

# Integrated River and Coastal Hydrodynamic Flood Risk Mapping of the LaHave River Estuary and Town of Bridgewater



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## **Executive Summary**

Like so many other towns in Nova Scotia, Bridgewater is located along a major river where the tide from the Atlantic Ocean can influence the water level. The combined effects of river runoff and a storm surge on top of high tide possibly put Bridgewater at risk of flooding. Projections from climate change will make the risk of flooding in the future worse with increased sea-level rise (SLR) and possible increased river runoff. Past flooding events of the town and the LaHave River were part of the background research and documented in this report. A set of river and ocean water level simulations were carried out to determine the risk of flooding to the Town of Bridgewater today and in the future under climate change. Fieldwork to support these modeling efforts included installing water level sensors at the Marine Terminal Wharf in the town and at Kraut Point near the mouth of the LaHave River, and conducting bathymetric surveys and river cross-sections to be integrated with a high-resolution elevation model derived from a lidar survey. Environment Canada measurements of flow-discharge of the LaHave River upstream of the town date back to 1913 and were analyzed to calculate the return period of specific flood events, such as March 31, 2003, and the 50 year and 100 year return periods of flood events. The flows associated with these return periods were used to define the river discharge boundary at the upstream section of the river and a tidal boundary was established near the mouth of the LaHave River for the modeling. The tidal boundary used for the modeling consisted of a normal annual high tide as well as the simulation of a 2.2 m and 3.5 m storm surge event to include SLR in the future.

The results of the various flood risk simulations indicate that the area upstream of the Veteran's Memorial Bridge is vulnerable to flooding from large discharge events of the LaHave River. However, the downtown waterfront does not appear to be susceptible to flooding from significant discharge events. This is probably a result of the deeper river channel in this area. However, the modeling does suggest that the downtown area is vulnerable to SLR and storm surge flooding. Based on the simulations, areas such as the Bridgewater Mall parking lot, the Marine Terminal and sections of LaHave Street and Shipyards Landing Park become inundated under a 2.2 m storm surge generated at the mouth of the LaHave River. When the storm surge level is increased to 3.5 m, the flood extent expands to cover the parking lot of the Bridgewater Mall up to LaHave Street and inundates Old Bridge Street and Davison Drive. The flooding extends from overtopping the Marine Terminal Wharf to inundating LaHave Street and Route 3 either side of the terminal. Flooding covers a larger section of LaHave Street upstream of the Veteran's Memorial Bridge including lower Elm Street. Flooding at Shipyards Landing Park along the waterfront expands to cross King Street and the lower section of School Street. The area surrounding the southwest side of Veteran's Memorial Bridge begins to flood under these storm surge or SLR conditions condition. The model suggests that floodwater west of Old Bridge Street appears to get trapped and does not easily drain back into the river once the storm surge levels subside while the mall parking lot is able to drain back into the river quickly. The risk of such events (2.2 and 3.5 m storm surge) occurring today are low, although a 4 m storm surge was associated with Hurricane Sandy in New Jersey in 2012, and with increased SLR ranging from present conditions of 0.32 m/century to projections of 1.56 m/century by 2100 coupled with possible increased storm intensity, the risks will increase over time of such an event occurring. Other areas of the town at risk of local flooding after extreme rainfall events include Wile Brook and Hebb Brook which were also modeled in this study.

Aerial photos dating from 2009 to 1948 were used to measure the coastline position and determine areas of erosion. The results indicate the downtown waterfront area does not appear to be vulnerable to erosion, although upstream of Veteran's Memorial Bridge do show areas with higher erosion rates.

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## **1. Introduction**

The Town of Bridgewater, Nova Scotia, is built along the banks of the LaHave River, about 20 km from where the river meets the Atlantic Ocean. Like many coastal communities, Bridgewater is vulnerable to flooding from storm surge and sea-level rise. In addition, heavy rainfall and spring melt water can cause the LaHave River to flood, potentially putting Bridgewater and the surrounding communities at additional risk.

This study has been conducted for the Town of Bridgewater to determine the risk of flooding from the LaHave River as well as some small streams which drain through the town. Similar studies of flood risk for communities located along major estuaries have been conducted as part of the Atlantic Climate Change Adaptation Solutions (ACAS) project by the Applied Geomatics Research Group for the Nappan River near Amherst, NS, and River Phillip at Oxford, NS. Like the previous two studies, the flood risk analysis of the LaHave River incorporates high-resolution lidar elevation data, bathymetric river data, and river cross-section information. These data are merged to generate a seamless digital elevation model which is used, along with tidal elevation data to incorporate the influence of the tide, to run an integrated one and two-dimensional hydrodynamic model to produce flood risk predictions for the Town of Bridgewater.

### **1.1. Study Area**

The LaHave River watershed covers 1686 km<sup>2</sup>, extending from Riverport at the coast to the south side of South Mountain in the Annapolis Valley (Figure 1:1). The watershed contains a mix of land use, including industrial and residential within the Town of Bridgewater, and shifting to mainly forested and agricultural in the majority of the watershed.

Deforestation can contribute to flooding caused by excess runoff, therefore an analysis of satellite images was done to detect land use change in the LaHave River watershed over the past several years. The difference between a pair of multi-temporal Band 5 Landsat images from June 14, 2004 and August 15, 2009 show the clear cuts during that timeframe (Figure 1:2). Band 5 is the best band to use for this type of analysis because it captures the mid-infrared range of wavelengths and shows a sharp contrast between vegetation and soil, or post-clear cut residue. The satellite analysis is an efficient method to show cleared land over a large area, but can produce falsely detected areas such as cloud cover or lakes.

The orthophotos and true colour satellite images (Figure 1:3) were used to reject any falsely detected areas and to confirm areas detected as clear cut or growth.



Figure 1:1 LaHave River study area showing the watershed boundary, Kraut Point Harbour (location of AGRG tide gauge), Environment Canada river level gauge at West Northfield, and two dams in the watershed: the Morgan Falls Power Station at New Germany, and a private dam on a LaHave River tributary located north of the Town of Bridgewater.

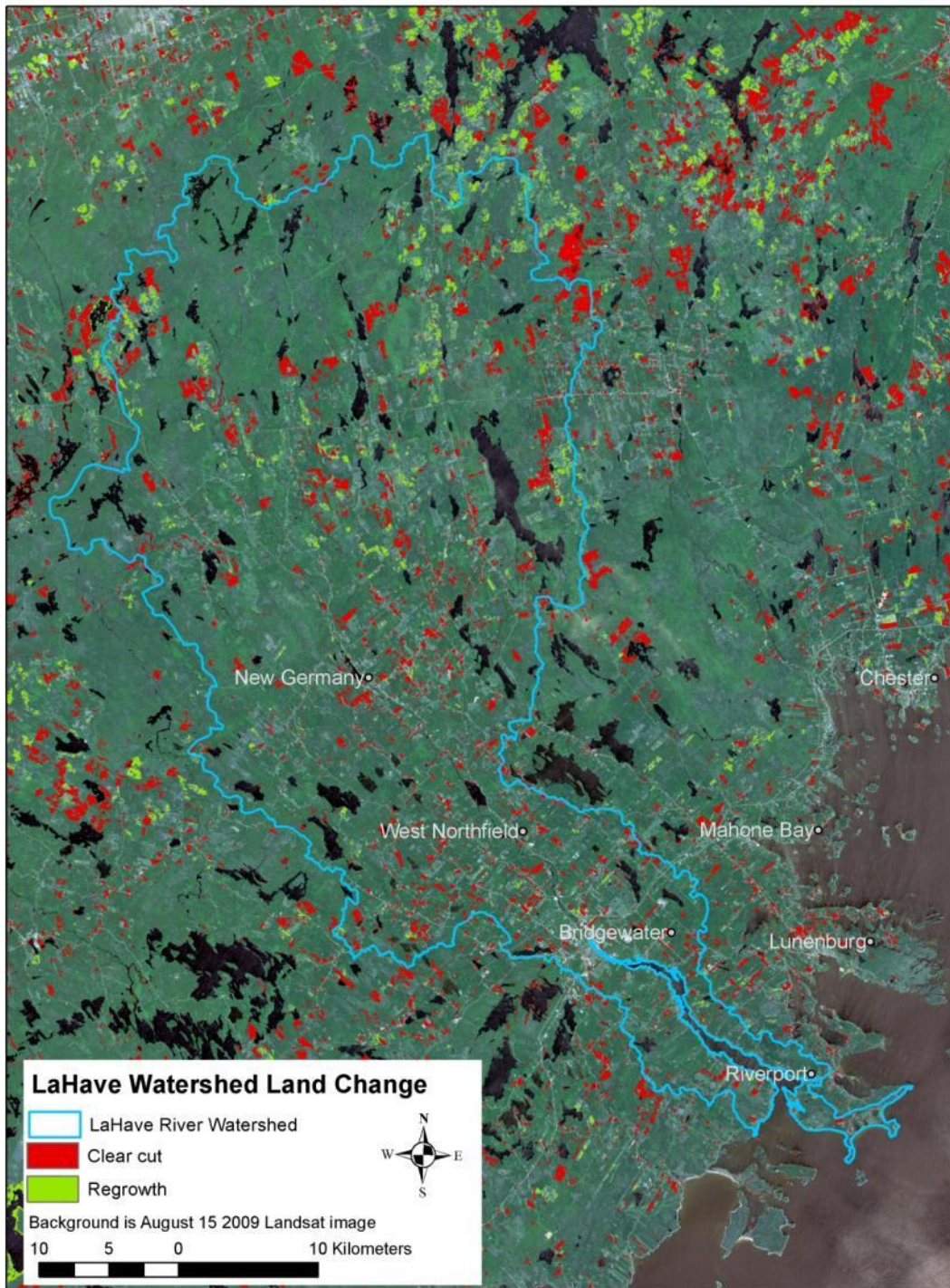


Figure 1:2 Change detection satellite analysis for the LaHave watershed between 2004 and 2009.

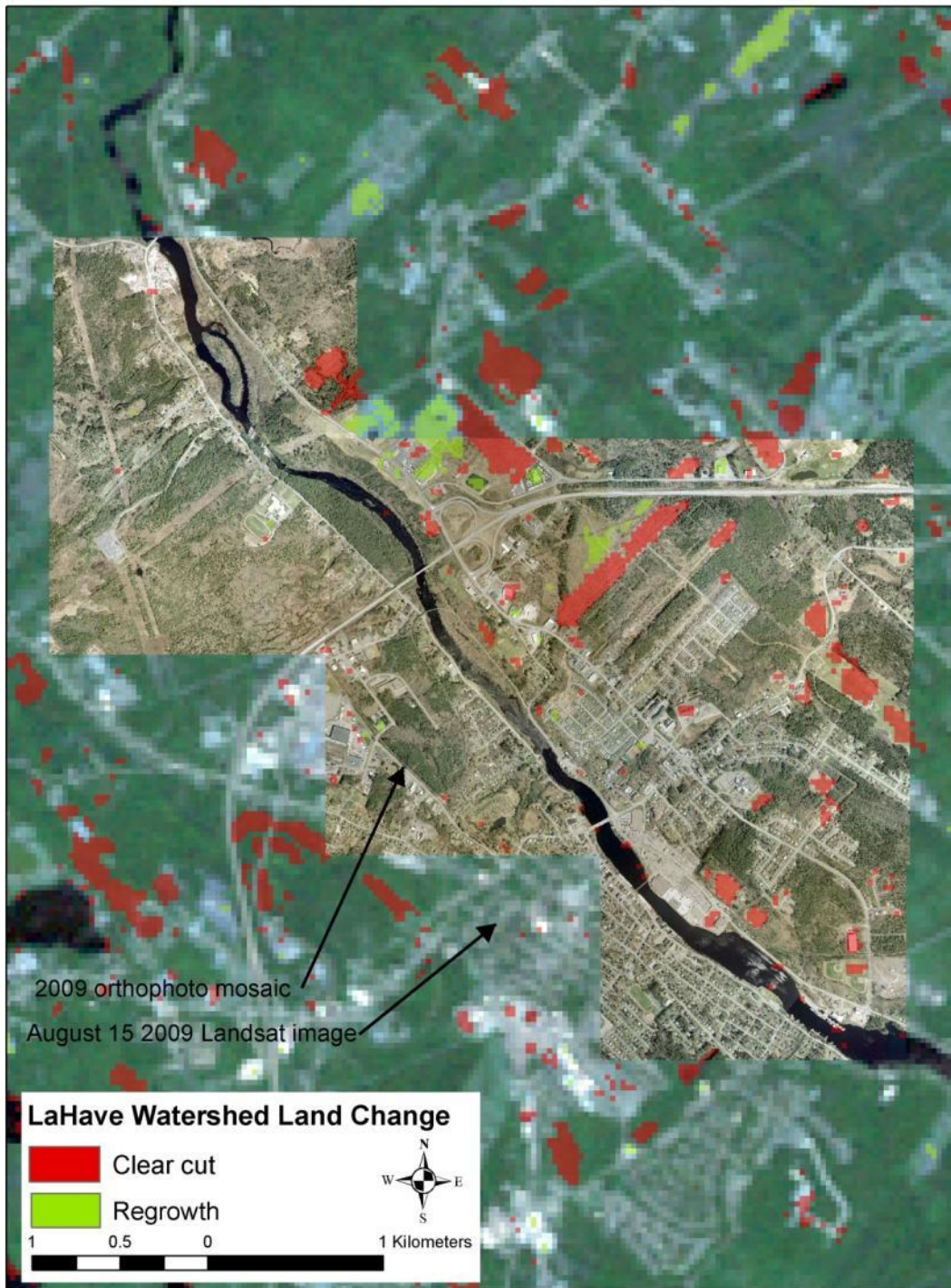


Figure 1:3 Areas of clear cut and regrowth over 2009 orthophoto mosaic and Landsat images.

