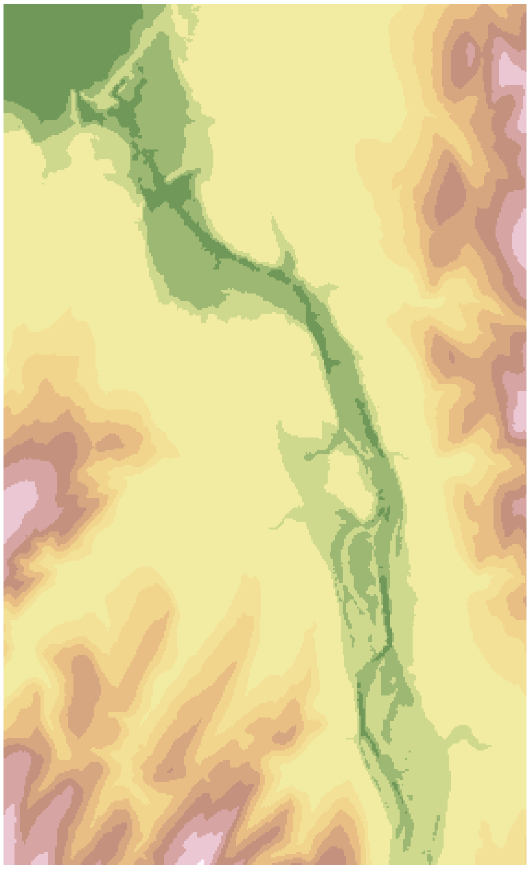

Nova Scotia Municipal Flood Line Mapping – Margaree River

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Copyright and Acknowledgement

1. Executive summary

Nova scotia Department of Municipal Affairs and Housing identified three test cases for Flood line mapping in the province. Dillion Consulting Ltd. in partnership with the Nova Scotia Community College – Applied Geomatics Research Group (NSCC-AGRG) was successfully granted for the test case two which is Margaree River in Inverness county. The estuarine component was modelled by NSCC-AGRG using DHI Mike 21 2-D hydrodynamic model with river discharge and coastal water levels elevated by potential coincident storm surges for return periods of 1:20 and 1:100 years along with the effects of relative sea level rise and Antarctic ice sheet melt considering climate change for present to a timeframe of 2100. Existing data were not adequate to develop an accurate model of the Margaree estuary. Additional depth data were collected by NSCC-AGRG using a single beam echo sounder in the river and estuary and compiled from various sources. Flood extent and depth maps have been generated for the estuary and river to reflect recommended scenarios presented in the recent provincial guidelines. Due to the restricted time frame it was difficult to collect data for validation, but comparisons made with a documented 2010 storm show model results are valid.

2. Introduction

1.1 Project Background

The Department of Municipal Affairs and Housing in Nova Scotia identified three test cases for flood line mapping – River John, Margaree and Guysborough. Dillion Consulting Ltd. in collaboration with the Nova Scotia Community College – Applied Geomatics Research Group (NSCC-AGRG) modelled a test case which consisted of the Margaree river watershed and the coastal area adjacent to the watershed. NSCC-AGRG's contribution to the project was the coastal and estuary flooding component. The estuarine environment required coupling a costal circulation model with a fluvial model to capture the interaction of the ocean and fluvial hydrodynamics. For this purpose, NSCC-AGRG used the DHI suite of tools including Mike 21 2-D hydrodynamic Flow Model (FM). Fresh water inputs were provided by engineers from Dillon who conducted the upstream fluvial floodplain analysis utilizing the HEC tool suite from the US Army Corp. of Engineers.

The estuarine component was modelled with the river discharge and coastal water level elevated by potential coincident storm surge for return periods of 1:20 and1:100 added to Higher High Water Large Tide (HHWLT) along with relative sea level rise (climate change + subsidence) and an additional 65 cm sea level rise caused by the projected collapse of the West Antarctic ice sheet (James et al, 2014). Flood depth maps were successfully generated for present and future conditions using the described storm surges and sea level rise scenarios.

3. Study Area Description

The study area was divided into two sections to support efficient coastal modelling: 1) deep-water (coastline from Inverness to Cheticamp extending 15km offshore) and 2) the Margaree estuary (Figure 2.3.1). The extents for the study areas were defined to accurately simulate the deep-water tidal movement and velocities coming from the West and North directions from the open ocean into the coast and estuary. Simulation results from the deep-water domain were used to validate tidal predictions at the mouth of the Margaree estuary which were subsequently used to drive the high-resolution estuary model. The study area makes an ideal test case for flood line mapping due to its history of flooding (5 Hydrodynamic modelling).

