Coastal Hydrodynamic Flood Risk Mapping of River Phillip, Nova Scotia

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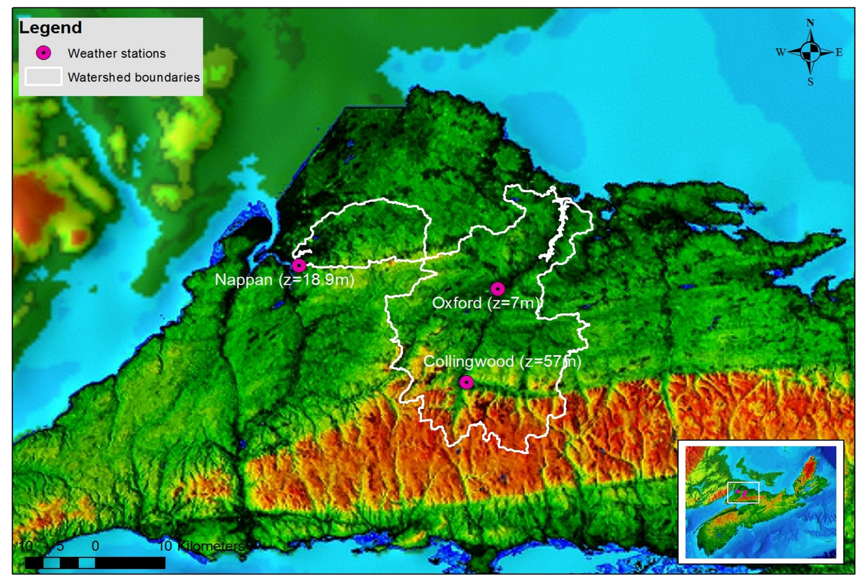

Figure 1: Environment Canada's Nappan weather station and AGRG's Oxford and Collingwood weather stations. The River Phillip watershed is outlined in white.

Introduction

The town of Oxford, NS (Fig.1) has undergone significant flooding for a number of years. Floods are caused by high precipitation events, storm surges, and a combination of both. Flood prediction recurrence and flood inundation modelling was accurately assessed for flooding associated with heavy rainfall by Stiff (2008). In order to fully understand flooding in coastal areas, rainfall events need to be linked with ocean surge events. It is the goal of this study to incorporate the important effect that storm surge and the tides can have on flooding in Oxford.

This study focuses on two major events
(1) September 21-24, 1999: A 1 in 23 precipitation-based flood event (Stiff, 2008)
(2) December 21, 2010: A Nor'easter that caused a 1.5 m storm surge and severe coastal erosion.

The system was modelled using coupled river (1-D model, Mike-11) and coastal (2-D model, Mike-21) hydrodynamic models. Bathymetric data for River Phillip was collected (Fig.2) in the fall of 2010 using a small boat equipped with RTK-GPS. The bathymetry was then combined with lidar data to form a seamless DEM to use in flood inundation modelling.

