the river channel and floodplain for the major rivers in Cumberland County to facilitate floodplain and flood risk mapping studies. Webster et al. (2016a, b) have recently reported details of the topo-bathymetric lidar and coastal mapping applications.

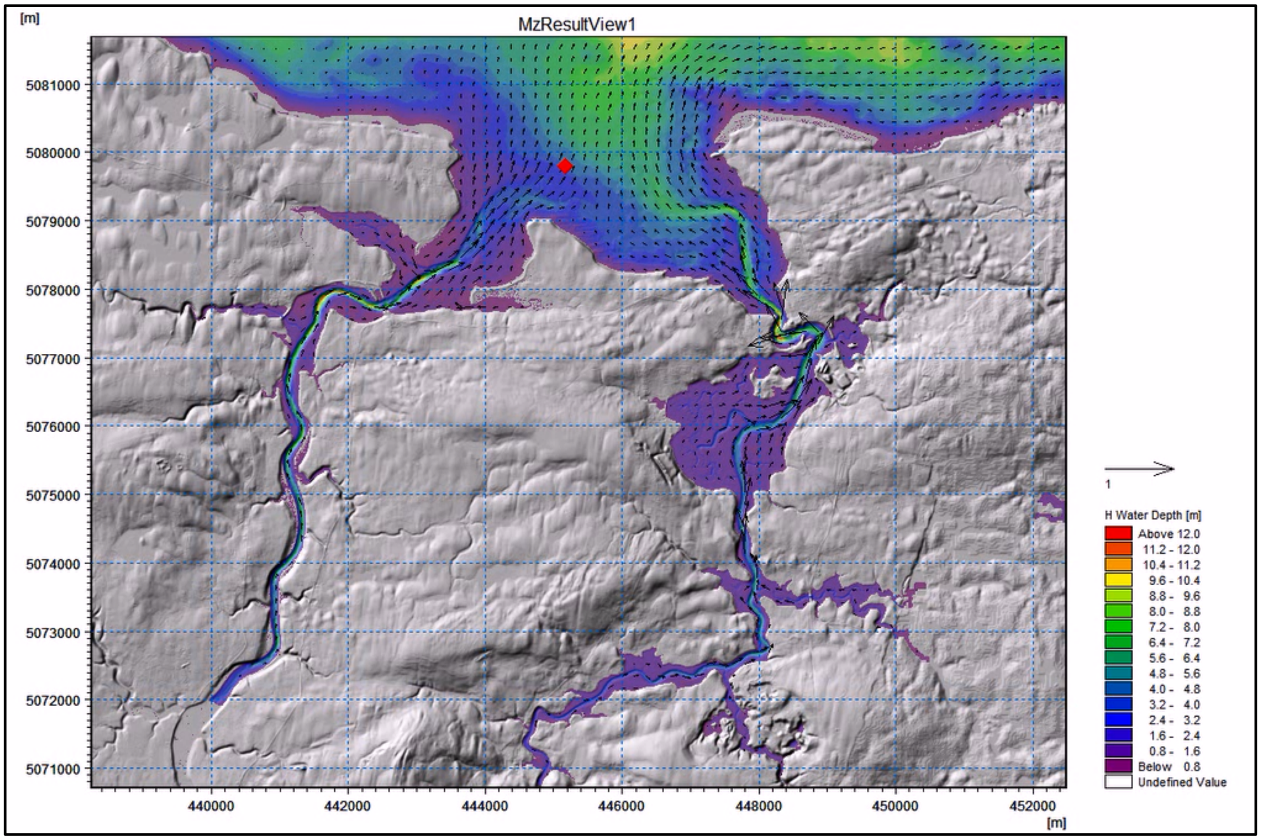



*Figure 30 Example of seamless DEM used to build a hydrodynamic model of the River Phillip and Pugwash river estuary. The red dot in the centre of the bay indicates where an ADCP was deployed for model validation (source AGRG-NSCC, 2016).*

## 4. Summary

The Municipal Planning Strategy is to cover coastal vulnerability to storm surges and rising sea levels, Inland flooding. Although not reported here, I have prepared and delivered a power point presentation documenting the storm damage associated with the Dec. 21, 2010 storm surge along the Northumberland Strait in Cumberland County. This included flooding extent, survey grade GPS elevations of the high water line, oblique air photos depicting the flooding, erosion, and ground photos from field visits. In this report I have reviewed what studies exist that have examined inland flooding in the county. Given the county is boardered to the north by the Northumberland Strait and to the south by the Bay of Fundy, most inland rivers drain to the coast and their discharge is strongly effected by a tidal influence. Therefore, most major rivers that are the focus of a flood risk mapping or floodplain delineation study must take into account the tidal influence and interaction. In addition to reviewing past studies, I have highlighted what data exists in the form of primary, secondary and tertiary watersheds from GeoNova. As well, I have documented and presented what data exists on the hydrology of some of the major river systems in the county. The Water Survey of Canada has historic water flows for a few rivers based on past hydrometric stations. These data have been downloaded and presented in this report. NS Environment has partnered with the Water Survey of Canada and has installed real-time water level gauges, from which flow can be inferred. The only real-time gauge in the county is located at Kelley's River presently. It is recommended in this report that NS Environment be approached about installing a similar gauge on River Phillip upstream of the town of Oxford, especially given the flood history of that region. In addition to direct measurements of river flows, engineers and scientists have made use of weather information to estimate the possible return period of significant storm events that may have caused flooding. In this regard, Environment Canada has generated IDF curves from some of their weather stations with long time-series of data. The IDF curves predict the return period of precipitation events of a certain duration and intensity. Although no IDF curves have been calculated for any sites within Cumberland County, representative IDF curves from Truro (Bay of Fundy) and Caribou Point (Northumberland Strait) have been presented in this report.

Lastly, an alternative approach to floodplain mapping is presented based on a study conducted by NSCC researchers for Kings County as part of their Kings 2050 vision. As with many municipalities, Kings County did not have the financial resources to instrument and conduct detailed flood risk studies for the many rivers they were interested in. A “geomorphic floodplain” was defined that represented a natural floodplain that forms adjacent to the river channel through years of it overtopping its banks. Although this floodplain does not have a specific return period time associated with it when it could flood, it highlights areas that are prone to flooding from excess precipitation events or snowmelt. NSCC researchers compared this GIS based method for floodplain delineation with that derived from using a 1-dimension hydrodynamic model (Mike-11) and found very good agreement. The accuracy of the floodplain extent is a function of the elevation data used, therefore most accurate results are obtained in areas where lidar elevations are available. A new lidar technology is available in the region in the form of a topo-bathymetric lidar sensor that is capable of surveying the topography and river channel simultaneously. This type of sensor allows a seamless DEM to be constructed that represents both the floodplain and the river channel and will facilitate further hydrologic modelling and better understanding the watershed and drainage characteristics of the rivers within the county.

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