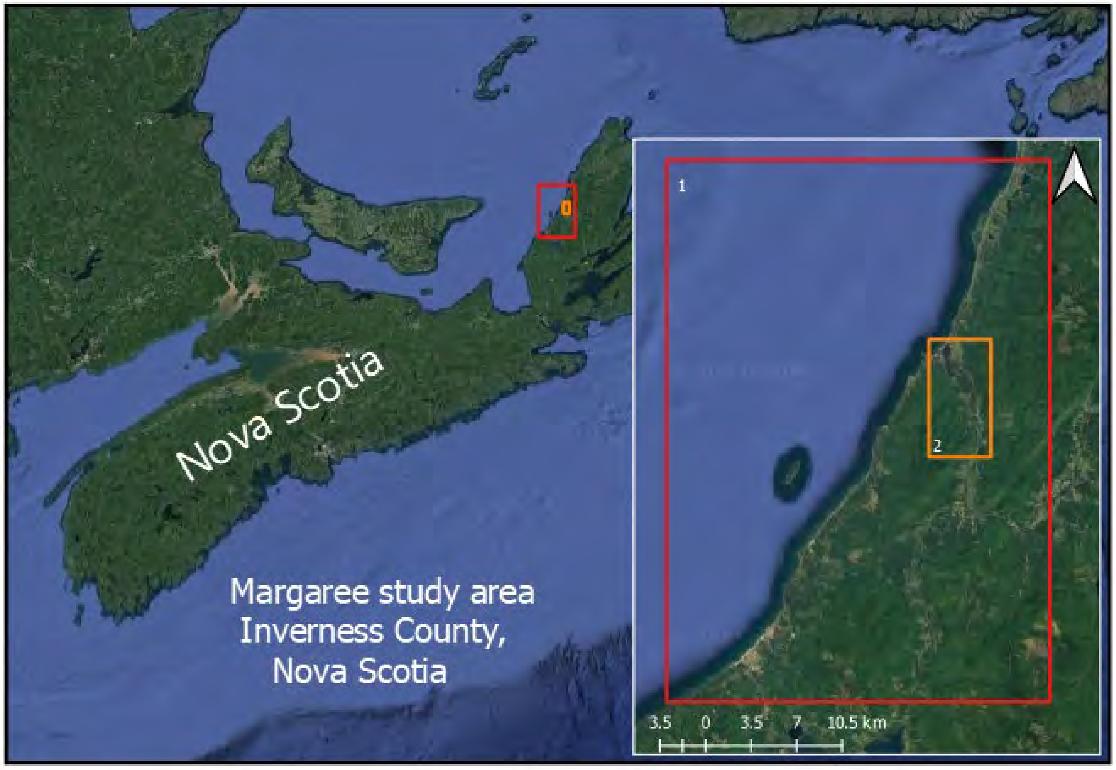


Figure 2.3.1 Margaree River study area 1) Deep waters and 2) Estuary and River till tidal pool (south of chapel bridge)

4. Data Compilation and Review

4.1 Coastal

NSCC-AGRG was required to model the coastal zone including the estuarine component. Data were compiled from several sources to accurately represent the near-shore bathymetric and coastal elevations. Bathymetric grids were generated for the two model domains to support the MIKE 2D model. While the deep water and land elevations were well represented, there were no soundings available for the river and in-situ data collection was required to support river and estuary modelling.

3.1.1 Coastal Bathymetry

AGRG researchers conducted a Single Beam Echo Sounder (SBES) survey with a BioSonics Mx system along with a survey grade GNSS mounted on the vessel on December 17th, 2019 to survey depths for the inter-tidal region of the Margaree. Data were collected in two transects along the river channel along with several cross sections to obtain the bathymetric profile of the channel (Figure 4.1, Figure 4.2). Secondary data were obtained from Canadian Hydrographic services (CHS) in the estuary and coastal areas to represent deep water elevations used develop the model. A terrestrial Digital Elevation Model (DEM) was obtained from GeoNova at 1m resolution and was used to represent topographical elevations (Table 4.1).

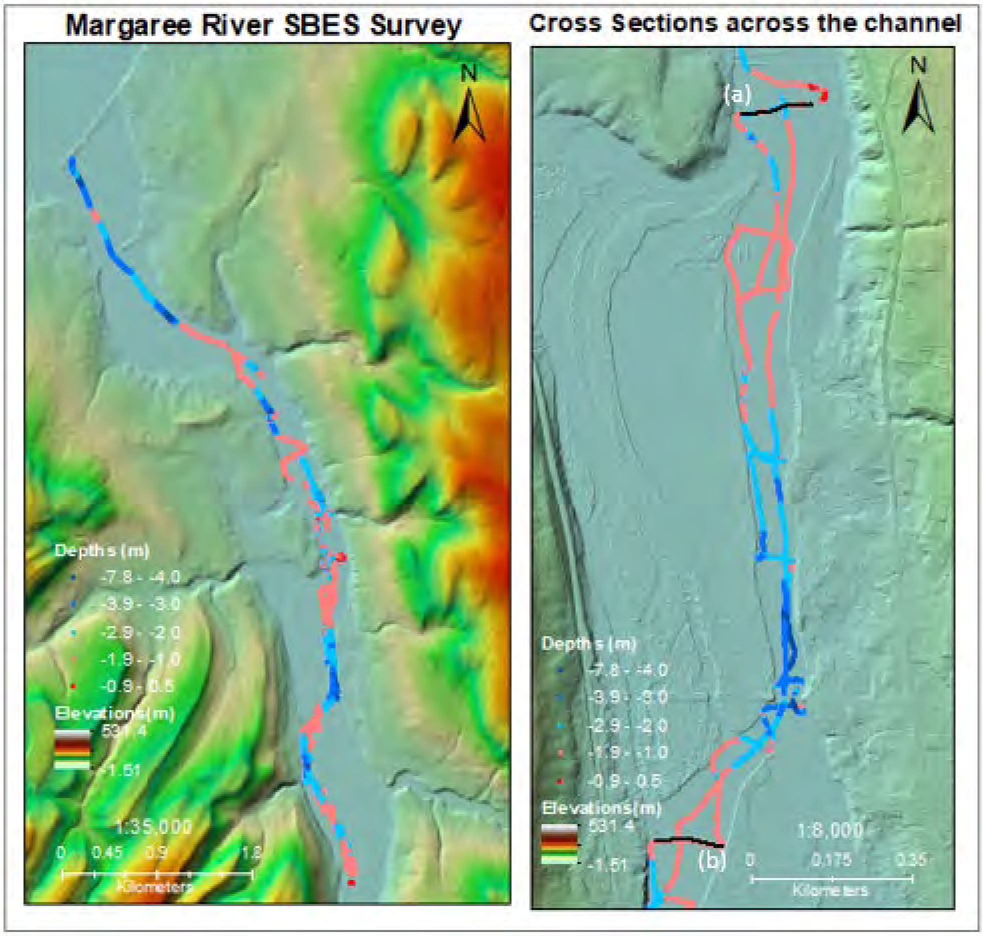
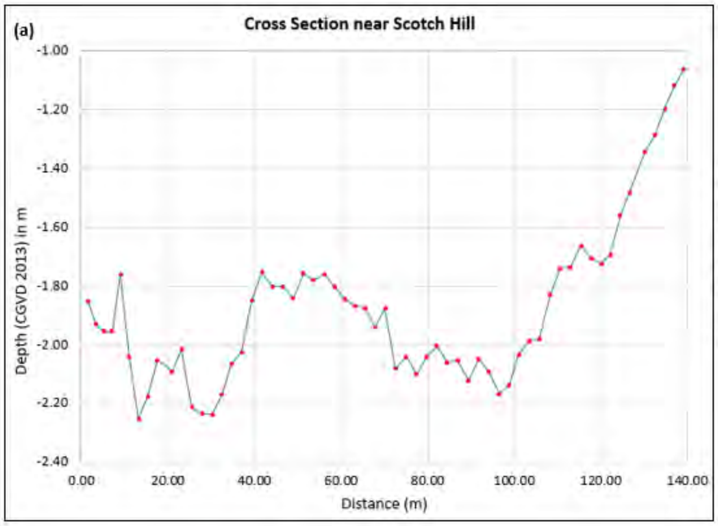


Figure 4.1 depth data collected by NSCC-AGRG using a single beam echo sounder overlaid on a lidar DEM provided by GeoNova.