The South Shore of Nova Scotia is characterized by drumlins composed of grey-brown clay till or red-brown sandy till, and promontories of slate bedrock (NS Museum of Natural History, 2012). Sandy, shale,

and cobble beaches can all be found in the region due to the variable quantity and texture of the coastal sediment supply.

GeoNet Technologies in PEI obtained historical photos of the Bridgewater area from 1948, 1965, 1967, 1992, 2001, and 2009. The ready-orthorectified dataset from 2009 was used as control during the orthorectification process of the remaining photo datasets. In addition, GeoNet Technologies manually created vectors to delineate the coastline of the LaHave River from each set of photos, defining the coastline as the most land-ward influence of the water. An analysis of the change of the coastline was conducted to assess the vulnerability of the coastline to erosion.

## **1.2. Coastal Flooding**

When a high tide coincides with the strong winds and low pressure of a storm, a storm surge can occur and cause coastal flooding. A storm surge is an increase in the ocean water level above what is expected from the normal tidal level that can be predicted from astronomical observations. Tidal range in the Bridgewater area is approximately 2.5 m.

### **1.2.1. Historical Coastal Flooding**

Hurricanes and tropical storms originating in tropical waters can enter Canadian waters and threaten the south shore of Nova Scotia, although often the cooler water offshore Nova Scotia slow a storm's progress, and hurricanes often veer out into the Atlantic before impacting Nova Scotia. The Canadian Hurricane Center (CHC) states that one or two tropical cyclone events (hurricanes or tropical storms) affect Canada per year (CHC, 2012). Although some sources cite that hurricane frequency and intensity are increasing with climate change (The Weather Network, 2011; CBC, 2010), the CHC states that hurricane frequency follows a 25-year cyclical pattern, and we are now in a more active cycle.

The beaches of the South Shore near Bridgewater- Hirtles, Rissers, and Crescent- are regularly battered by tropical storms, Nor'easters and the occasional hurricane. Powerful wind, waves, and storm surges can cause damage to dunes and beach infrastructure, coastal properties and roadways. Hurricane Hortense (1996), Hurricane Juan (2003), post-tropical storm Noel (2007), and Hurricane Bill (2009) caused significant damage to the coast near Bridgewater (Figure 1:4). Bridgewater enjoys some protection from coastal storm surge because it is nearly 20 km inland and because of a sharp bend in the LaHave River near the coast. However, it is not immune to storm surge-induced flooding. A low pressure system brought high winds and heavy rain to the area on October 30, 2011, causing a storm surge that

flooded some areas of downtown Bridgewater (Figure 1:5, Figure 1:6). A 1 m storm surge was measured at the Halifax tide gauge during this event (Figure 1.5).



Figure 1:4 (a) Crescent Beach following Post-Tropical Storm Noel in 2007. Source: <http://hurricane-noel-nova-scotia-damage.blogspot.ca/2007/11/photos-of-dammage-to-crescent-beach-and.html>. (b) Damage at Petite Riviere caused by Hurricane Bill in 2009. Source: [http://www.theweathernetwork.com/your\\_weather/details/786/1442612/bridgewater/hits/1#utmxd=EAAAACD\\_N29-7CmDyYe4sM7ENrk;utmxdpreview=0](http://www.theweathernetwork.com/your_weather/details/786/1442612/bridgewater/hits/1#utmxd=EAAAACD_N29-7CmDyYe4sM7ENrk;utmxdpreview=0).

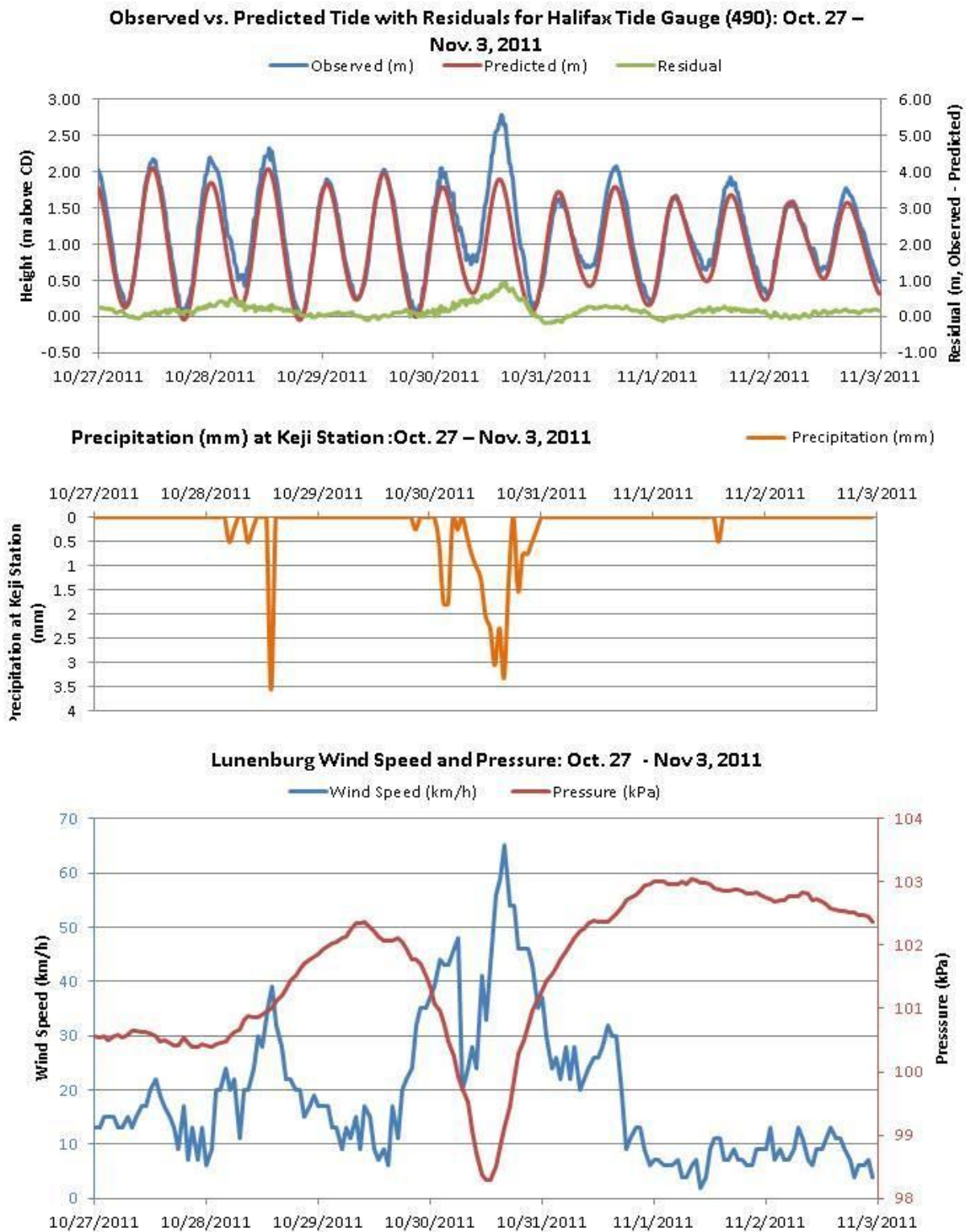


Figure 1:5 Top: Observed and predicted tides for Halifax show a storm surge on October 30, 2011; middle: Hourly precipitation at Kejimkujik, NS shows a peak on October 30; bottom: high winds and low pressure associated with the storm are seen in the Lunenburg, NS, weather station record, courtesy of Env. Can.

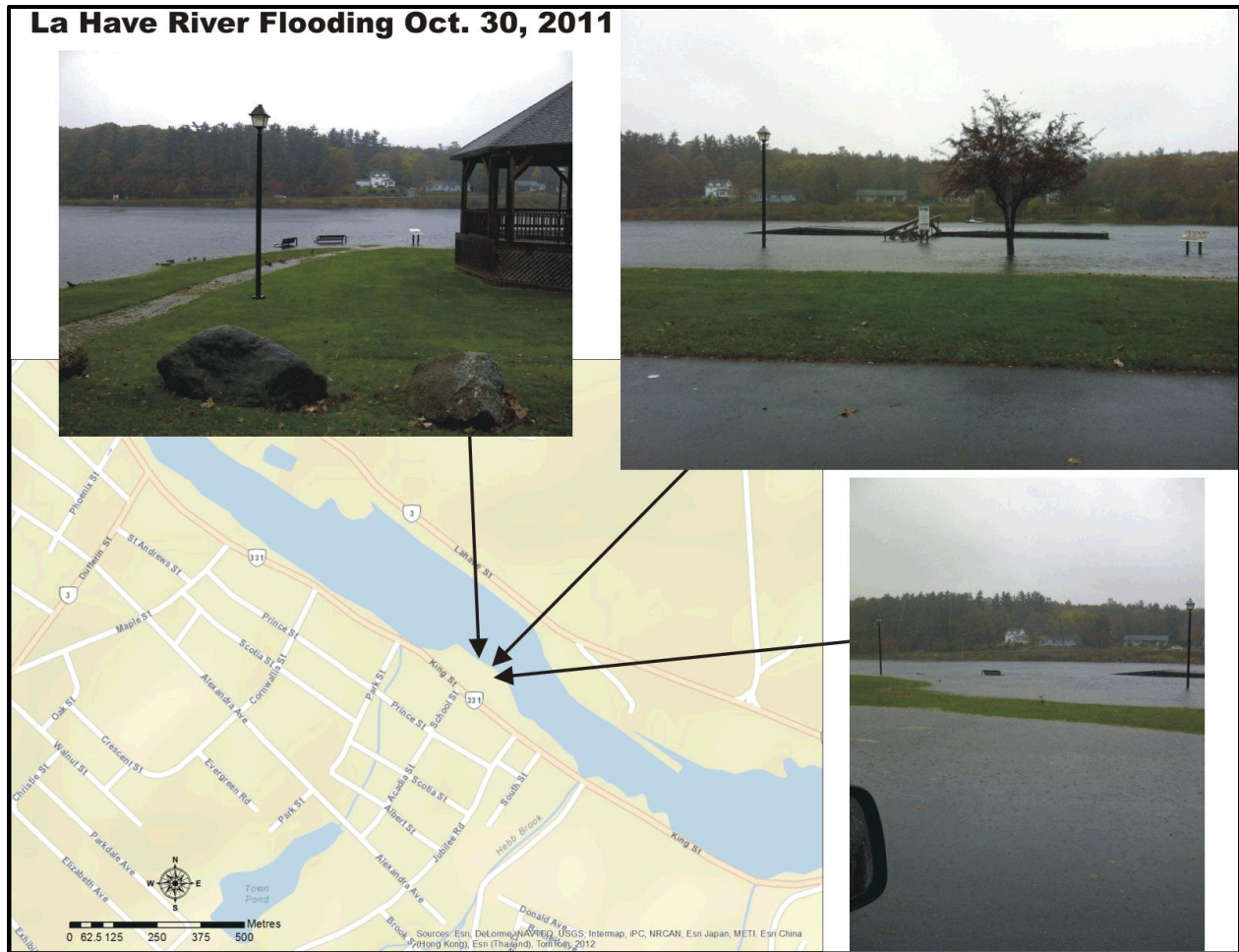


Figure 1:6 Flooding in downtown Bridgewater caused by a storm surge on October 30, 2011.