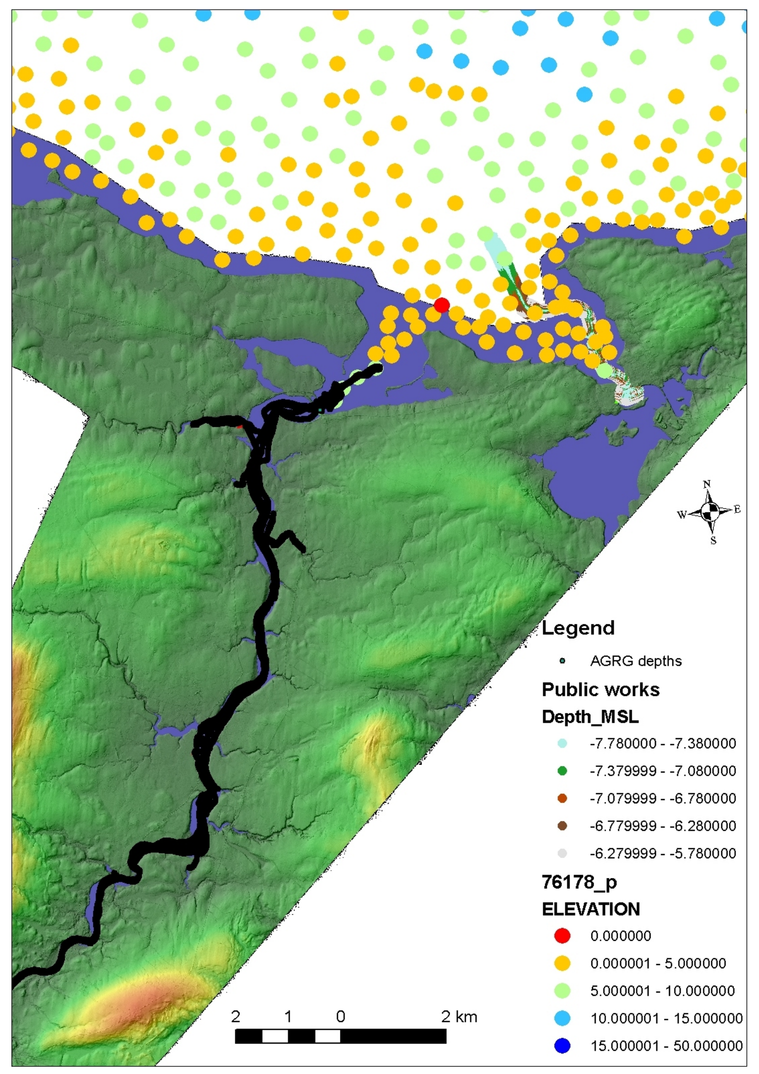

Figure 2: Chart soundings (large dots), public work multibeam survey near Pugwash, and River Phillip estuary bathymetric survey (this study) (black points).

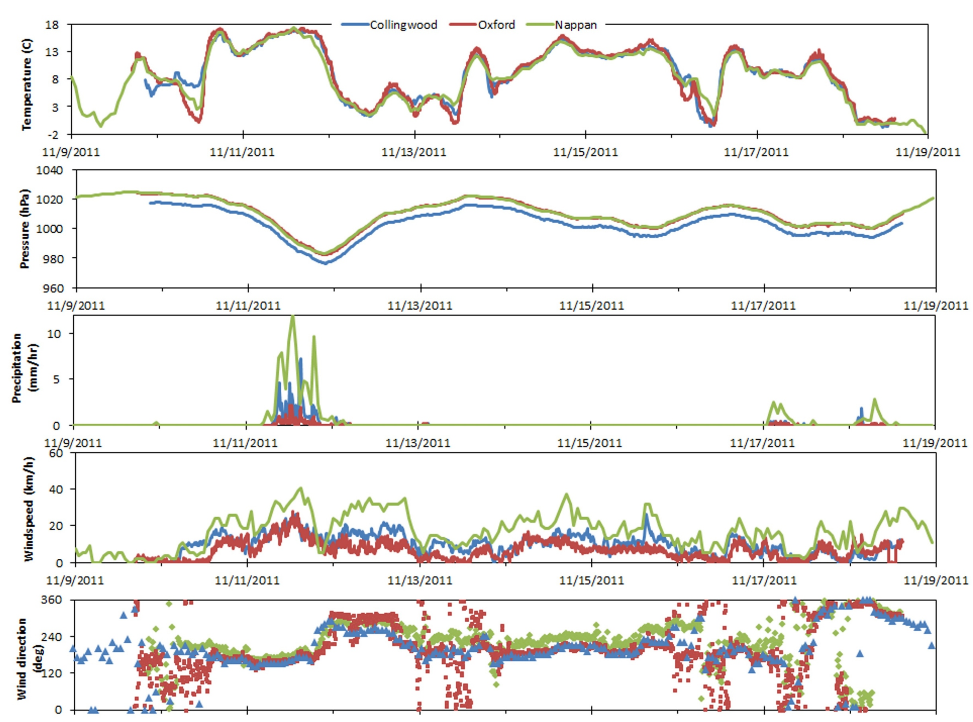

Figure 3: Weather measured at AGRG weather stations Collingwood and Oxford, and Environment Canada weather data from Nappan. Good agreement justifies using Nappan weather data for Oxford modelling.

Methods

Modelling

Rainfall events were simulated for the Oxford area by linking meteorological driving factors to a lumped runoff model. Inland storm surge events were modeled by linking deep ocean astronomical sea surface elevation predictions in the Northumberland Strait with a high resolution shallow water two dimensional hydrodynamic model.

DHI's Mike21 2D Hydrodynamic Module provided the linkage between deep and shallow ocean predictions by simulating unsteady flow dynamics of water level variations and flows in response to a forcing boundary of deep ocean tidal elevations provided by the WebTide Tidal Prediction Model produced by DFO (Fig. 14A). Mike21 model elevations were compared against a tide gauge installed by AGRG at Brickyard Rd. wharf in Pugwash (Fig. 14B) in order to establish proximal tide phase differences and elevation residuals caused by environmental factors. Once validated, Mike21 model elevations were extracted along a perpendicular portion of River Phillip which was coincident with a Mike11 Rainfall runoff / 1D Hydrodynamic Module boundary (Fig. 14C). Extracted elevations at the Mike11 were used to simulate the influence of tidal stage on inland areas which extended to the town of Oxford. This method of linking deep ocean predictions to shallow water hydrodynamics and rainfall runoff scenarios was ultimately used to establish the interaction between significant rainfall and ocean surge events in coastal flooding.

Figure 5: Flooding in Oxford in September, 1999.