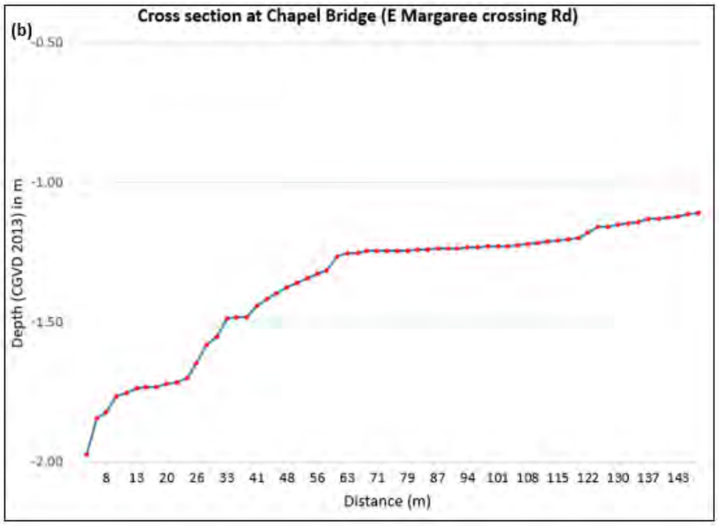


Figure 4.2 a, b Cross sections of the river before and after the Chapel Bridge (Distance from left bank -downstream) c: GNSS antenna mounted on the pole (port side) above the transducer head d: AGRG researcher collecting echosounder data in Visual habitat software package.

Table 4.1 Bathymetric and topographic data sources, resolution, method and offset applied to convert from CD, CGVD 1928 to CGVD 2013.

Domain	Provider	Method	Offset applied/ notes	Native Resolution	Year collected
River (inter-tidal)	AGRG	SBES (BioSonics)	-0.638 m (CGVD 28 to 2013)	Variable (< 5 m)	2019
Estuary	AGRG	Digitized (CHS charts - 4449)	-1.208 m (CD to CGVD2013)	Variable (> 20 m)	original data 1953
Coastal (deep water)	CHS	ENC - CA376249 (CHS chart – 4463)	-1.208 m (CD to CGVD2013)	Variable (> 20 m)	Last updated 2017
Topo DEM	GeoNova	REIGL Q1560 and VQ1560i	CGVD2013	1 m	2018

3.5.2 Met- Ocean Data

A 40-year analysis was conducted using tide predictions from the Department of Fisheries and Oceans (DFO) WebTide tool at the mouth of the Margaree. HHWLT was found to generally occur over the month of December which was found to be supported by the number of historic flood events occurring during that period such as the December 14-15, 2010 flood where 122.2 mm of precipitation was recorded at the Environment and Climate Change Canada Cheticamp station. Sea level storm surge residuals were calculated for the 2010 event at the mouth of the Margaree using the nearest active tide gauge, located in Charlottetown, PEI. Data were downloaded from DFO and compared against the WebTide prediction model (Figure 4.3). The calculated residuals were subsequently added to the predictions at Margaree (Figure 4.4) to simulate a similar sea level residual and drive a MIKE model to validate inundation extents and depths (5.3 Results and Validation). The transfer of residuals from the Charlottetown station to the Margaree is an imperfect method as these systems were impacted differently by the storm event due to coastal orientations and other factors. However, given the lack of available data, this comparison was determined to be the best comparison that could be achieved.

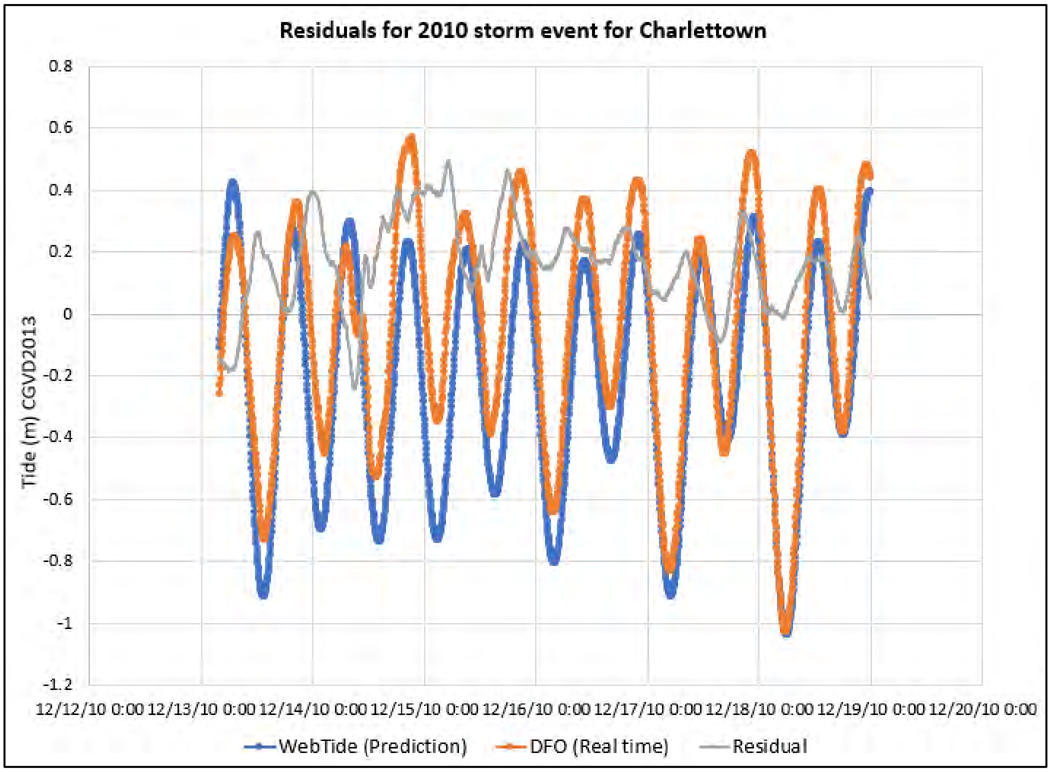


Figure 4.3 Comparing real time data collected at Charlottetown tide gauge station (Station # 1700) with the WebTide predictions for 2010 storm