### 1.2.2. Climate Change and Sea-level rise

The global climate is changing due in part to the increase of greenhouse gas emissions, and the resulting warming trends will contribute to an increase of global sea-level (Titus et al. 1991). Future projections of sea-level change depend on estimated future greenhouse gas emissions and are predicted based on a number of scenarios (Raper et al. 2006). Global sea-level rise, as predicted by climate change models, will increase the problem of flooding and erosion making more coastal areas vulnerable. The third assessment of the Intergovernmental Panel on Climate Change (IPCC) indicates that there will be an increase in mean global sea-level from 1990 to 2100 between 0.09 m and 0.88 m (Church et al. 2001). The latest IPCC Assessment Report 4 (AR4) has projected global mean sea-level to rise between 0.18 and 0.59 m from 1990 to 2095 (Meehl et al. 2007). However as Forbes et al. (2009) point out, these projections do not account for the large ice sheets melting and measurements of actual global sea-level rise are higher than the previous predictions of the third assessment report. Rhamstorf et al. (2007)

compared observed global sea-level rise to that projected in the third assessment report and found it exceeded the projections. They have suggested a rise between 0.5 and 1.4 m from 1990 to 2100. This projected increase in global mean sea-level and the fact that many coastal areas of Maritime Canada have been deemed highly susceptible to sea-level rise (Shaw et al. 1998) has led to various studies to produce detailed flood risk maps of coastal communities in PEI, NB, and NS (Webster et al. 2004; Webster and Forbes, 2005; Webster et al. 2006; Webster et al. 2008). The most recent set of flood risk maps for coastal communities in Nova Scotia has been produced during the Atlantic Climate Adaptation Solutions (ACAS) project (Webster, McGuigan, and MacDonald, 2012; Webster, Smith, and Collins, 2012.).

In addition to global sea-level rise, local crustal dynamics also affect relative sea-level (RSL). The major influence on crustal motion for this region is related to the last glaciation that ended ca. 10,000 years ago (Shaw et al., 1994; McCullough et al. 2002; Peltier, 2004). The areas where the ice was thickest were depressed the most and peripheral regions where uplifted, termed the “peripheral bulge”. The ice was thickest over Hudson Bay in central Canada, where the crust was most depressed, however today this area is still rebounding from the removal of the ice load and continues to uplift. The Maritimes represent part of the peripheral bulge and southern New Brunswick and Nova Scotia are subsiding (Peltier, 2004). Subsidence rates vary across the region with Nova Scotia having a rate of ~ 15 cm per century (Forbes et al., 2009). The subsidence of the crust is important for coastal communities in that it compounds the problem of local sea-level rise and must be considered when projecting future flood risk. Global sea-level rise and crustal subsidence must both be considered to produce a potential increase in RSL in the next century. This does not include the possibility of increased storm intensity or frequency.

A comprehensive, community-by-community report prepared for ACAS by Richards and Daigle (2012) provides estimated extreme total sea levels that consider sea-level rise and storm surge. Estimates for Lunenburg are presented for 10, 25, 50 and 100-year return periods, for years 2000, 2025, 2055, 2085 and 2100. Richards and Daigle (2012) explain return periods as such:

“A return period represents the average time between occurrences of an event exceeding a given level. Another way of interpreting a level with a given return period (T) is that in any year there is a 1/T chance that the return level will be exceeded. For example, in any given year there is a 10% chance that 10 year return period value will be exceeded. Similarly, in any given year there is a 1% chance that a 100 year return period will be exceeded.”

For Lunenburg, this means that a 10-year storm could result in a sea-level of 3.29 by 2025, 0.86 m higher than HHWLT (Higher High Water Large Tide). A 100-year storm in 2055 would increase water level by 1.37 m to 3.80 m. The water levels in Table 1-1 are referenced to chart datum (CD), which is the same datum used for a hydrographic chart showing depths in the offshore and for tide tables. It should be noted that topographic maps on land and the elevations associated with lidar terrain models are referenced to the Canadian Geodetic Vertical Datum of 1928 (CGVD28). Thus, in order to convert the water levels referenced to chart datum (CD) the relationship between CD and CGVD28 must be known and applied to the values. Contour elevations on topographic maps are referenced to CGVD28 which is approximately mean sea level whereas the elevations tide tables and hydrographic charts are referenced to CD which typically represents the lowest possible tide in a local region.

Table 1-1 Estimated Extreme Total Sea Levels (HHWLT + Sea-Level Rise + Storm Surge) for Return Periods of 10, 25, 50 and 100 years for Years 2000, 2025, 2050, 2085 and 2100. Lunenburg, HHWLT 2.43 m (CD), Return Period levels estimated as per Halifax tide gauge. From Richards and Daigle (2012).

<b>Extreme Total Sea Level (meters CD) – Lunenburg</b>						
Return Period	Residual	Level 2000	Level 2025	Level 2055	Level 2085	Level 2100
10-Year	0.71 ± 0.20	3.14 ± 0.20	3.29 ± 0.23	3.57 ± 0.35	3.97 ± 0.56	4.20 ± 0.68
25-Year	0.81 ± 0.20	3.24 ± 0.20	3.39 ± 0.23	3.67 ± 0.35	4.07 ± 0.56	4.30 ± 0.68
50-Year	0.88 ± 0.20	3.31 ± 0.20	3.46 ± 0.23	3.73 ± 0.35	4.14 ± 0.56	4.37 ± 0.68
100-Year	0.95 ± 0.20	3.38 ± 0.20	3.53 ± 0.23	3.80 ± 0.35	4.21 ± 0.56	4.44 ± 0.68

In addition Webster, McGuigan and MacDonald (2012) examined the Halifax tide gauge record and fitted an extreme value model to the data to estimate the return periods of total water levels, rather than separating out storm surge from predicted tide. Their approach used the hourly recorded tide, whereas the Richards and Daigle (2011) approach is based on work by Bernier (2005) who used the Dalhousie University storm-surge model to reconstruct storm-surges for the last 40 years in order to calculate return periods of water levels and how they might change under climate change scenarios. Bernier (2005) plotted the return periods of observed extreme annual water level maxima residuals (observed water level minus predicted) for various locations where tide gauge data exists in the region. The purpose of her study was to test the “skill” of the storm-surge model by comparing model outputs based on atmospheric wind and pressure fields with the observed water level records for several stations (36 sites) around the North Atlantic coast. The tide gauge data are reported hourly based on a 5 minute average to remove surface wave effects (Bernier, 2005). Sea-level residuals were calculated which represent the difference between observed sea-level and predicted tide sea-level. The Atmospheric Environment Service (AES) of Environment Canada have produced AES40 wind fields for

the past 4 decades. The AES40 winds fields have a horizontal resolution of about  $0.625^\circ$  latitude by  $0.833^\circ$  longitude and have been used by Bernier (2005) to infer the air pressure field. The surge model is driven by winds and air pressure every 6 hours. Thus, the surge model output will not generate variability at periods shorter than 12 hours (Bernier, 2005). Therefore, to compare the storm-surge model output and the observed water levels and residuals, variability in the residuals at periods shorter than 12 hours were removed by applying a low-pass filter, effectively removing high-frequency signals. The examination of large surges was accomplished by external analysis of the low-pass filtered residual data. The smoothed residual annual maxima and minima were calculated for each station and return periods were plotted (Bernier, 2005). Bernier (2005) states that there is a tendency to underestimate the 40 year return levels; however, the estimates are within the 95% confidence intervals of the filtered observed return levels. She also acknowledges that the resolutions of the forcing fields (i.e. AES40 winds and inferred pressure) are too coarse to be able to resolve hurricanes and the method underestimates these events. Thus, the return periods and associated storm-surge water levels reported in Bernier (2005) represent a conservative calculation of past events where the effects of some short lived events such as hurricanes have been filtered out.

This method of estimating the return period for storm surges based on the storm surge model allows predictions to be made in areas that do not have a tide gauge. Richards and Daigle (2011) used the results of the model and analysis by Bernier (2005) to estimate the storm surge residuals for the different regions for return periods of 10, 25, 50 and 100 years. These storm surge water levels were then added to the highest predicted tide (HHWLT) to determine the total water level expected within these time frames (Table 1-1). This approach is quite different than the one utilized in this report where the total water level, as measured hourly at the tide gauge locations, was used to determine the statistics. The Richards and Daigle (2011) method is conservative in the estimation of storm surge levels and return periods as a result of the temporal (6 hrs.) limitations of the driving forces (wind and atmospheric pressure) of the storm surge model. However, when these storm surge values are applied to the HHWLT, which occurs relatively infrequently within the 18 year tidal cycle, they represent the worst case scenario. The astronomical conditions which govern tidal amplitude repeat every 18.61 years. The next peak tides of the 18.61 tidal cycle will be in 2015. It is important for the coastal practitioners to understand the background used in both methods and the associated limitations of each. For example, Webster, McGuigan and MacDonald (2012) estimate the 100- year water level based on the Halifax tide gauge record to be 3.03 m (CD) as of 2012 whereas the Richards and Daigle (2011) estimate 3.38 m (CD) and 3.53 m (CD) as of 2000 and 2025 respectively.

### **1.3. Fluvial Flooding**

Fluvial flooding is a common occurrence in Bridgewater and the LaHave watershed. Intense or prolonged rain events, melting snow and ice, or a combination of the two causes property and infrastructure damage frequently.

Fluvial flooding is caused when high or intense precipitation, or snow and ice melt within the watershed flows into the river, causing it to overtop its banks. High or intense precipitation can be defined using Environment Canada's Rainfall Warning Criteria, wherein warnings are issued when 25 mm or more of rain is expected in one hour, when 50 mm or more is expected within 24 hours or 75 mm or more within 48 hours during the summer, or when 25 mm or more of rain is expected within 24 hours during the winter (Environment Canada, 2011). While flooding from snow and ice melt can be easy to predict, flash flooding from sudden downpours can be more of a challenge to forecast (Royal Institute of British Architects, 2011).

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 runoff 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.

Figure 1:7 shows a short duration rainfall Intensity-Duration-Frequency (IDF) graph for Kentville, the monitoring station nearest to Bridgewater. The graph is produced by Environment Canada 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. The IDF shows that high intensity rainfall events occur for short durations of time, while longer duration storms have less intense rainfall. The highest intensity rainfall events occur least frequently. More information on IDFs can be found here: [ftp://ftp.tor.ec.gc.ca/Pub/Engineering\\_Climate\\_Dataset/IDF/IDF\\_v\\_2.100\\_2011\\_05\\_17/Notes\\_on\\_EC\\_IDF.pdf](ftp://ftp.tor.ec.gc.ca/Pub/Engineering_Climate_Dataset/IDF/IDF_v_2.100_2011_05_17/Notes_on_EC_IDF.pdf).