Meteorological Data

Environment Canada (EC) weather data from nearby Nappan, NS (Fig.1), was used as meteorological forcing to model the River Phillip watershed, as there is no EC station in Oxford. To justify this choice, AGRG installed a weather gauge at Oxford in 2011. The good comparison of Nappan and Oxford data justifies the use of Nappan data for the modelling (Fig.3).

September 1999 Rainfall Event

Rainfall between September 21 and 23rd reportedly exceeded 200 mm at Oxford. Nappan recorded ~165 mm (Fig.6). Figures 4 and 5 show the extent of the flooding in Oxford.

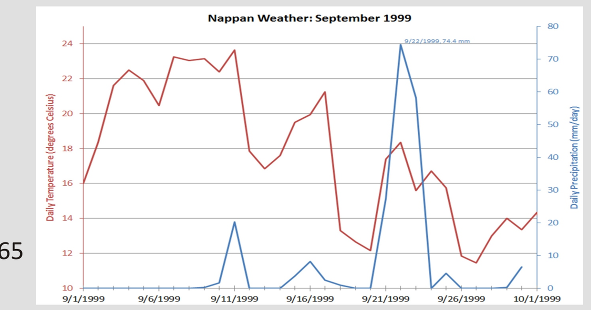

Figure 6: Daily temperature and rainfall record from Environment Canada meteorological station, Nappan, for September, 1999.

Figure 4: A baseball field in Oxford before (left) and after (right) the flood of September, 1999. Source: Doug Stiff thesis. View down

Figure 7: Flooding/storm surge at Northport on December 21, 2010. Source: The Amherst Times.

Tides

River Phillip empties into the Northumberland Strait at Pugwash, 18 km from Oxford. Tidal range at Pugwash is 2.5 m during highest high tide. There is anecdotal evidence that during extreme high tide events flood waters recede more slowly.

December 2010 Storm Surge Event

The storm of December 21, 2010 was a Nor'easter, characterized by prolonged strong winds from the North and low pressure (Fig.11). High tide along the Northumberland Strait coast coincided with peak high winds (Fig.11) to cause a 1.5 m storm surge. Precipitation was minimal. Figures 7-9 show storm surge and related flooding in Northport, Pugwash, and along the Amherst shore.

Figure 8: Flooding at the Port Phillip Bridge, December, 2010. Source: Andrew MacDonald

Figure 9: Coastal erosion following the Dec. 21, 2010 storm at the Amherst Shore.

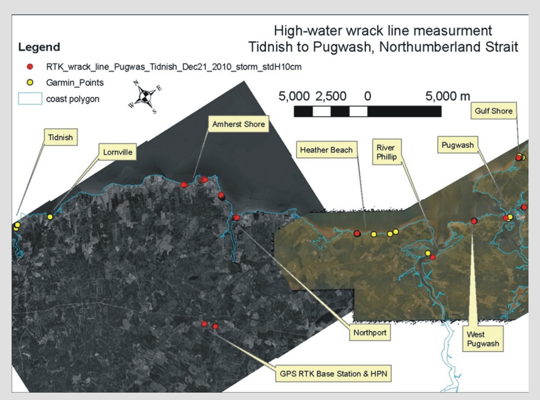

Figure 10: The map shows the coastal sites that were visited and high water GPS elevation were obtained for the Dec. 21, 2010 storm.