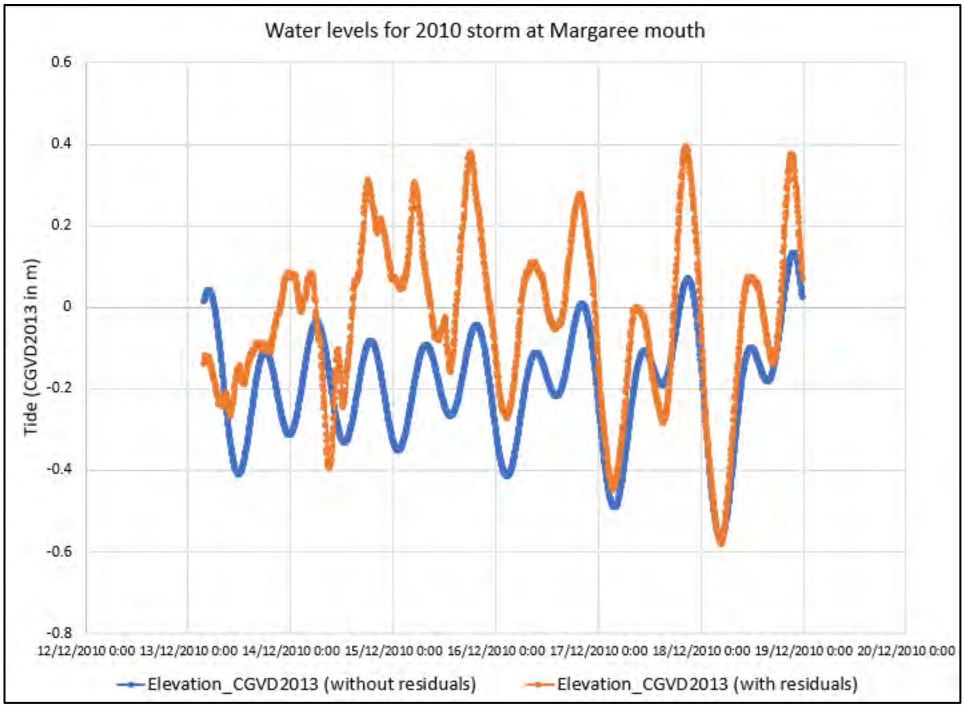


Figure 4.4 Water levels at the mouth of the Margaree river obtained after adding the residuals from Charlottetown for 2010 event

5. Hydrodynamic modelling

A high-resolution 2-D hydrodynamic (HD) model was developed using DHI Mike-21™ software to simulate current flow and water level variations within the study area domains. Mike 21 Flow Model was determined to be the best application for this study area as the two-dimensional model would simulate accurate in-land flooding while neglecting the minimal water column stratification. The model could be run with minimal high-quality inputs including a bathymetric surface and tidal predictions at the model boundaries that are described in detail in sections below.

5.1 Model set up

A variety of sources and resolutions of topography and bathymetry data were compiled (Table 4.1) to generate a high-quality bathymetry grid in order to complete the flow model for the two model domains. Elevation models were computed using the spline technique (Wahba, 1990) within the ESRI ArcGIS software package to generate a low-resolution 50 m grid for the deep-water area (Domain 1) and high-resolution 5 m grid for estuary and river (Domain 2) (Figure 5.1, Figure 5.2). Topo data were restricted to a maximum elevation of 5 m to limit the number of cells grid cells used in the simulations while ensuring that inland areas were well represented and susceptible to maximum inundation levels for all modelled storm surge events.

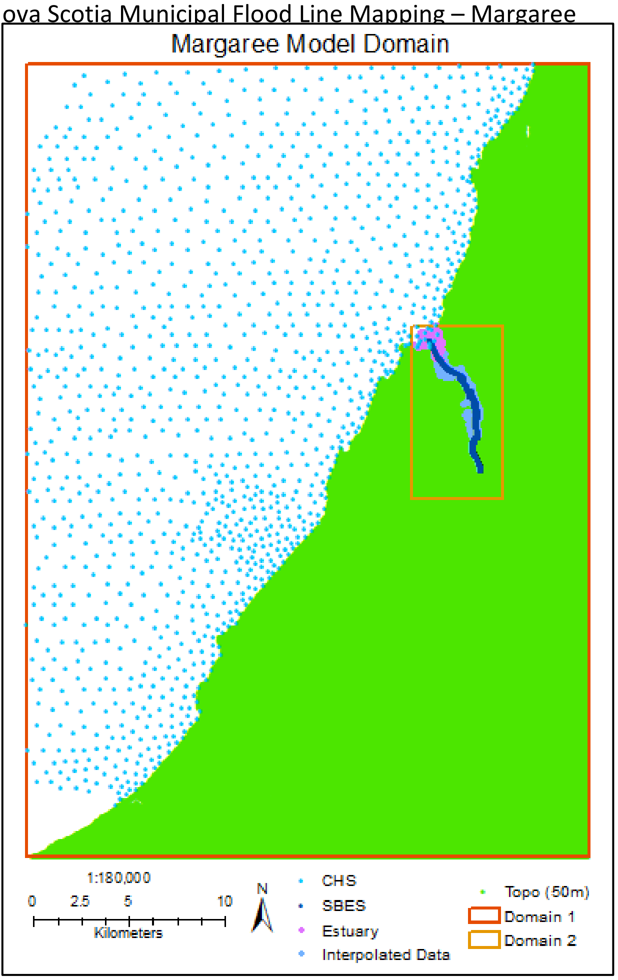


Figure 5.1 Model Domain of the Margaree study area showing data sources

Figure 5.2 Model Domain grids of the Margaree study area with varying resolutions

Hydrodynamic simulations were driven by tidal predictions along the open water boundaries in the west and north edges for Domain 1 and mouth of the river for Domain 2 using time series files generated by WebTide (Dupont et al., 2002) (Figure 5.3) for the month of December at 15 minute timestep intervals.