**Short Duration Rainfall Intensity–Duration–Frequency Data**  
 2012/02/09  
**Données sur l'intensité, la durée et la fréquence des chutes de pluie de courte durée**

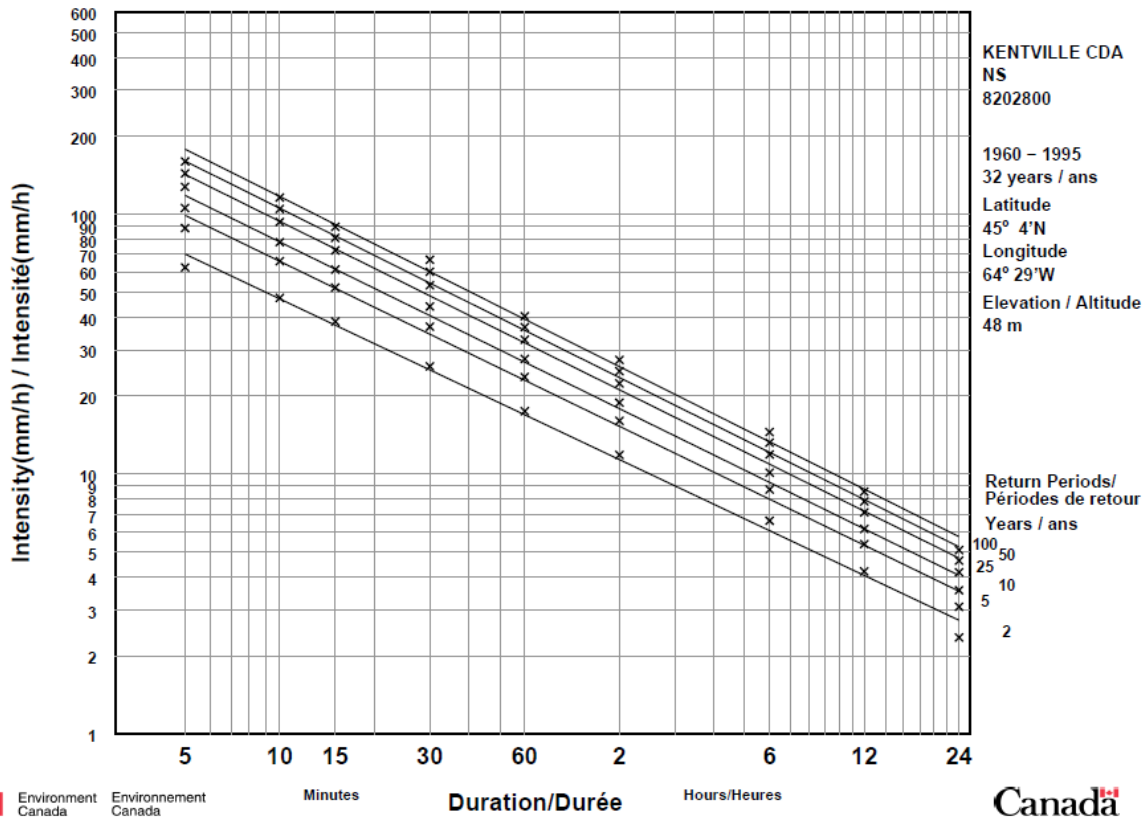


Figure 1:7 Short Duration Rainfall Intensity–Duration–Frequency Data for Kentville, the station nearest Bridgewater. Source: [ftp://ftp.tor.ec.gc.ca/Pub/Engineering\\_Climate\\_Dataset/IDF/](ftp://ftp.tor.ec.gc.ca/Pub/Engineering_Climate_Dataset/IDF/).

**1.3.1. Historical Floods**

Flow in the LaHave River follows a typical pattern, with maximum flow occurring in the spring and minimum flow occurring in the summer (Table 1-2, Figure 1:8). Values for three times the average monthly flow show that April is the highest at 220 m<sup>3</sup>/s (Table 1-2), while notable historic floods (Figure 1:8) all have peak flows of >300m<sup>3</sup>/s, closer to four times the April monthly average flow. These values can be used to estimate a flow threshold such that flow levels higher than that threshold indicate a flood event. Analysis of the 95-year LaHave River flow time series derived from the Environment Canada water level gauge in West Northfield (Figure 1:1) shows that there were 23 events, lasting from one to six days, for which flow was greater than 300m<sup>3</sup>/s (Figure 1:9). The distribution of flood events defined as such is shown in the final column of Table 1-2; almost 80% of the floods occurred during winter or spring, times when snow melt is likely to have contributed to the flood.

Table 1-2 Average monthly, 3x average monthly LaHave River flows, and distribution of flood events by month. Data are from Environment Canada's Real Time Hydrometric Network database.

<b>Month</b>	<b>Average LaHave River Flow: 1915-2010 (m<sup>3</sup>/s)</b>	<b>3x Average LaHave River Flow: 1915-2010 (m<sup>3</sup>/s)</b>	<b>Distribution of flood events by month</b>
January	46	138	5
Feb	39	116	3
Mar	54	162	5
Apr	73	220	5
May	39	116	1
Jun	20	61	0
July	11	34	0
August	11	34	0
Sept	9	28	0
Oct	20	61	1
Nov	44	133	3
Dec	51	153	0

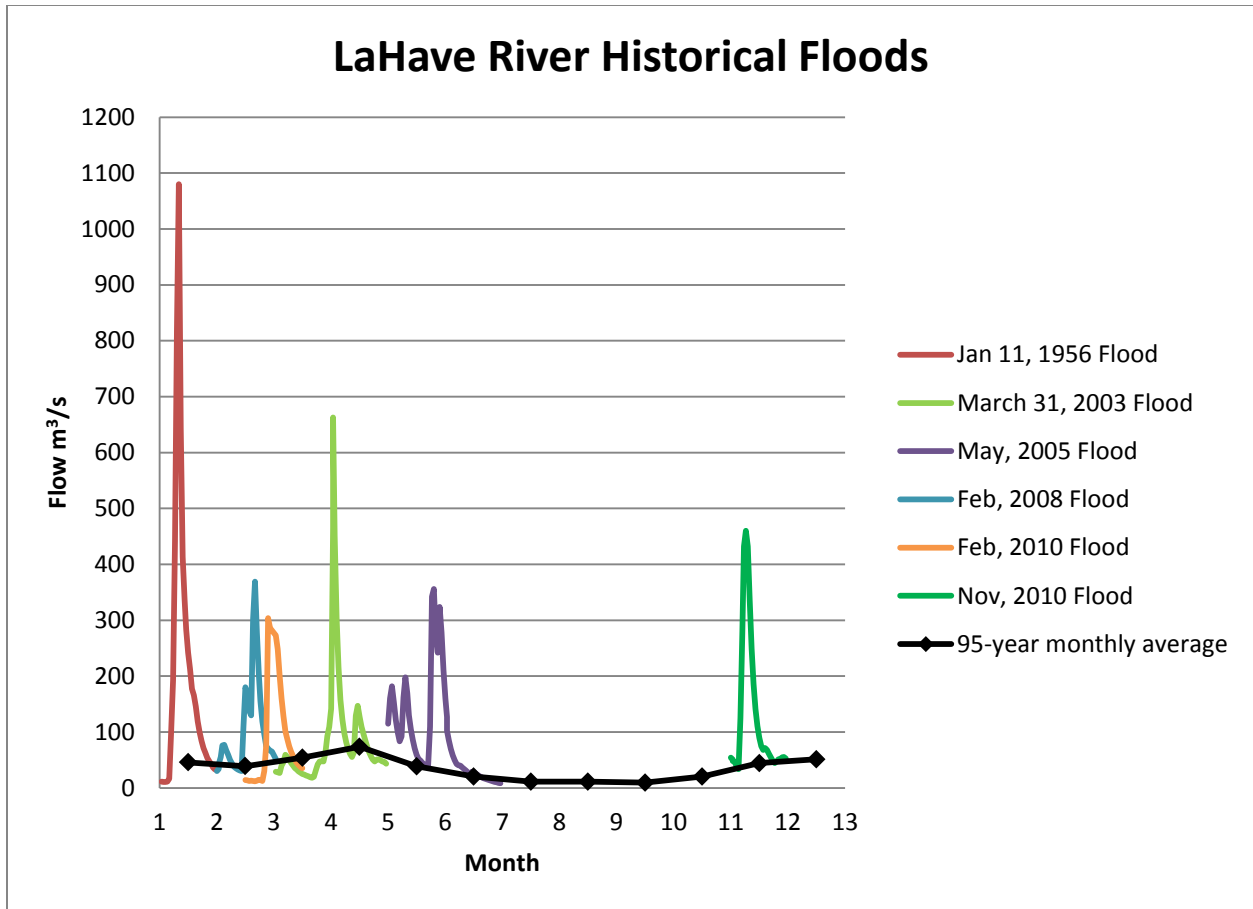


Figure 1:8 Historical LaHave River flood events (coloured lines) and the 95-year (1915 – 2010) monthly average flow (black line). Data are from Environment Canada’s Real Time Hydrometric Network database.

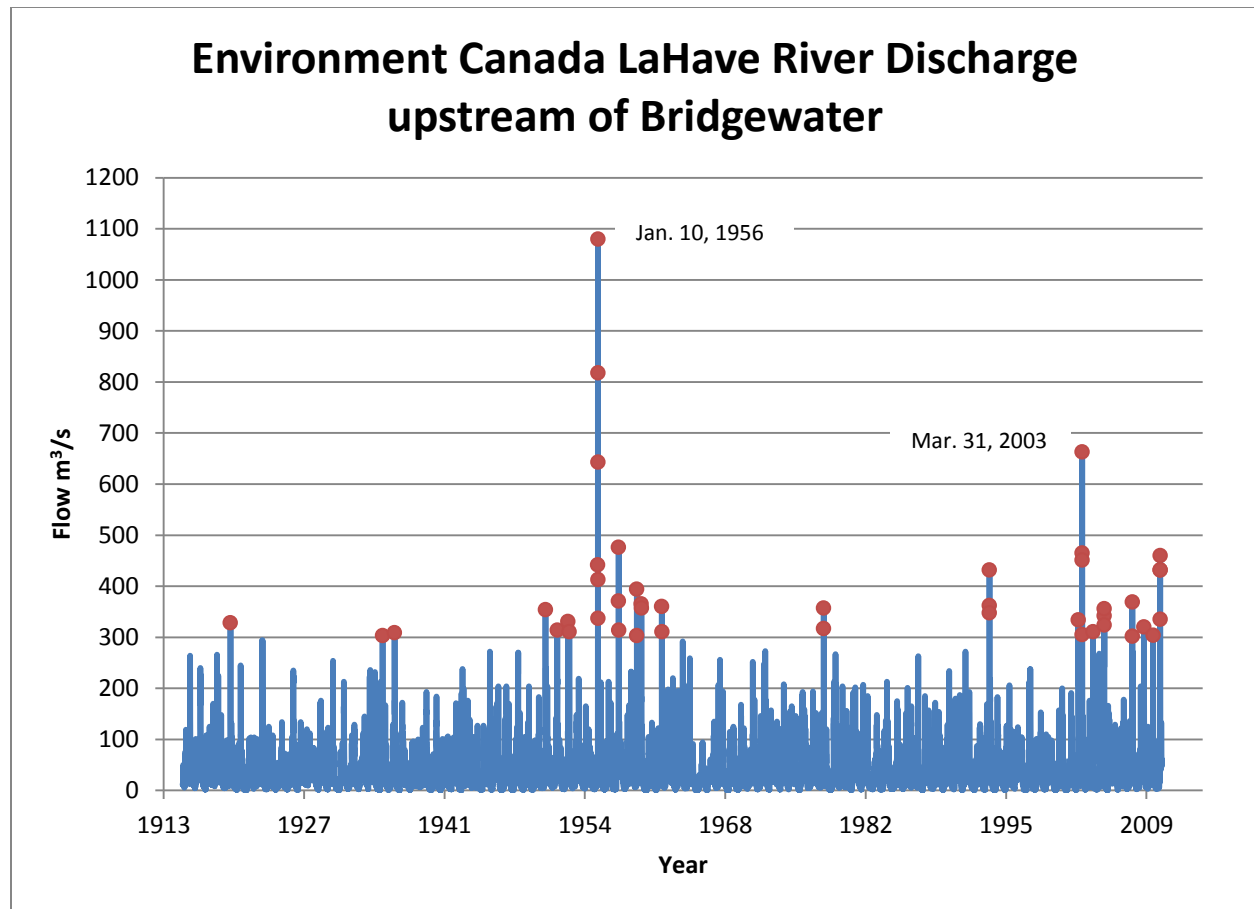


Figure 1:9 LaHave River discharge, 1915-2010, measured upstream of Bridgewater (see Figure 1:1 for gauge location). Data from Environment Canada’s Real Time Hydrometric Database.