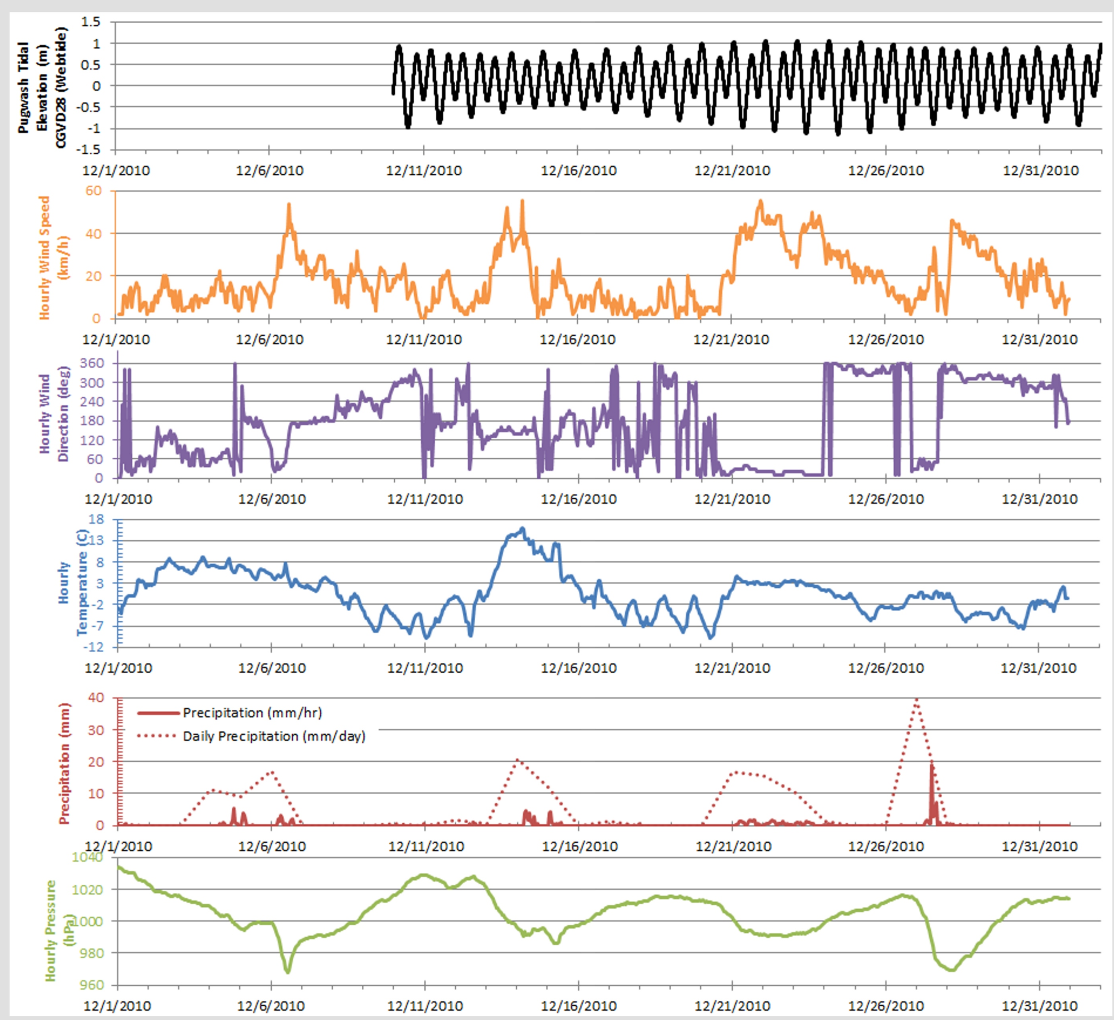

Figure 11: Top panel is tidal elevation at Pugwash (Webtide); next 5 panels are weather measured at Nappan, NS during December, 2010 showing strong northerly winds on Dec. 21, 2010.

Results

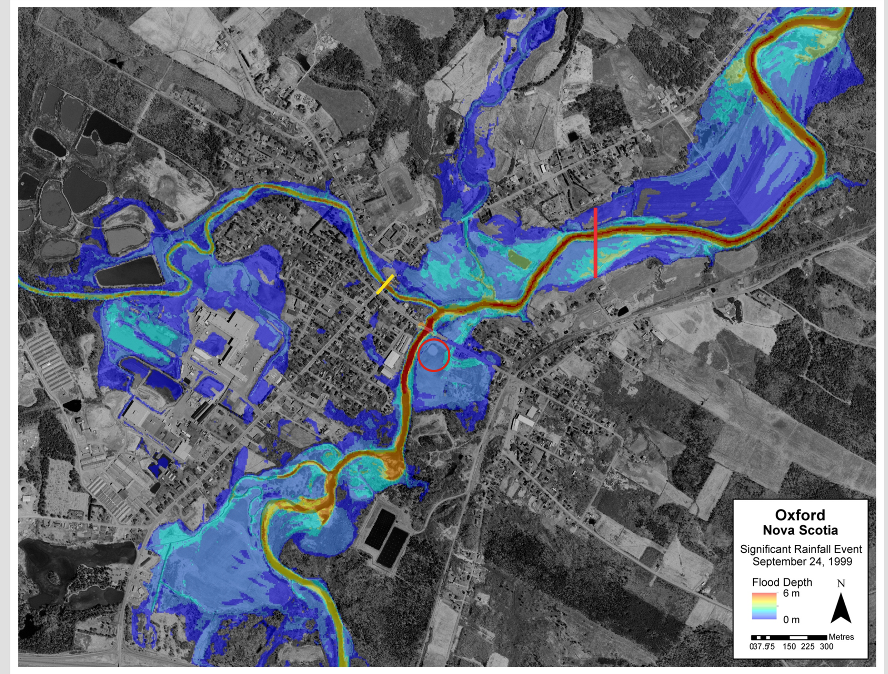

Figure 12: Flood extent produced by modelling the rain event of September, 1999. The red circle and yellow line mark the ball field and bridge, respectively, shown in Fig.4; the red line indicates the location of the results in Fig.13.

September 1999

Modelling of the heavy precipitation event in September 1999 was successful. Figure 12 shows the extent of River Phillip flooding on September 24. The area flooded was 2.06 km^2 and the baseball field was covered with 1.6 m of water.