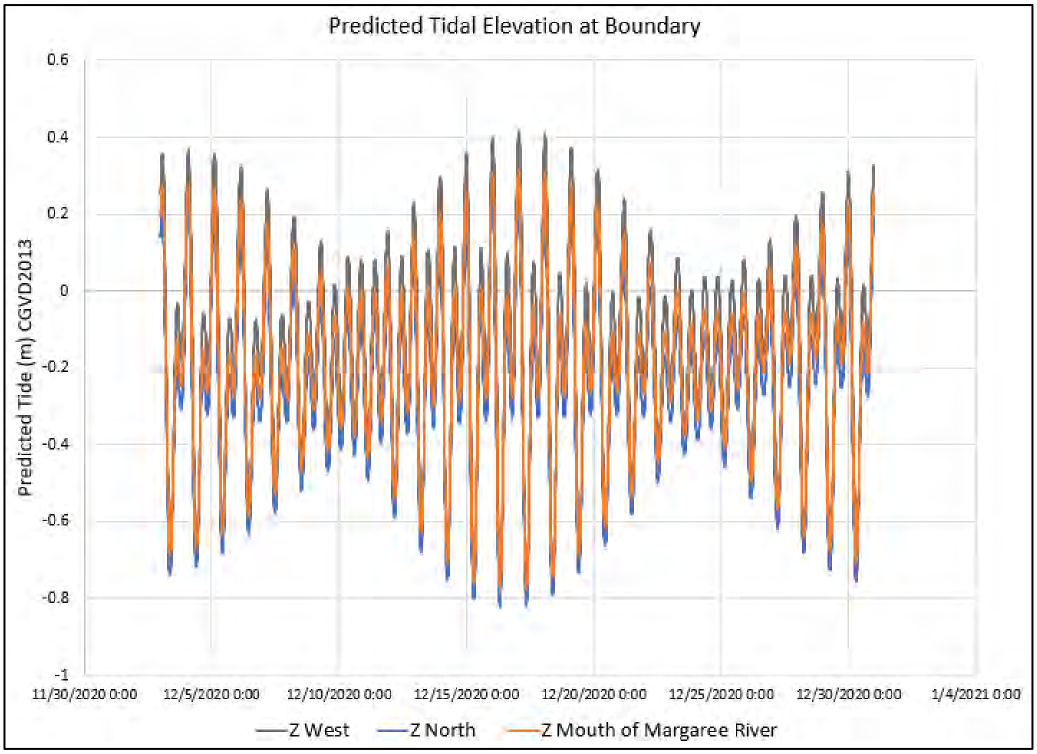


Figure 5.3 Predicted tidal elevations at boundaries

Model results from Domain 1 were compared to WebTide predictions generated at the mouth of the Margaree river to determine if the low-resolution Domain 1 model was required to transfer deep-water tidal predictions to the near-shore area of the high-resolution Domain 2 model. Results of the comparison showed very little difference between the Domain 1 model results and WebTide predictions generated at the mouth of the Margaree with the modelled results being 0.06 cm lower than the predictions (Figure 5.4). Based on this finding it was determined that the higher values generated by WebTide were suitable to drive the high-resolution model to support a coastal vulnerability study.

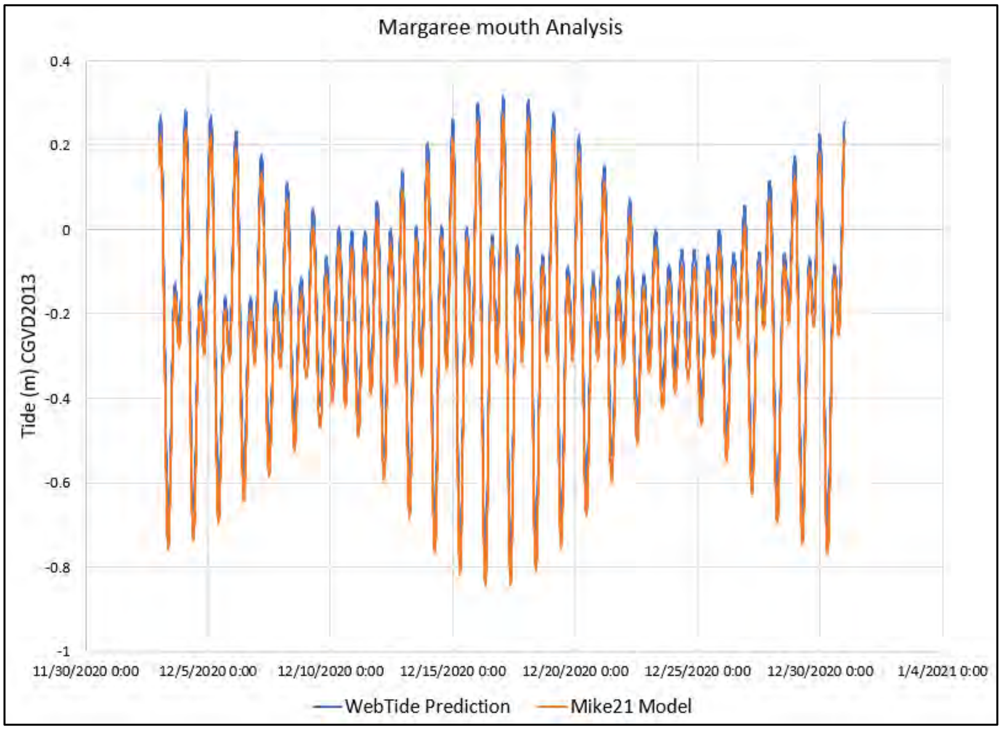
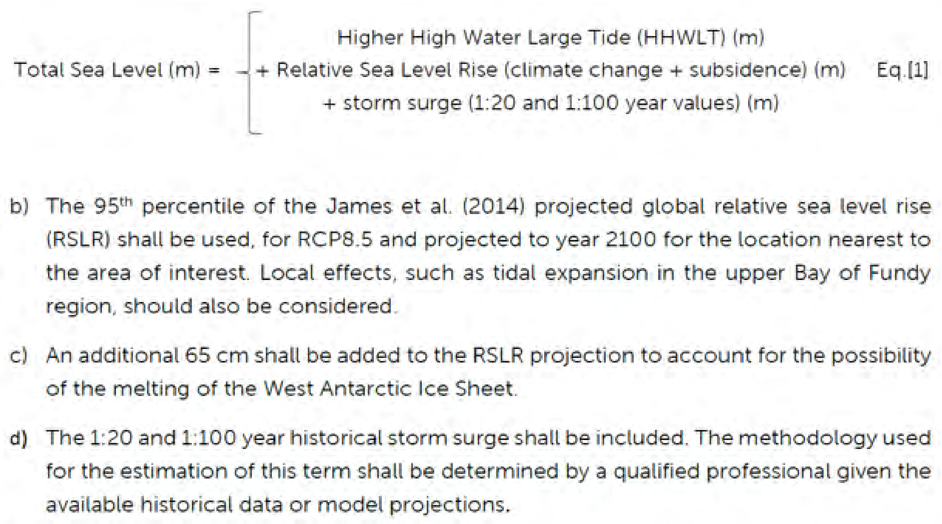


Figure 5.4 Results obtained from Mike 21 model compared with Tidal predictions

The high-resolution estuarine model was found to accurately simulate the flow of water within the Margaree river and estuary and remained stable when simulating high flow during the peak tides of December 2020. Once the developed model was determined to be stable, several model scenarios were developed to model inundation in response to climate change and storm events by making calculated adjustments to the model boundaries. These adjustments accounted for freshwater input from precipitation, provided by Dillion for 1:5 and 1:100 year rain events, storm surge residual sea levels for 1:20 and 1:100 storm events, and additional increases due to climate change projections to the 2100 timeframe.