The notable historic flood events in Figure 1:9 show that Maximum Instantaneous Peak Flow was highest on January 10, 1956 (1080 m<sup>3</sup>/s) and second-highest on March 31, 2003 (663 m<sup>3</sup>/s). Both of these floods were caused by heavy rain and melting snow and caused the highest water levels ever recorded (5.550 m and 5.301 m for 1956 and 2003, respectively), 1.5 to 2.0 m higher than any other flood event in the years preceding the 2003 flood (Fogarty, 2003).

### January 10, 1956

Mainly anecdotal evidence of the January, 1956 flood exists, although there is some text and photos available. The January 10, 1956 edition of the Bridgewater Bulletin describes that flood event of that day:

*A full week of heavy rain, melting snow, above-freezing temperatures and strong easterly winds took their toll in Lunenburg County, as the usually benign LaHave River rose steadily to become a dangerous, threatening torrent, flooding many square miles of low-lying country, washing out bridges, mills and buildings, and causing two dozen families to evacuate their homes, leaving all*

*their possessions to the raging flood waters.*

(<http://newgermanycap.ednet.ns.ca/NewGermanyhistory/Flood1956.htm> )

Figure 1:10 shows images of the 1956 flood, which is still remembered today by those who were around.



Figure 1:10 Flooding of the LaHave River on January 10 and 11, 1956. Top: Zwicker's Mill; bottom: homes on Lake Road. Source: <http://newgermanycap.ednet.ns.ca/NewGermanyhistory/Flood1956.htm>

### ***March 31, 2003***

Much more information on the March 31, 2003 flood is available. On that date, several days of heavy rain combined with melting ice and snow caused flooding all over the province. Figure 1:11 shows the

precipitation accumulated between March 29 and 31 showing levels near the Bridgewater area at approximately 100 mm; Environment Canada recorded 90.0 mm at Kejimikujik National Park between March 30 and 31, and 105.9 mm at Halifax International Airport. Before the rain began there was 34 cm of snow on the ground at Kejimikujik.

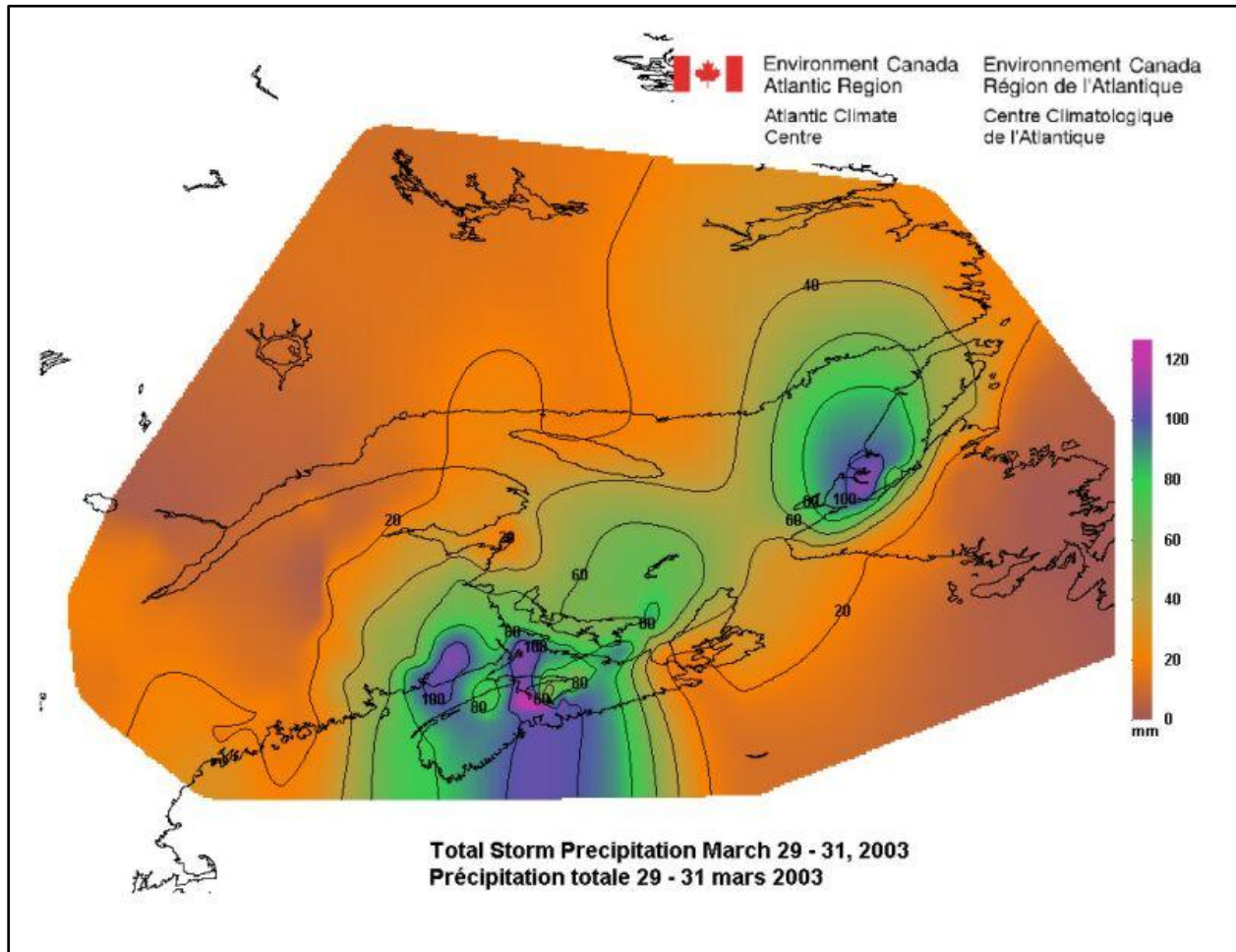


Figure 1:11 Total storm precipitation for late March, 2003, showing heaviest rainfall near the South Shore.  
[http://www.novaweather.net/Flood\\_2003/Flood\\_Total\\_Precip.jpg](http://www.novaweather.net/Flood_2003/Flood_Total_Precip.jpg)

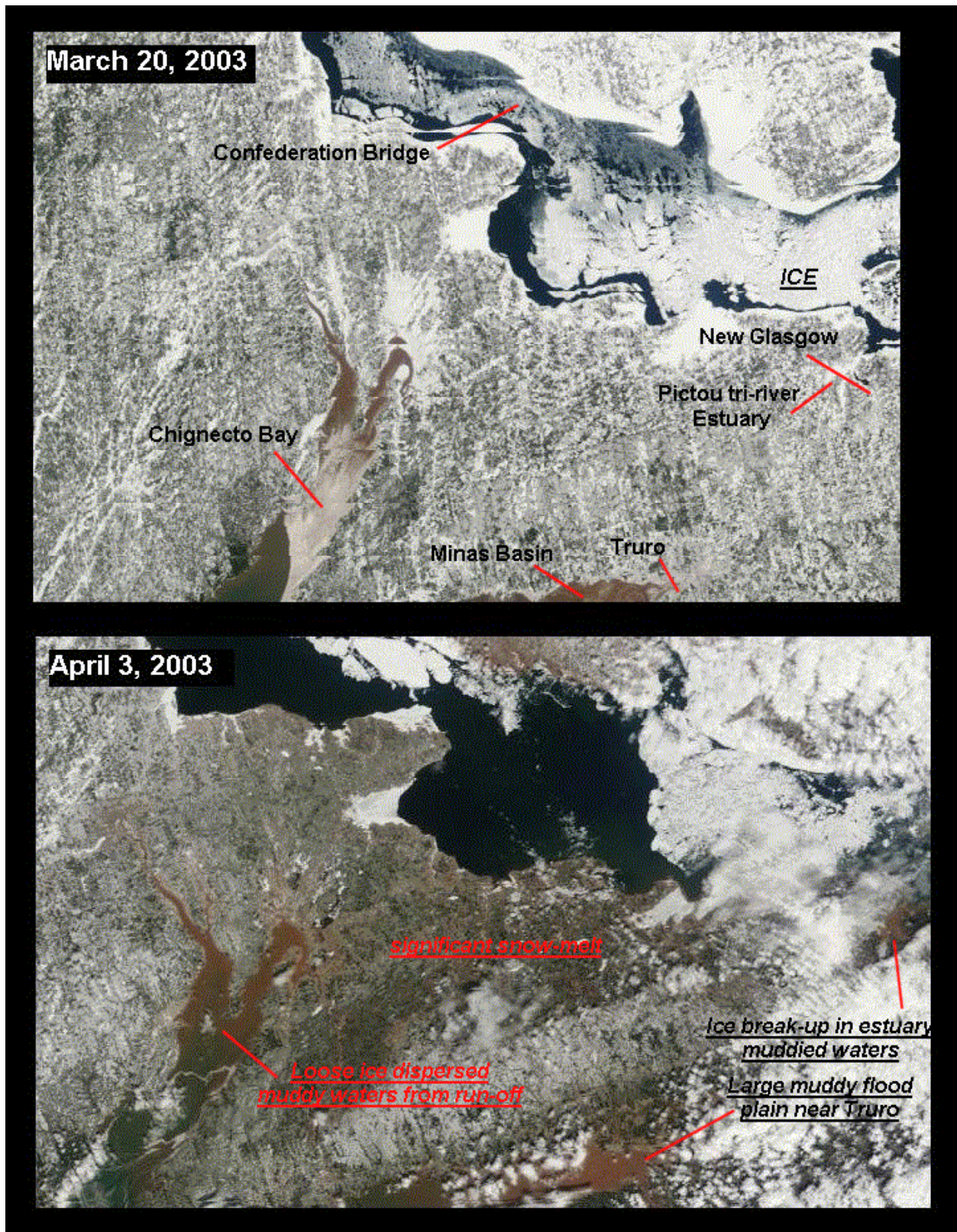


Figure 1:12 High resolution before (top) and after (bottom) satellite images showing the snow on the ground before the storm, the muddy water due to floodwater runoff, and the ice breakup. Source: [http://www.novaweather.net/Flood\\_2003/Flood\\_Before\\_After\\_sat.gif](http://www.novaweather.net/Flood_2003/Flood_Before_After_sat.gif).

The flooding was most severe upstream of Bridgewater, between Cookville and New Germany. On April 1 two cars were swept from Highway 10 at Pinehurst, about 20 km from Bridgewater, resulting in the death of an elderly couple. An ambulance reportedly plowed through three feet of water in an attempt to reach the scene of the accident, and it ultimately took the efforts of several boats and tractors to retrieve the car from the deep ditch where it was submerged (Brown, 2003). The flooding caused a sewage pipe to break within the Town of Bridgewater, resulting in an estimated 250,000 gallons of sewage flowing into the LaHave River per day (Brown, 2003a). The repair was estimated to cost about \$100,000 and take several weeks to complete (Brown, 2003a). The flooding washed out roads and bridges (Figure 1:14) and left at least one family homeless. Nova Scotia claimed \$7.5 million in damages for the storm, with the Town of Bridgewater accounting for \$208,196 of that total (Corcoran, 2009).



Figure 1:13 A boat continues the effort to rescue people in two cars that were swept off the road into the flooded LaHave River in Pinehurst on April 1, 2003. Source: <http://southshorenova.ca/archives/viewer.php?sctn=2003/040903/news&article=1>

Figure 1:14 shows the old bridge on Bruhm Road flooded to the deck during that flood event. According to locals, the 1956 flood reached the handrails on that bridge. The bridge has been replaced since the 2003 flood. Figure 1:14 shows the Morgan Falls Hydropower Station on March 31, 2003; Figure 1:16 shows the falls during the summer for comparison purposes.



Figure 1:14 Right: The Bruhm Road Bridge on March 31, 2003. Source: <http://southshorenova.ca/archives/viewer.php?sctn=2003/040903/news&article=20> (Left) Another bridge over the LaHave River during the same flood event. Source: Stan Mason.



Figure 1:15 Morgan Falls on the March 31 flood. Photos courtesy of Stan Mason, Morgan Falls Power Company.



Figure 1:16 Morgan Falls on August 20, 2012.