Figure 13 shows modelled discharge and stage at the red line shown on Fig.12. Stage was ~6 m and discharge exceeded 600 m^3/s.

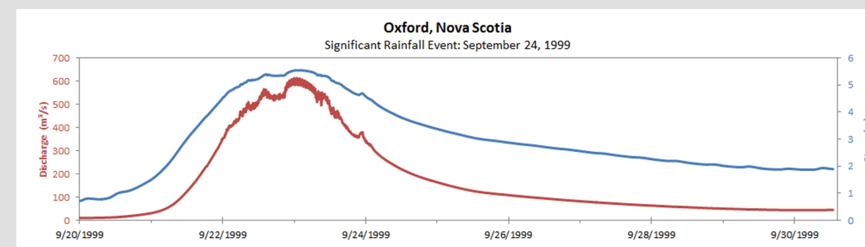

Figure 13: Modelled discharge and river stage for September, 1999, measured at the red line shown in Fig.12.

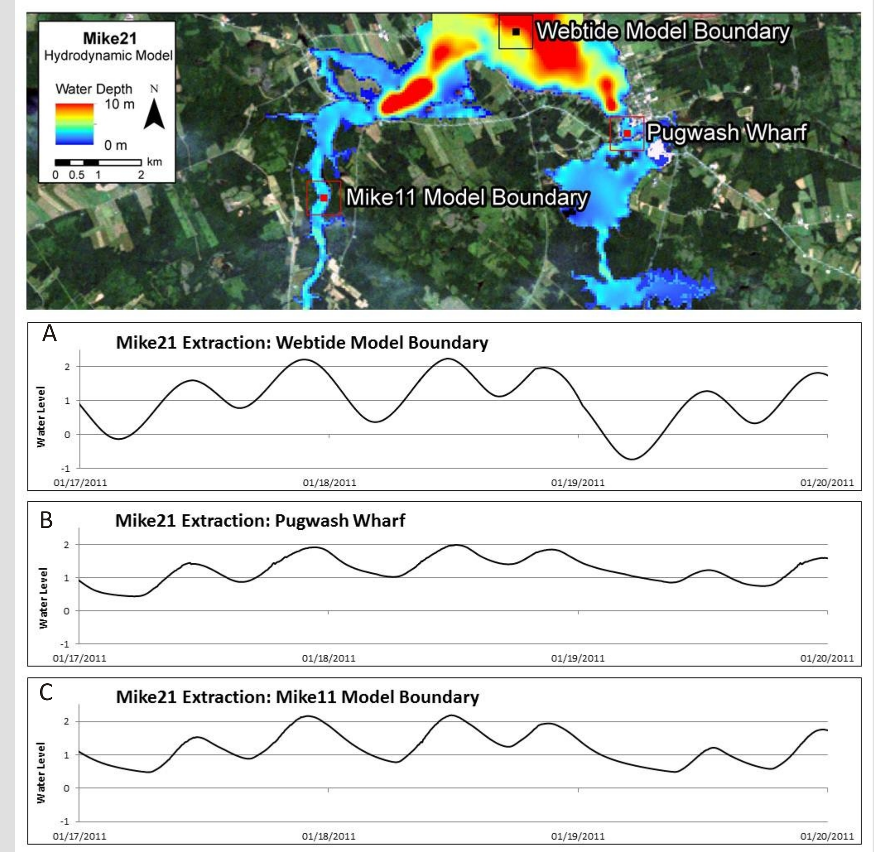

Figure 14: Landsat image with water depth from the Mike21 2-dimensional hydrodynamic model. Extraction points are displayed along with elevation time series data for WebTide model boundary (A), Pugwash Wharf (B) and Mike11 model boundary (C).

December 2010

The storm surge event in December 2010 was well-modelled. Figure 15 shows the extent of River Phillip flooding on December 21. The area flooded was 0.36 km^2, Far less than the 1999 event. The ball field was not flooded in this event.

Figure 16 shows modelled discharge and stage at the red line shown on Fig.15. Stage was ~3 m at the marker and reached a maximum of 4m in the model domain. Discharge remained low (~40m^3/s).