5.2 Seal level rise

Nova Scotia Department of Municipal Affairs presented guidelines to be followed for flood line mapping cases (Jamieson et al 2019). These guidelines state that the total sea level rise to be used in riverine and coastal flood mapping is to be computed by Equation 1 (Figure 5.5).



$$\text{Total Sea Level (m)} = \begin{cases} \text{Higher High Water Large Tide (HHWLT) (m)} \\ + \text{Relative Sea Level Rise (climate change + subsidence) (m)} \\ + \text{storm surge (1:20 and 1:100 year values) (m)} \end{cases} \quad \text{Eq.[1]}$$

b) The 95th percentile of the James et al. (2014) projected global relative sea level rise (RSLR) shall be used, for RCP8.5 and projected to year 2100 for the location nearest to the area of interest. Local effects, such as tidal expansion in the upper Bay of Fundy region, should also be considered.

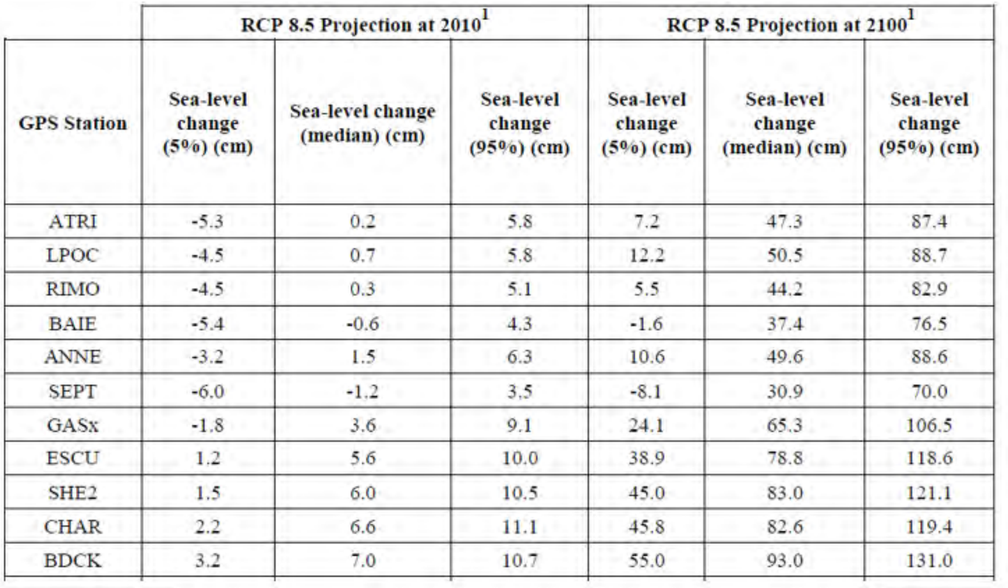
c) An additional 65 cm shall be added to the RSLR projection to account for the possibility of the melting of the West Antarctic Ice Sheet.

d) The 1:20 and 1:100 year historical storm surge shall be included. The methodology used for the estimation of this term shall be determined by a qualified professional given the available historical data or model projections.

Figure 5.5 Guidelines for computing total sea level (Jamison et al, 2019).

HHWLT was calculated to be 0.34 m at the mouth of the Margaree using the DFO CHS continuous vertical datum (CVD). The CVD value was found to be 0.09 m above the HHWLT reported at the CHS Cheticamp station (0.25 m). However, when compared to a 40-year tidal prediction generated at the mouth of the Margaree using WebTide the predicted 40-year HHWLT matched the CVD value and the 0.34 m HHWLT was determined to be valid.

The projected relative sea level change at a coastal site depends on local vertical motion of the ground, spatial variations in redistribution of glacial meltwater in the global oceans, and regional changes to sea label due to dynamic oceanographic effects in addition to projected global sea level change. The total relative sea level rise at 95% percentile by 2100 for Representative Concentration Pathways (RCP) scenarios 8.5 was calculated to be 1.31 m at the most proximal station located in Baddeck, Nova Scotia (Figure 5.6; James et al, 2014). An additional 0.65 m was added to future projections to account for the melting of the West Antarctic Ice Sheet (Jamison et al, 2019).



	RCP 8.5 Projection at 2010[1]			RCP 8.5 Projection at 2100[1]		
GPS Station	Sea-level change (5%) (cm)	Sea-level change (median) (cm)	Sea-level change (95%) (cm)	Sea-level change (5%) (cm)	Sea-level change (median) (cm)	Sea-level change (95%) (cm)
ATRI	-5.3	0.2	5.8	7.2	47.3	87.4
LPOC	-4.5	0.7	5.8	12.2	50.5	88.7
RIMO	-4.5	0.3	5.1	5.5	44.2	82.9
BAIE	-5.4	-0.6	4.3	-1.6	37.4	76.5
ANNE	-3.2	1.5	6.3	10.6	49.6	88.6
SEPT	-6.0	-1.2	3.5	-8.1	30.9	70.0
GASx	-1.8	3.6	9.1	24.1	65.3	106.5
ESCU	1.2	5.6	10.0	38.9	78.8	118.6
SHE2	1.5	6.0	10.5	45.0	83.0	121.1
CHAR	2.2	6.6	11.1	45.8	82.6	119.4
BDCK	3.2	7.0	10.7	55.0	93.0	131.0

Figure 5.6 Projected Relative Sea- Level Change at 2010 and 2100 for RCP 8.5 (James et al., 2014)

Residual tides were calculated for the Margaree using the most proximal long-term gauged system located in Charlottetown, PEI. Storm surge return periods were calculated by Bernier (2005) and presented by Daigle (2011). Using the generated model (y = 0.1858ln(x) + 0.6981) the 20-year and 100-year residual tides were calculated to be 1.25 m and 1.55 m respectively. A summary of sea level increases and model scenarios can be found in Table 5.1.