### **May 22, 2005**

Major rain-induced flooding caused widespread damage and prompted the evacuation of approximately 100 people from 41 homes in the LaHave River watershed in late May, 2005, when more than 235 mm of rain fell over a week's time (Figure 1:19). A state of emergency was declared on May 28 and stayed in effect until June 1 at 7:00pm. Several bridges and roads were closed, some for several days, due to the flooding that affected the Hebbville and Fancy Lake areas (Figure 1:17) as well as downtown Bridgewater (Figure 1:20, Figure 1:21). The damage caused to properties in Lunenburg County was so extreme it prompted donations of \$10,000 from Scotiabank, Manulife Financial and The Home Depot to assist with housing, food, cleanup, clothing and home repairs (Cocoran, 2005).



Figure 1:17 Morgan Falls during the flood in late May, 2005. Source: <http://newgermanycapecap.ednet.ns.ca/text/morganfalls.htm>.



Figure 1:18 Left: Peter Redden of the Conquerall Bank fire department checks the depth of water covering the road to Lakeview Circle on May 26. Stacey Colwell photo, retrieved from: <http://www.southshorenova.ca/archives/viewer.php?sctn=2005/060105/news&article=1>. Right: More than a foot of water flowed through System Care on Highway 3 in Hebbville during much of the flooding. Owner Bren Vanderzwaag estimates damage will total more than \$20,000. Lisa Brown photo, retrieved from: <http://www.southshorenova.ca/archives/viewer.php?sctn=2005/060105/news&article=15>.

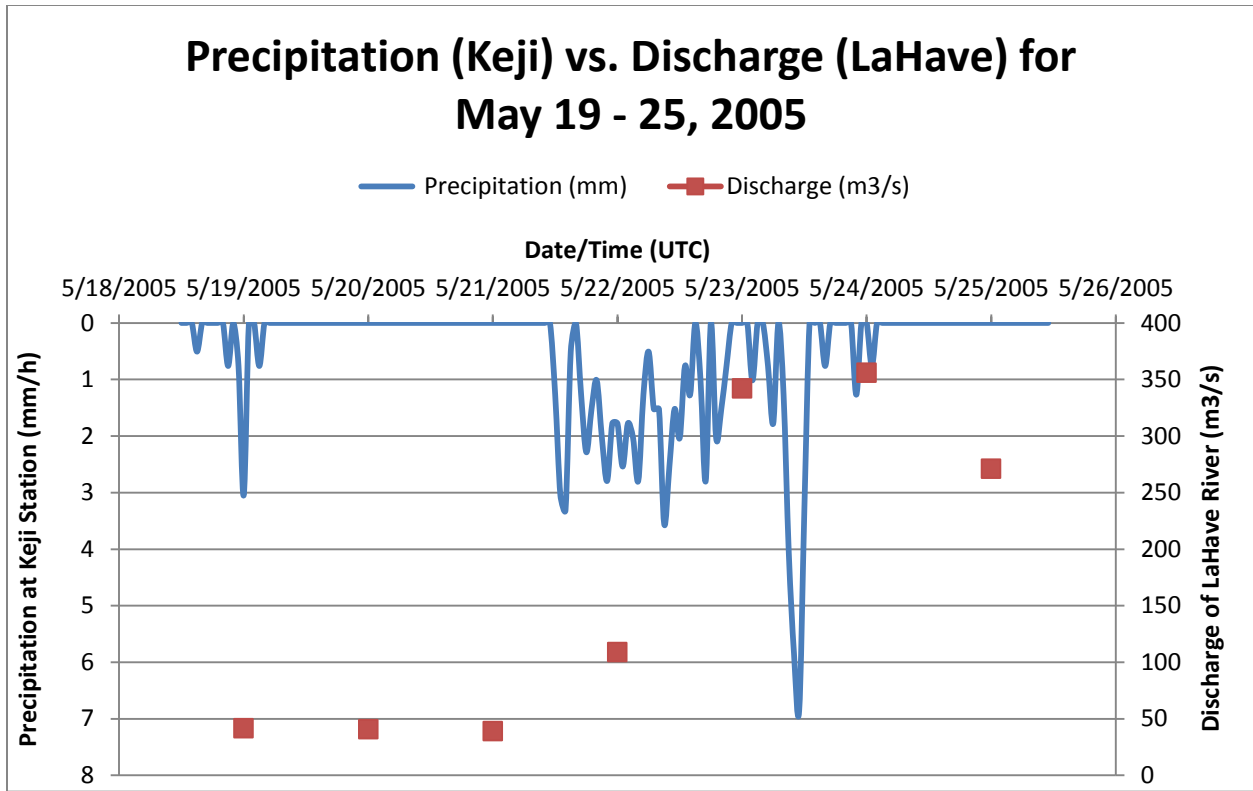


Figure 1:19 Hourly precipitation at Kejimkujik, NS (blue line) and daily discharge of the LaHave River (red squares) for May 19-25, 2005.



Figure 1:20 Prince Street in downtown Bridgewater is flooded following heavy rains in May, 2005.

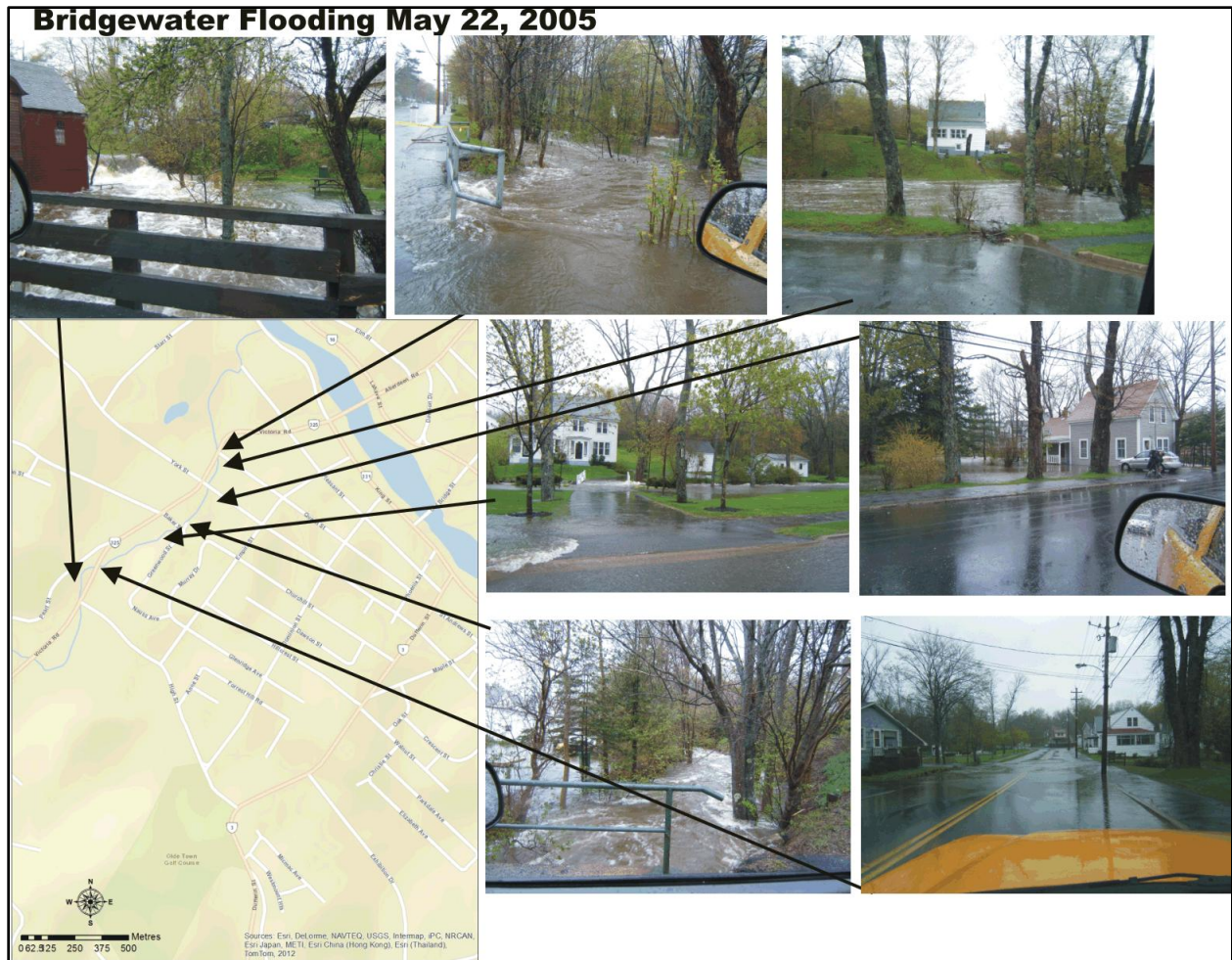


Figure 1:21 Flooding in Bridgewater following heavy rains in May, 2005.

### ***February 28 and November 10, 2010***

The LaHave River saw two major floods in 2010: one in late February caused by heavy rains and melting snow (Figure 1:22), and one in November caused by heavy rain (Figure 1:23). In February, flooding was mainly on Highway 10 near New Germany. The November event, however, caused widespread flooding in downtown Bridgewater (Figure 1:24, Figure 1:25) and flooded several sections along Highway 10 (Figure 1:26, Figure 1:27). In November, several days of heavy rains resulted in flooded roads, closed bridges, flooded basements, downed power lines and a set of gas pumps being blown over (Figure 1:28, Figure 1:29) (Cocoran, 2010). Environment Canada issued Rainfall Warnings for three days. Closed roads included the Wentzell Road between Branch LaHave and Wentzells Lake, the Veinot Road between Highway 10 and Lower Branch Road, and sections of Highway 10 in Pinehurst, the Chester Grant Road, East Clifford Road, the Lower Branch Road in New Germany, Haines Road in Barss Corner and Highway 3 in East River (Cocoran, 2010). Figure 1:30 shows pre-flood and non-flood conditions for LaHave bridges.

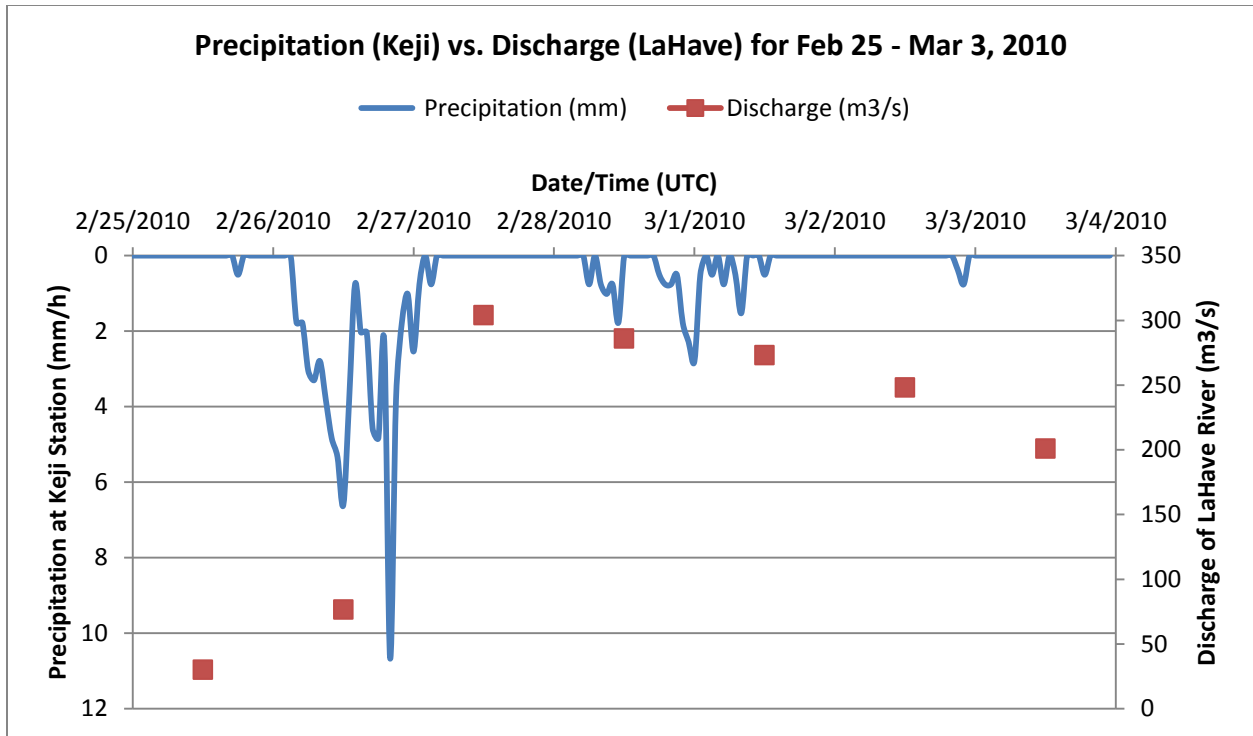


Figure 1:22 Hourly precipitation at Kejimkujik, NS (blue line) and daily discharge of the LaHave River (red squares) for Feb 25- Mar 3, 2010.