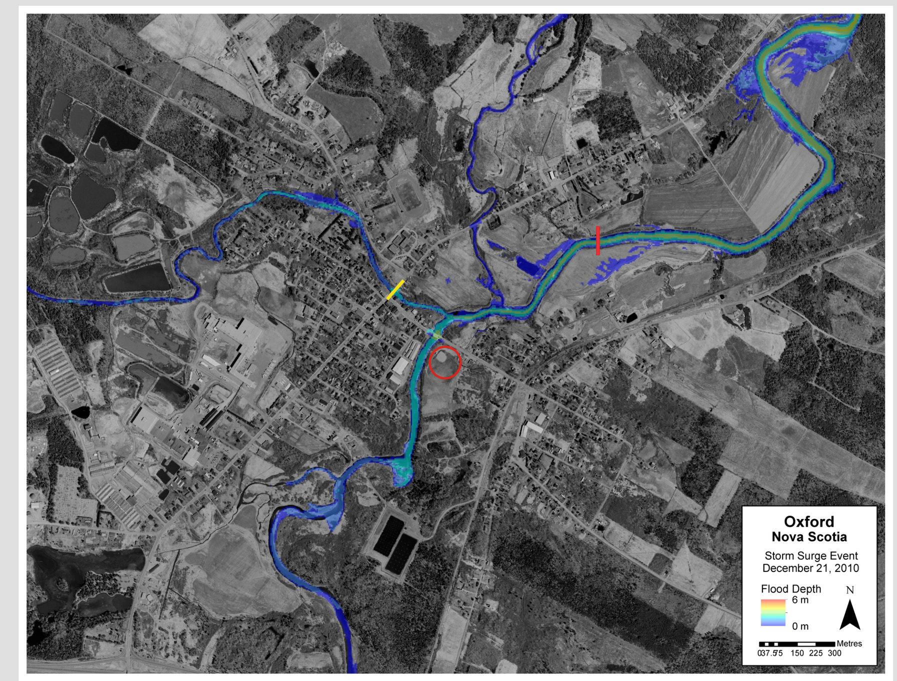

Figure 15: Flood extent produced by modelling the storm surge event of Dec., 2010. The red circle and yellow line mark the ball field and bridge, respectively, shown in Fig.4; the red line indicates the location of the results in Fig.16.

Combined Events

To predict the extent of flooding if an event with the heavy precipitation of September 1999 combined with the extreme storm surge of December 2010, Mike11 was forced with September 1999 precipitation records and December 2010 tides and storm surge as initial conditions.

The combined event flooded the model domain by 0.38 km^{2}more than flooding caused by precipitation alone (Fig.18). The ball field is under 1.8 m of water, 20 cm more than during the 1999 flood.

Stage exceeded the level of the 1999 flood by ~60 cm at the red line shown on Fig.18, and by 1m over the whole domain. Discharge exceeded the value of the 1999 flood by ~200 m^3/s (Fig.17).

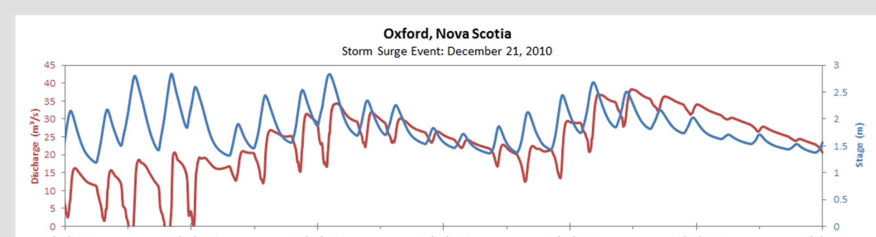

Figure 16: Modelled discharge and river stage for Dec., 2010, measured at the red line shown in Fig.15.

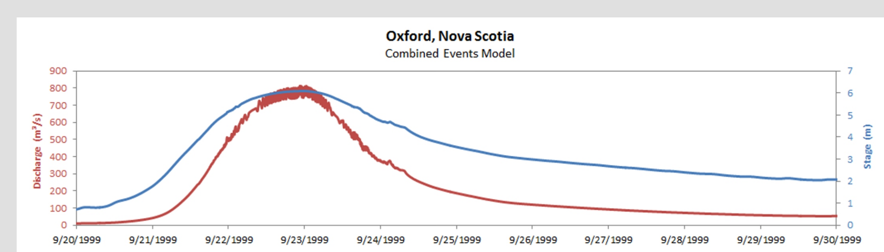

Figure 17: Modelled discharge and river stage for September, 1999, measured at the red line shown in Fig.18.