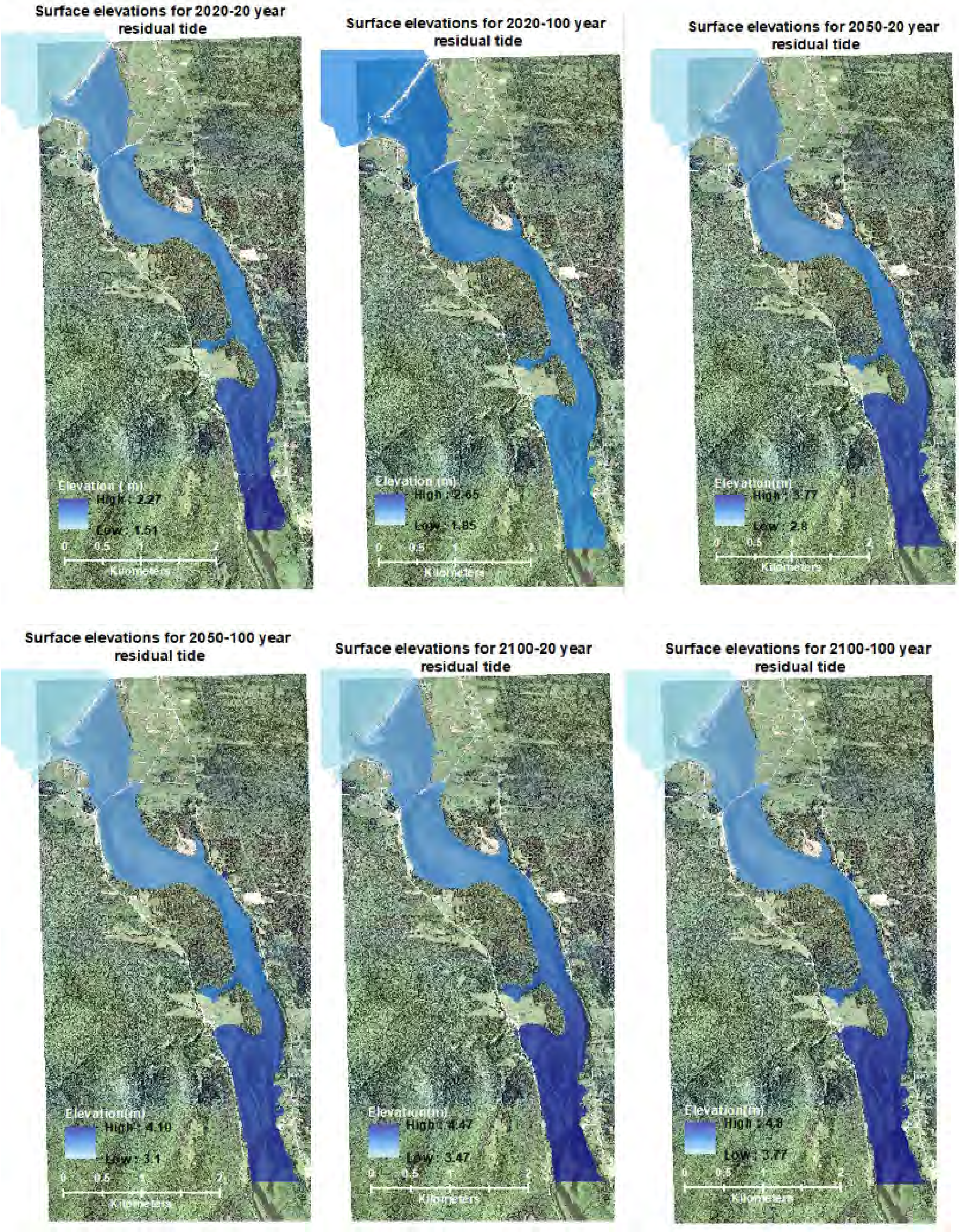
Scenario	RSL 95% (m) *A	Residual Tide (m) *B	HHWLT (m) CGVD2013 *C	Ice Melt (m) *D	Total Sea Level (m CGVD2013)	Freshwater Input *E
2010 Validation	0.00	0.55	0.34	0.00	**0.89**	1:100
2020 – 1:20 Year	0.00	1.25	0.34	0.00	**1.59**	1:5
2020 – 1:100 Year	0.00	1.55	0.34	0.00	**1.89**	1:5
2050 – 1:20 Year	0.64	1.25	0.34	0.65	**2.88**	1:5
2050 – 1:100 Year	0.64	1.55	0.34	0.65	**3.18**	1:5
2100 – 1:20 Year	1.31	1.25	0.34	0.65	**3.55**	1:5
2100 – 1:100 Year	1.31	1.55	0.34	0.65	**3.85**	1:5

*A - James et al (2014) - Baddeck - Specified by Jamieson et al (2019); 2050 projection is interpolated.
*B - Daigle (2011) from Bernier (2005), Charlottetown residual tide model (y = 0.1858ln(x) + 0.6981)
*C - Daigle (2011) - CHS, Cheticamp STN 1539: HHWLT = 1.37 m CD = 0.25 m CGVD2013. Value from CVD = 0.34 m (CHS 2015)
*D - Jamieson et al (2019) probable Wester Antarctic Ice Sheet collapse (0.65 m). No information is specifically given for 2050.
*E - Calculated by Dillon.

Table 5.1 Total sea level rise computed for 2020, 2050 and 2100 for 1:20 and 1:100 storm surge return periods

5.3 Results and Validation

HD models were run for the 1:20 and 1:100 storm surge events for 2020, 2050, and 2100. HD model results were converted into grids for by calculating the maximum surface elevation of inundated areas during the simulation period (Figure 5.7).



Surface elevations for 2020-20 year residual tide

Surface elevations for 2020-100 year residual tide

Surface elevations for 2050-20 year residual tide

Surface elevations for 2050-100 year residual tide

Surface elevations for 2100-20 year residual tide

Surface elevations for 2100-100 year residual tide

Figure 5.7 Maximum inundation extents and surface elevations for each of the modelled scenarios.

While inundation extents appeared to be realistic, no data were available to empirically validate model results. The best option for validating the model was to compare simulated results to observed historical flooding captured in media. The best observations were produced by Bellecote Breaker for the December 15, 2010 storm event published to YouTube on

December 16, 2010. It was found that the 2010 validation simulation underestimated flood extents which was expected as storm surge values were generated by calculating residuals at the Charlottetown gauge which would not directly translate to the Margaree system. Simulation results suggest that the 2010 event closely resembled a 1:5 year storm surge combined with a 1:100 year rainfall event (Figure 5.8).