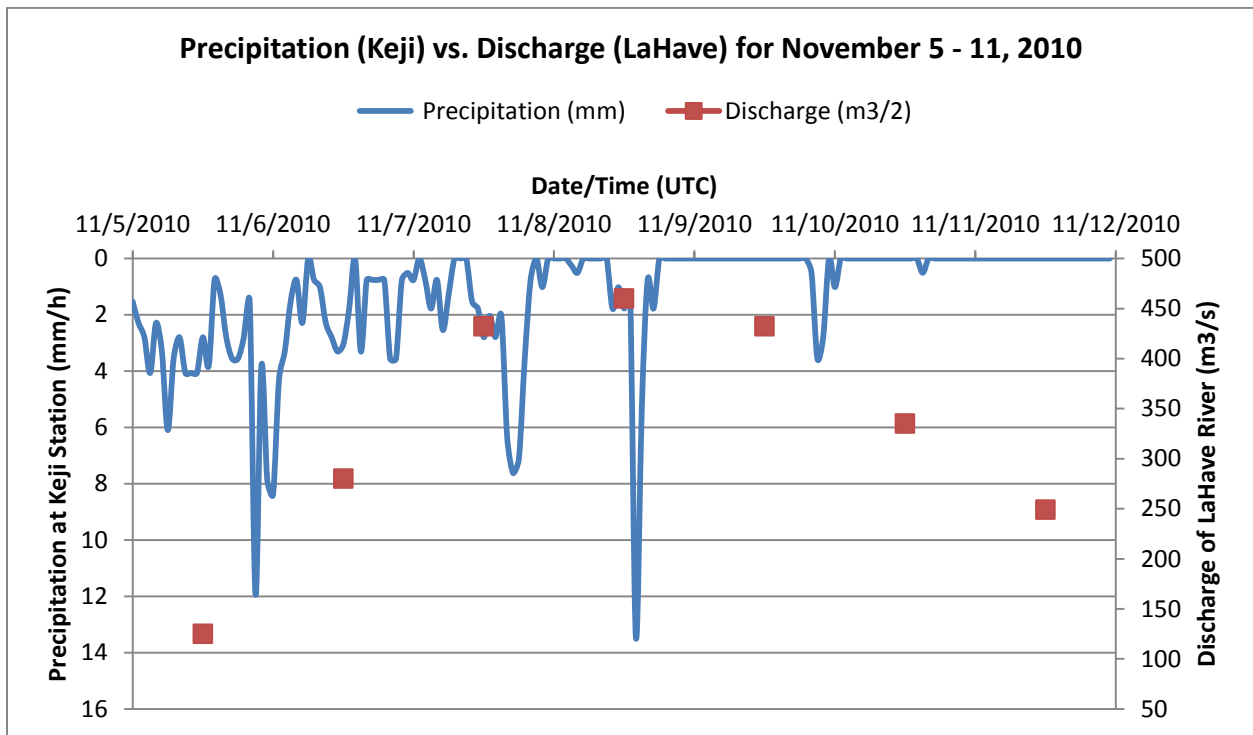


Figure 1:23 Hourly precipitation at Kejimkujik, NS (blue line) and daily discharge of the LaHave River (red squares) for Nov 5- 11, 2010.

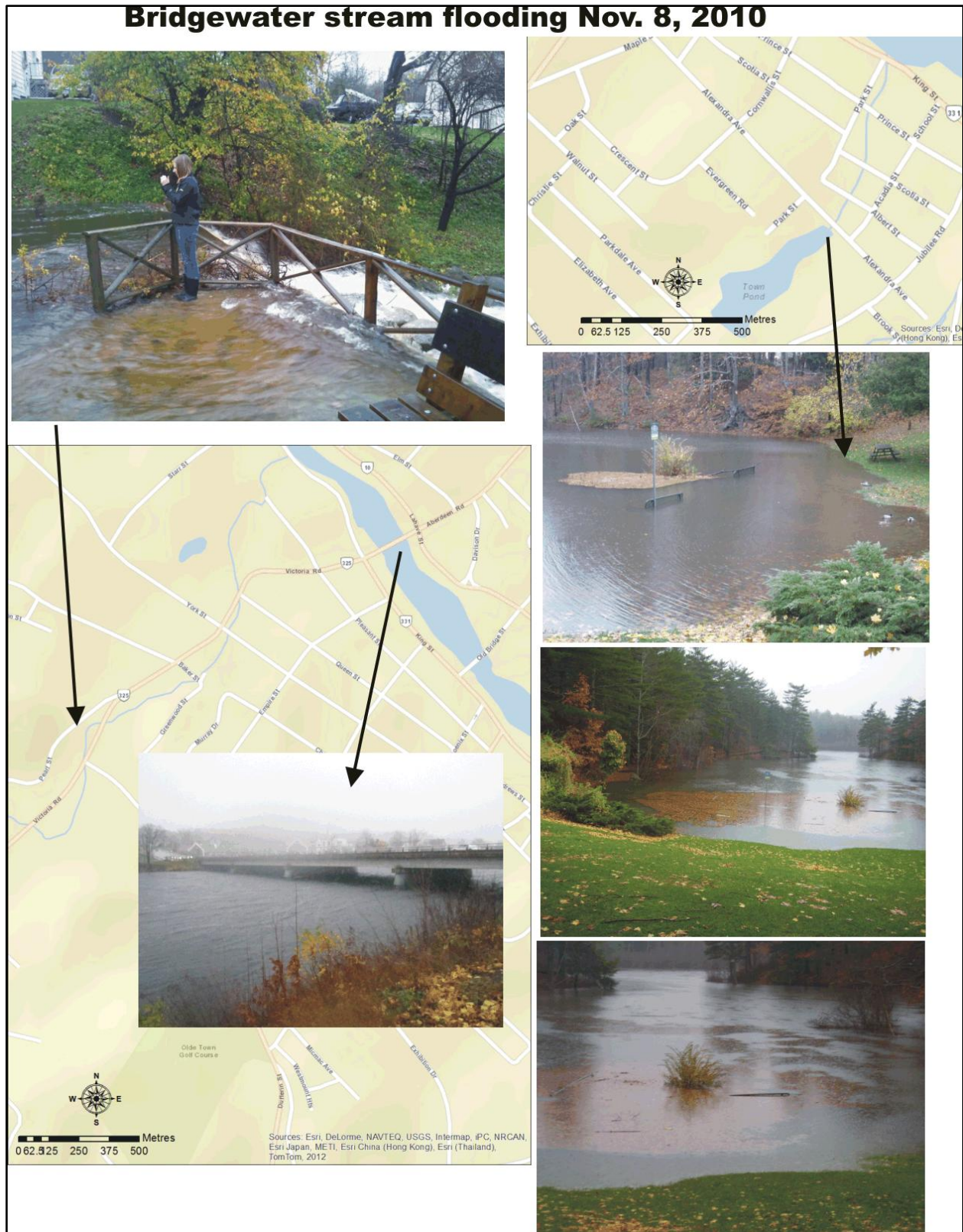


Figure 1:24 Flooding in Bridgewater following heavy rain in November, 2010.

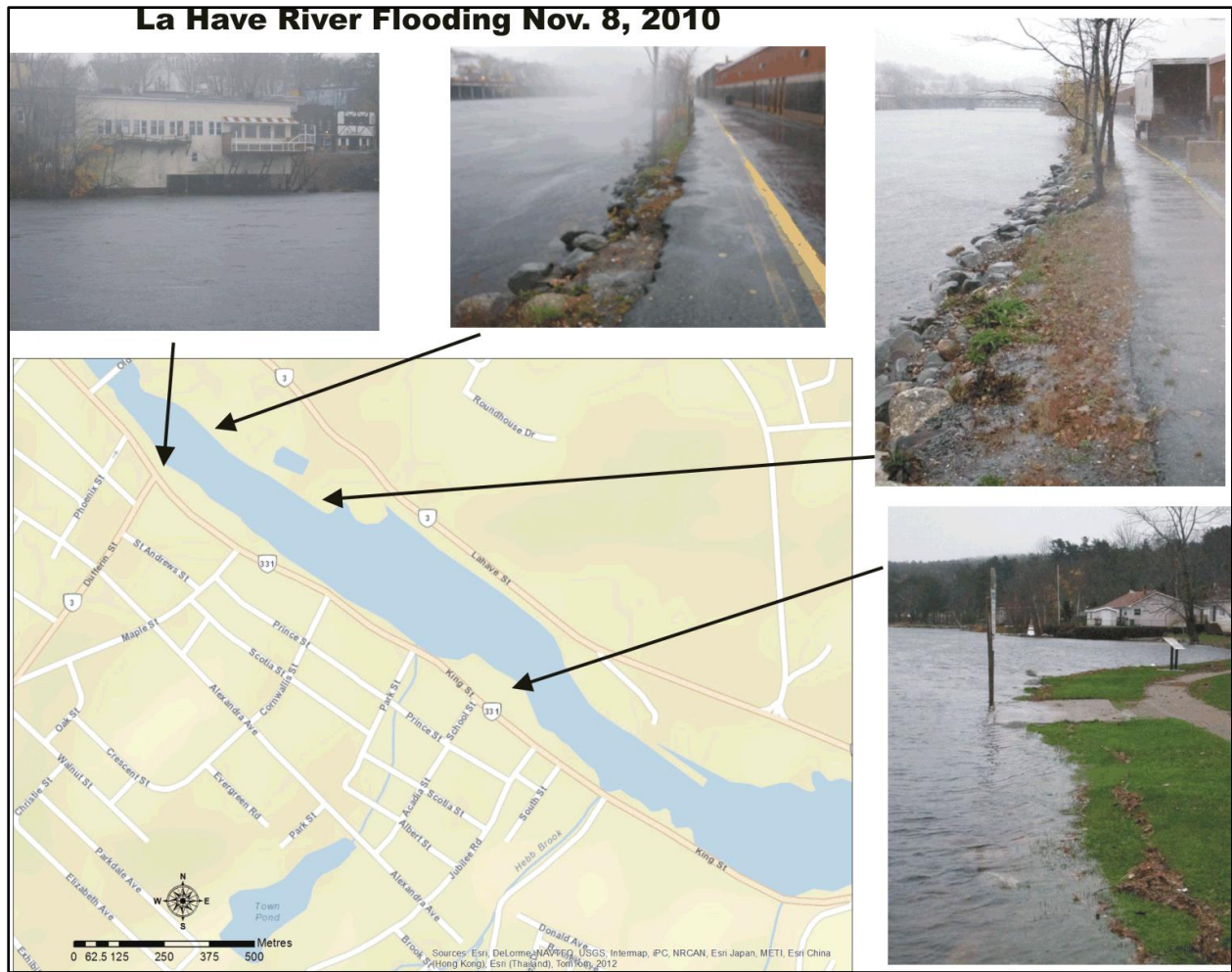


Figure 1:25 Flooding in downtown Bridgewater following heavy rains in November, 2010.



Figure 1:26 Highway 10 near New Germany during flooding in February, 2010 (top left) and November, 2010 (top right); the bottom photo is from December, 2012 during non-flood conditions.



Figure 1:27 A section of Highway 10 near New Germany during flooding in February, 2010 (top left) and November, 2010 (top right); the bottom photo is from December, 2012 during non-flood conditions.



Figure 1:28 Rail bridge on November 7, 2010 (left) (photo courtesy of theweathernetwork.com); and on August 20, 2012 (right).



Figure 1:29 Water levels approach the bridge deck on Veinot Road following flooding in February, 2010 (left) and November, 2010 (right).



Figure 1:30 Left: The bridge on Veinot Road in April 2009, showing pre-flood conditions; right: the same bridge in December 13, 2012 during non-flood conditions.