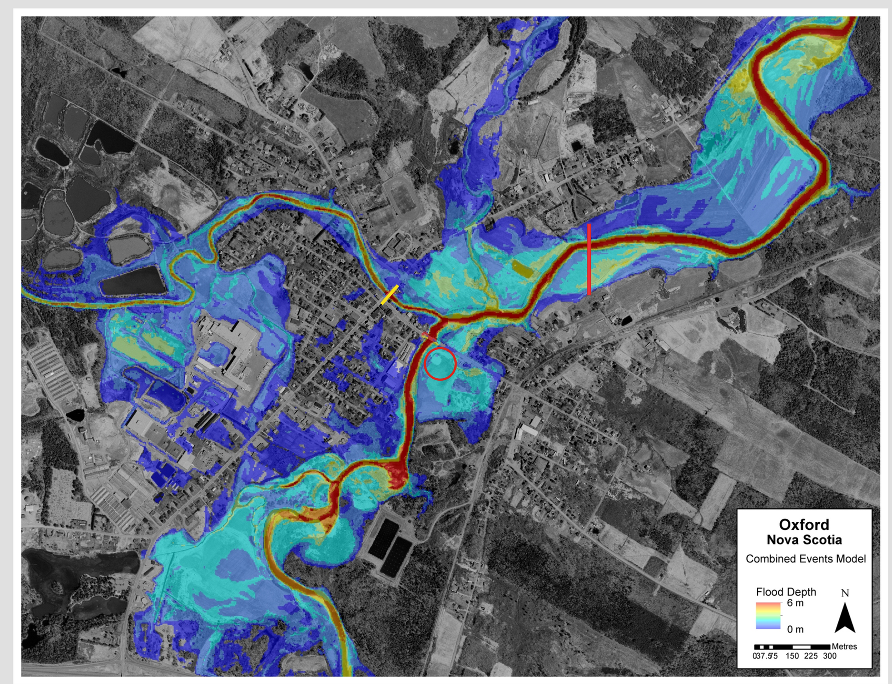

Figure 18: Flood extent produced by modelling a scenario that combined the rain event of Sept., 1999 and the storm surge of Dec., 2010. The red circle and yellow line mark the ball field and bridge, respectively, shown in Fig.4; the red line indicates the location of the results in Fig.17.

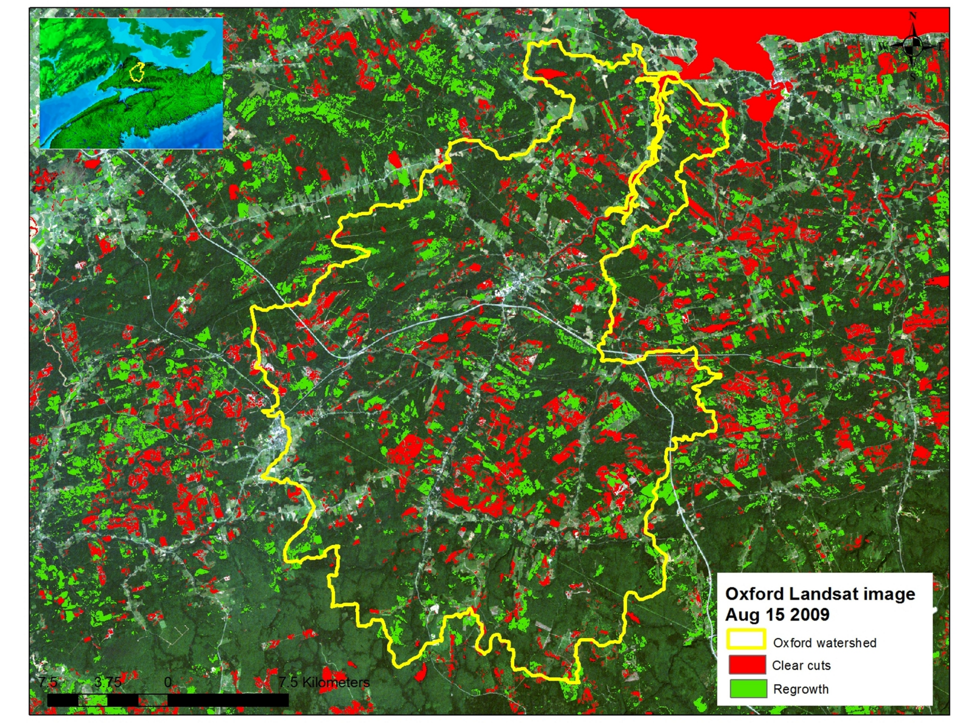

Figure 18: Change in land use between 1999 and 2009 in the Oxford watershed, showing clear cuts and regrowth, on the 2009 satellite image.

Conclusions

It is important to consider both rainfall and storm surge events in low elevation coastal communities prone to significant flood events. This work has demonstrated that storm surges coupled with rainfall do produce higher magnitude floods than either event alone. The tidal influence of the Northumberland Strait has an effect on the discharge of the River Phillip estuary for a significant distance from the coast. This influence has been reported by local residents at Oxford during river flood events. This study, which linked the river runoff model and the tidal-surge model has demonstrated this interaction. This type of coupled modelling can be applied to many coastal estuaries around Nova Scotia.