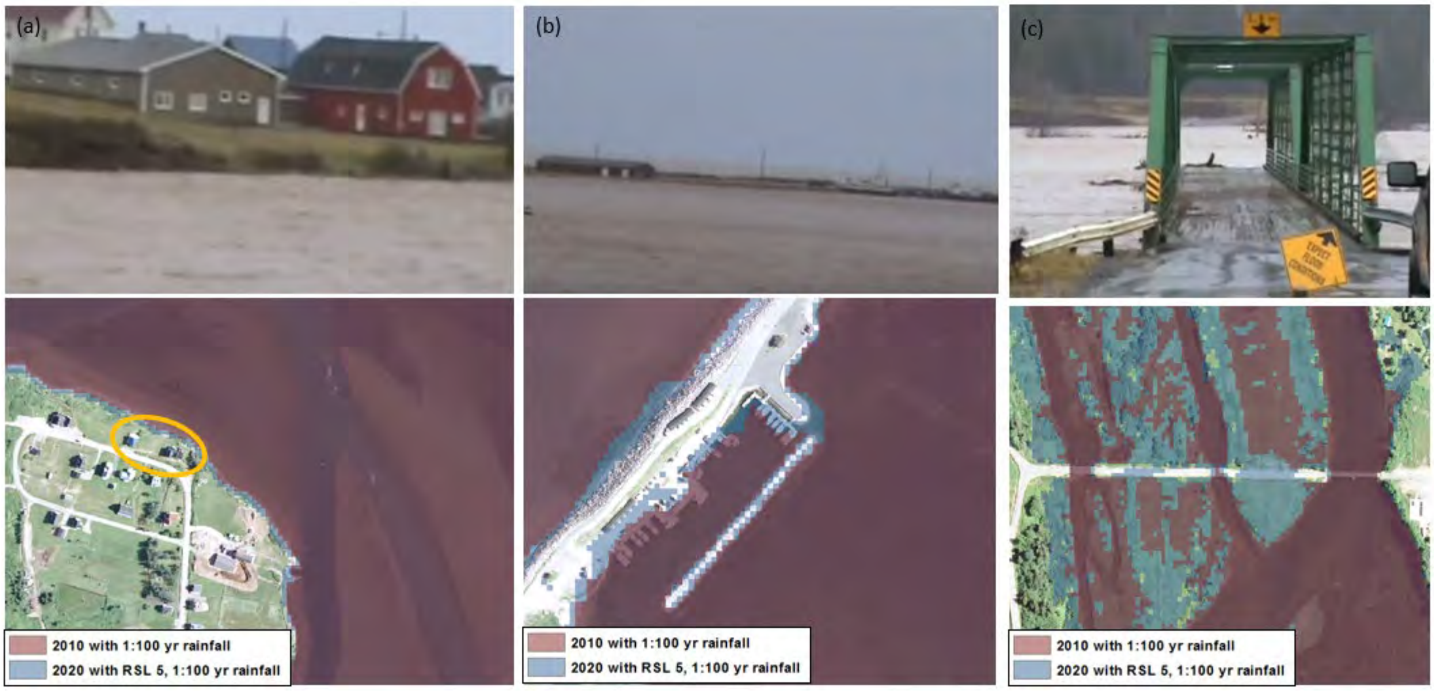


Figure 5.8 2010 ground truth data (video footage by Bellecote Breaker, December 16, 2010) compared with Mike 2D model results. Red model results represent inundation extents generated using observed residual tides from Charlottetown, PEI. Blue model results represent inundation extents generated using a modelled 1:5 year surge event. Observed flood levels closely resemble the 1:5 year modelled surge combined with the 1:100 year rainfall event at the downstream area near the mouth of the Margaree (a) at the eastern wharf (b) and at East Margaree crossing Rd (c).

6. Discussion

6.1 Study Limitations

The primary limitations of the study revolved around time and data. Contracts were awarded _____ which did not provide enough time to establish short-term water level monitoring gauges to validate model results. Environmental data were also limited for the Margaree area. The nearest long-term tide gauge was located 150 km away in Charlottetown, PEI. And the nearest rain gauge was located 20 km away in Cheticamp. These lacks in non-predicted data made empirical model validation impossible.

6.2 Draft Specifications Review and Recommendations

Upon review of the Standard for the incorporation of climate change into riverine and coastal flood mapping in Nova Scotia document, it was expected that actual projections for Nova Scotia on temperature and precipitation changes and coastal water level return periods to be used for future flood assessment studies would be presented. The most useful component of the document presented standards to use for flood line mapping. The biggest data gap is the ability determine the 1:20 and 1:100 year storm surge water levels which must be calculated through extreme value statistical analysis using tide gauge observations. The number of active tide gauges is very limited when considering the size and complexity of the Nova Scotia coastline. Bernier (2005) produced a limited set of return values by using historic wind information every 6 hours to drive the Dalcoast storm surge model. However, because of the limited time step of the wind fields she states that the analysis does not capture short lived events such as hurricanes. Since hurricanes are one of the major sources of coastal flooding, estimates generated using this method are underestimated and not available for everywhere along the coast. The current best source of storm surge return periods is from Richards and Daigle (2011) where they relied on work by Bernier (2005) to estimate storm surge return periods for 10, 25, 50 and 100 year storm surges for future dates 2025, 2055, 2085 and 2100. There is a lack of detailed accurate storm surge return period water levels for the coast around Nova Scotia, apart from areas where there are still operating tide gauges (Halifax, North Sydney, and Yarmouth). Similarly, the chapter on Climate Data & Simulations for Atlantic Canada did not actually present future rainfall and temperature estimates, but rather presented a discussion on possible methods to downscale regional and global models. Again, in order to project future climate change effects on flooding, the Richards and Daigle (2011) report provides estimates annual temperature changes and intensity of short period rainfall percentage change for 2020, 2050 and 2080.

The documents from CBCL Limited, Nova Scotia Municipal Flood Line Mapping Guidance Document, Draft Report ver. 2 and Nova Scotia Municipal Flood Line Mapping Specifications, Draft Report ver. 2 provides more insight as to how flood line maps should be generated. However, they recommend a set of approved modelling platforms that appear to be somewhat limited in scope and do not clearly state the criteria that was used to select them. For one-dimensional Steady State and Unsteady Flow they list HEC-RAS and SWMMS as approved models but do not mention the DHI suite of models such as Mike-11 that are used by many engineering and research groups. For two-dimensional hydrodynamic models they state HEC-RAS, PCSWMM2D (Quasi-2D flow) and Deflt3D but do not include the DHI Mike-21 suite or FVCOM that have been used to model coastal circulation including storm surge. They state that the client should be able to re-run the developed models and push for open source programs. This is highly unlikely as most municipalities do not have the skilled personnel to perform such modelling procedures. It is a good idea that the client be delivered all data required in the modelling effort so that it could be reanalyzed by an experienced professional.