### 1.3.1. Climate Change Scenarios

As is the case with sea-level rise predictions, there are many different scenarios for how precipitation patterns will change with climate change, although there does seem to be consensus that there will be much more variability and frequency of intense rainfall in Nova Scotia (NRCAN, 2010; Climate Change NS, 2012; Clean Nova Scotia, 2010; ACASA, 2012). Richards and Daigle (2011) predict an annual increase in precipitation in Bridgewater; most of that increase is predicted to occur in the winter and spring, with minimal increase in summer and fall precipitation. Climate Change Nova Scotia (2012) warns that extreme rainfalls that happened only once every 50 years in the last century are likely to occur once every 10 years in this century, and precipitation is expected to vary more from season to season and from year to year. Some predict that the time between rainfalls will likely grow longer, meaning that precipitation will arrive as single, intense storms instead of many small showers spread throughout the year (Clean Nova Scotia, 2010). In addition, NRCAN (2010) predicts that Nova Scotians will see more precipitation falling as rain, rather than snow.

A study on global warming and precipitation in the United States reports that snowstorms and rainstorms have already become 30% more frequent than in 1948 and more severe, producing 10% more precipitation, on average (Madsen and Willcox, 2012). Of particular note to Atlantic Canada is the reported 85% increase in frequency of extreme rainfall and snowfall events in New England, meaning that a storm that used to occur every 12 months now occurs on average every 6.5 months (Madsen and Willcox, 2012).

Atlantic Canada is projected to see hotter and drier summers, and warmer winters, especially in the interior (NRCAN, 2010; Clean Nova Scotia, 2010), and increased intensity of hurricanes impacting

Atlantic Canada as ocean waters continue to warm (The Weather Network, 2011; CBC, 2010). Richards and Daigle (2012) produced a report where they project a variety of climate variables into the future based on the average results of several climate models. Their report is discussed in more detail in the methods section related to climate change.

## 2. Methods

### 2.1. Field Work & Instrumentation

In order to model the fluvial and storm surge flood risk for the Town of Bridgewater the hydrology of the area must be determined. The factors driving the potential for flood risk include the weather and tidal and storm conditions. Fortunately Environment Canada monitors the water level or stage of the LaHave River and through the use of a rating curve publishes flow rates for the river (Figure 2:1). We have used these data of river flow or discharge as the main input to the river runoff model. To supplement these data, AGRG has deployed several instruments in the field to measure the weather and water level (Figure 2:1). The closest weather station operated by Environment Canada is in Lunenburg; however it does not appear to measure precipitation. As a result we have used the Kejimkujik (Keji) weather station that does measure precipitation and has a long time series (record). However, the Keji station is not directly within the LaHave watershed. As a result we have deployed two AGRG weather stations; one at Cherryfield in the center of the watershed and another at Hirtles Beach along the Atlantic coast (Figure 2:1). In addition to the Environment Canada discharge measurements two water level sensors (tide gauges) were deployed by AGRG to measure the water level in the town at the Marine terminal and the water level near the mouth of the river at Kraut Point (Figure 2:1).

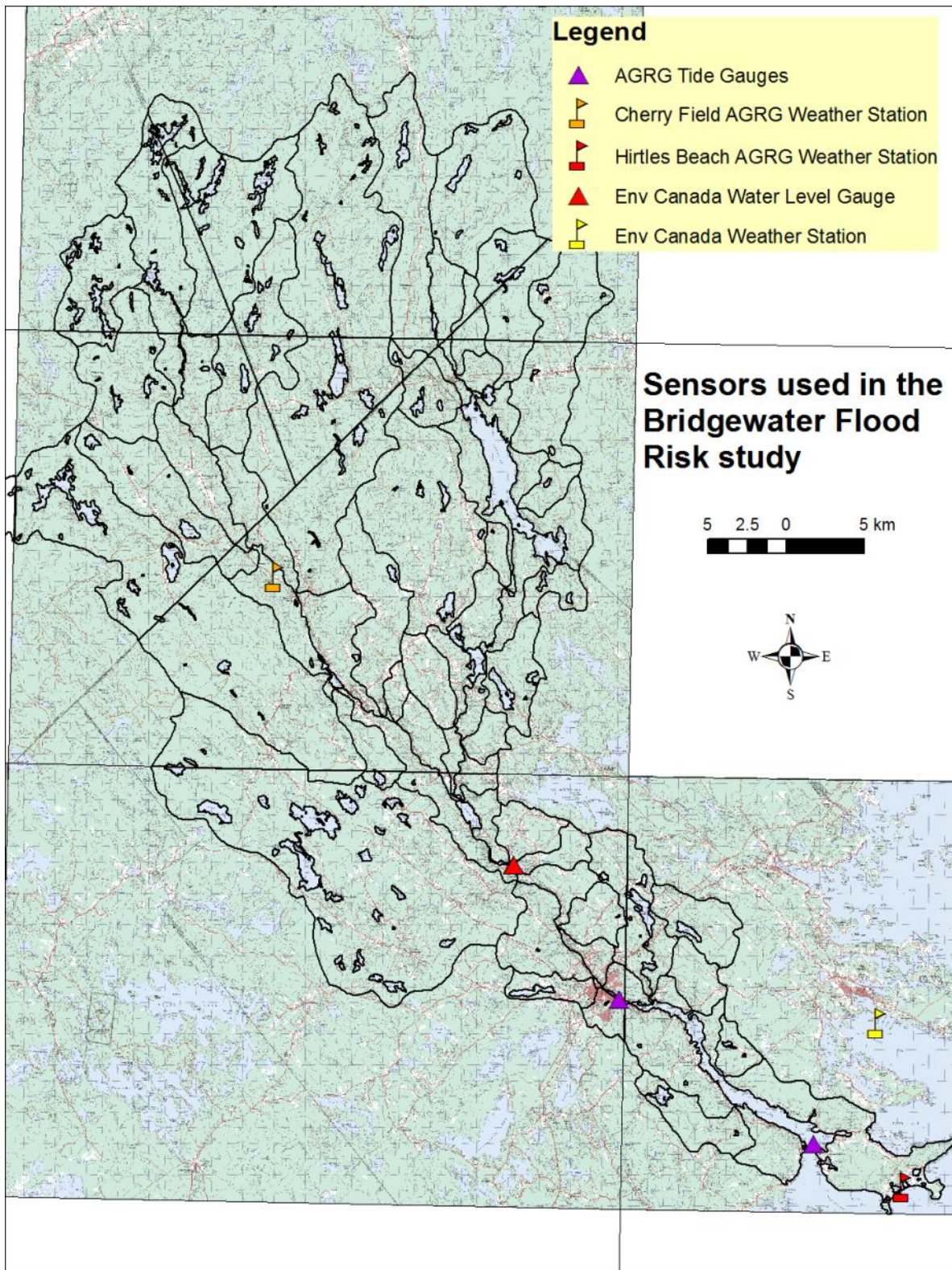


Figure 2:1 Map of instrument locations used in the flood risk study.

The weather station at Hirtles Beach was used to monitor the coastal conditions and the barometric pressure measured by this system was used to compensate the Kraut Point tide gauge (Figure 2:2, Figure 2:3).



Figure 2:2 Weather station installed at Hirtles beach July 25, 2012.



Figure 2:3 Kraut Point tide gauge. Tide board (black and white 10 cm divisions) with the sensor deployed in a PVC tube.

In addition to deploying the field instrumentation the geometry of the river bed had to be determined in order for the river channel topography to be accurately represented in the flood modeling. This involved compiling the depth soundings from nautical charts produced by the Canadian Hydrographic Service for off shore and tidal areas. The digital Chart 4381 information covered the offshore and the mouth of the LaHave River to approximately Kraut Point. These data were supplemented by digitizing additional sounding from the paper chart which extended from Kraut Point to Upper LaHave. To further supplement these data, AGRG collected additional depth soundings using their 15 foot aluminum boat and depth sounder for the section of the river from Upper LaHave to the northern town limits where the river becomes too shallow to safely navigate the boat (Figure 2:4).

For the areas upstream of Bridgewater a combination of depths were measured using the depth sounder mounted on a canoe (Figure 2:5) and for extremely shallow locations GPS and depth measurements were obtained manually by walking across the river (Figure 2:6, Figure 2:7).

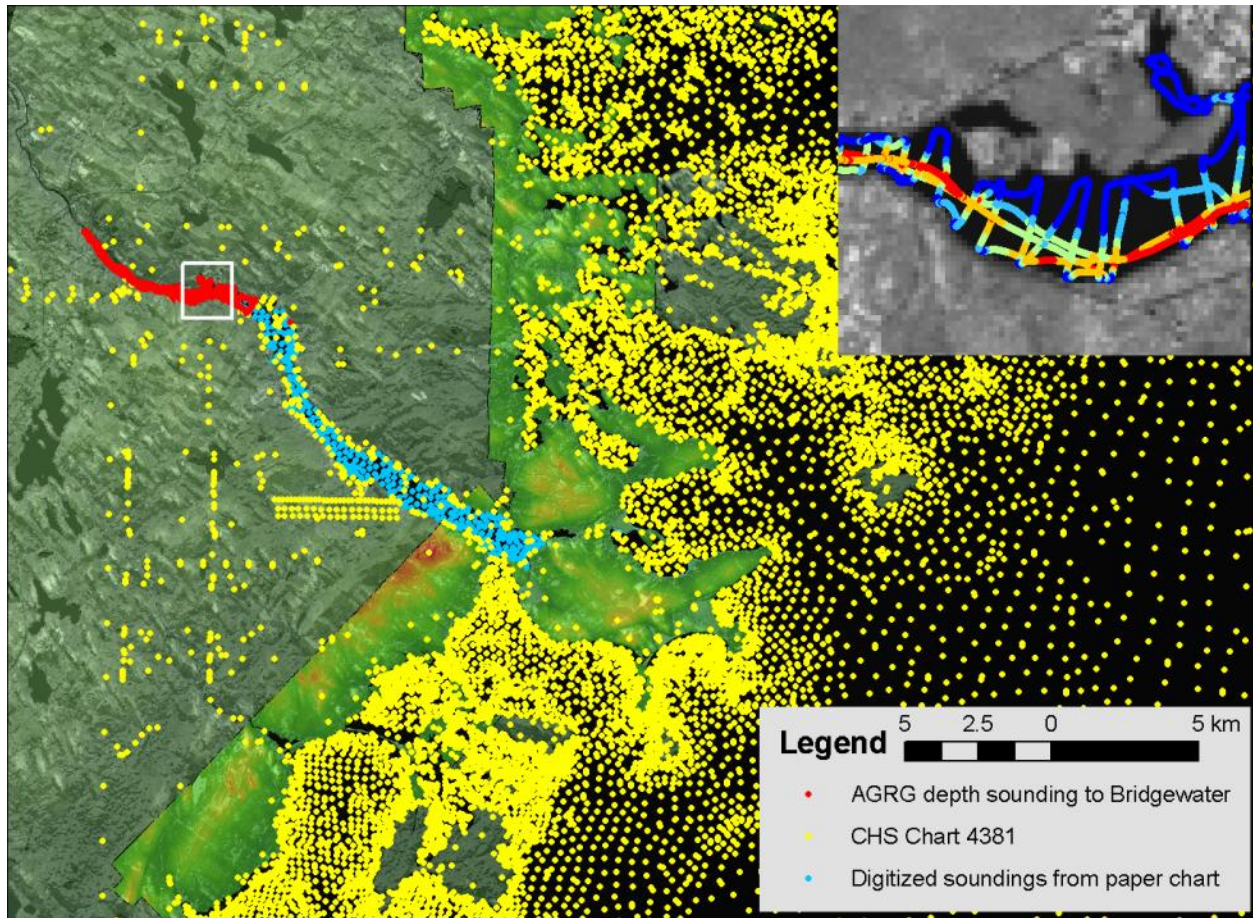


Figure 2:4 Sounding information available in digital format (yellow points, NOTE: points on land represent text label locations in the file), digitized from paper chart (blue points), and the AGRGR survey (red points) up to Bridgewater; the white box denotes detailed inset map of depths (upper right). The background map is the 20 m DEM except along the coast where lidar exists.