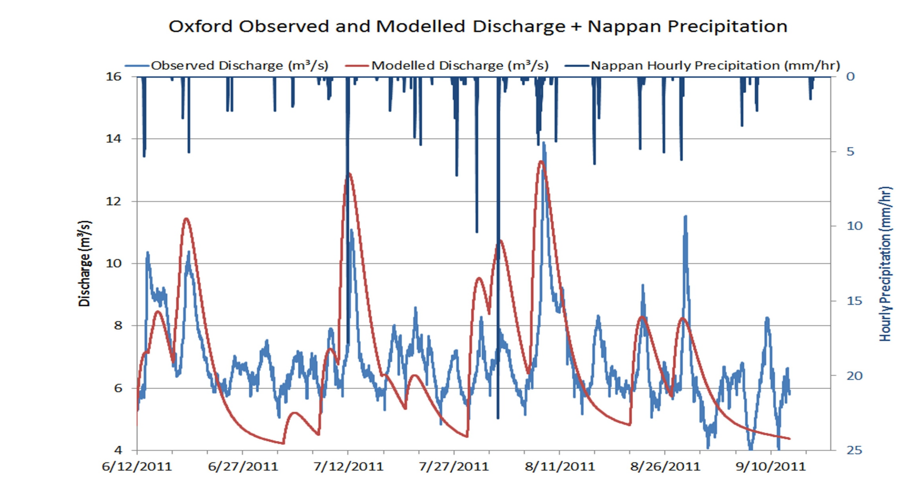

Fig. 19: Mike11 watershed model validation hydrograph showing observed and modelled discharge, and precipitation at Nappan.

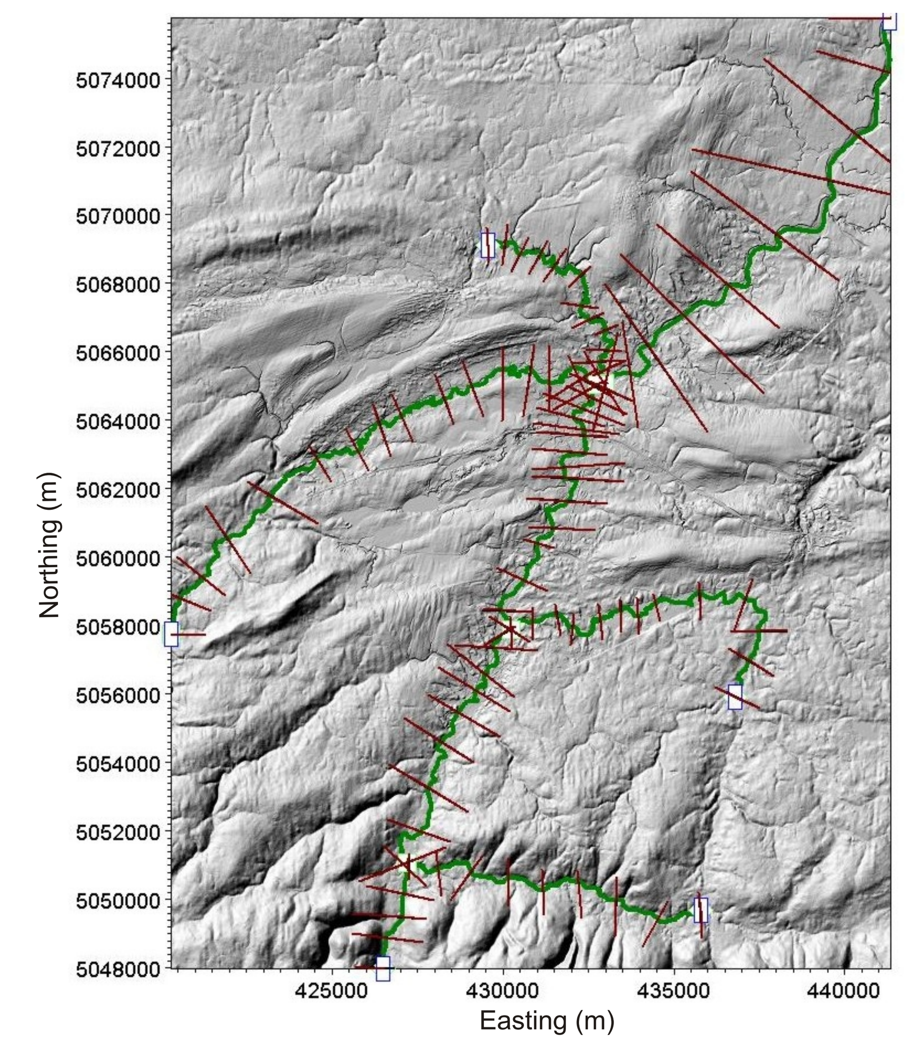

Figure 19: Shaded relief model showing the extent of the Mike11 model. Red lines indicate cross-sections along river branches, which are depicted in green. Cross-sections were drawn to capture potential flood areas.

References

Stiff, Douglas T. "INVESTIGATING FLOOD RISK IN AN UNGAUGED WATERSHED USING LIDAR, GIS, AND HEC TOOLS." MSc thesis Acadia University, 2008.

Acknowledgements

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