and after determining the maximum water elevation of the 3.5 surge simulation, the 5 m GIS-based still-water level (Figure 4:1).

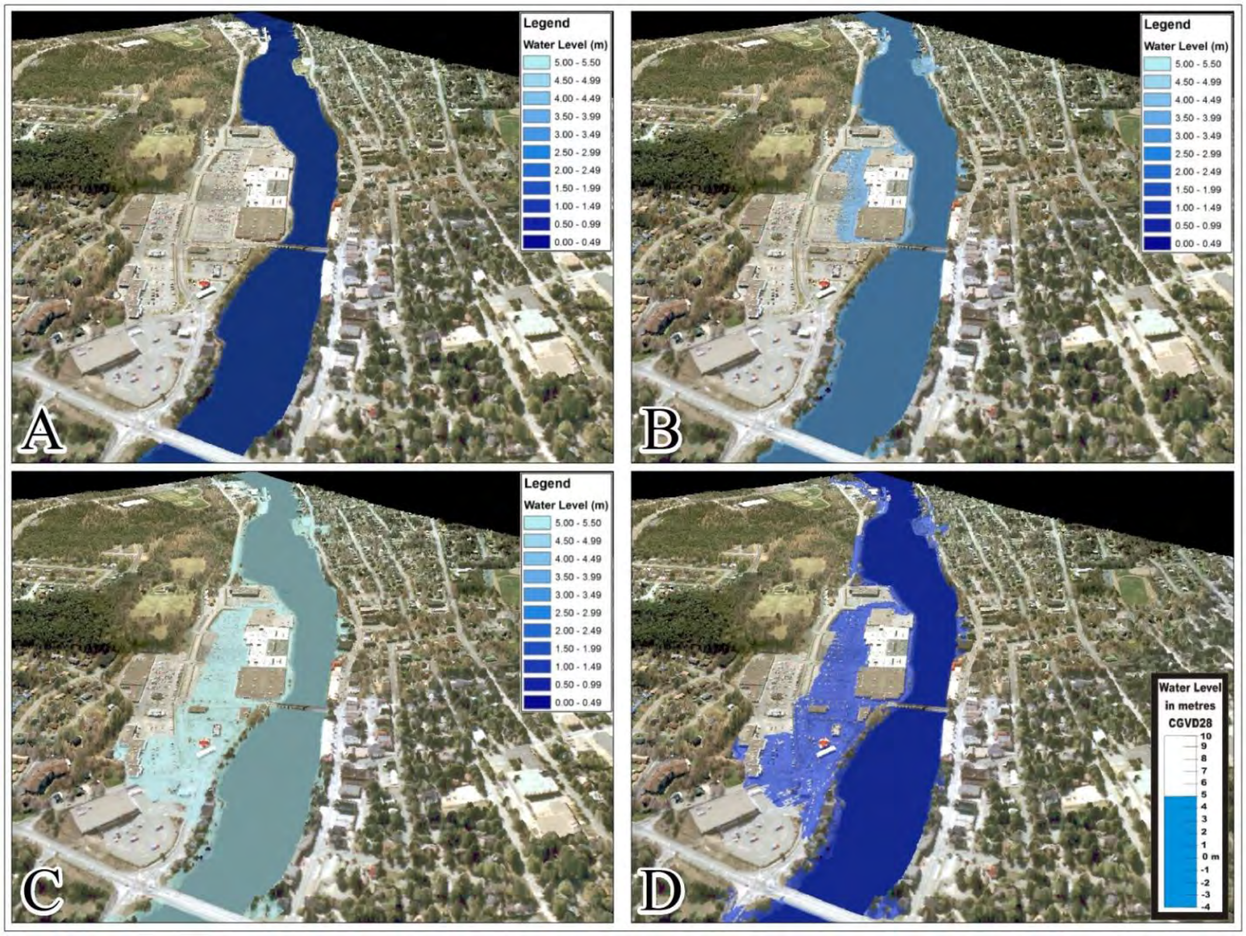

Figure 4:1 Comparison perspective views of the flood risk extents from the combined hydrodynamic (HD) model and still-water GIS method. A) Normal water level HD model, B) Normal tide + 2.2 m storm surge HD model, C) Normal tide + 3.5 m storm surge HD model, D) GIS still-water model for the 5 m water level.

There are subtle differences between the flood extent of the hydrodynamic model and the GIS still-water model. However, for small sections of the coastline, the GIS model produces very similar results. However, we have had the benefit of generating a storm surge of 2.2 m and 3.5 m on top of high tide at the tidal boundary, located at the mouth of the LaHave estuary (Figure 2:16) and determining what the maximum water elevation is for the waterfront areas in order to know which GIS still-water levels to compare (Figure 4:2). In general, the flood layers produced by the GIS-still water approach over estimates the flood inundation (see A compared to B for Figure 4:2). This is a direct result of the method used in the GIS approach which assumes a horizontal water surface. In the case of the hydrodynamic approach, the water surface is variable and conforms to the gradient of the river channel for each time-step. However, with that said, the flood extents produced by the GIS model are very similar to those produced by the more sophisticated and complicated HD model (Figure 4:2).

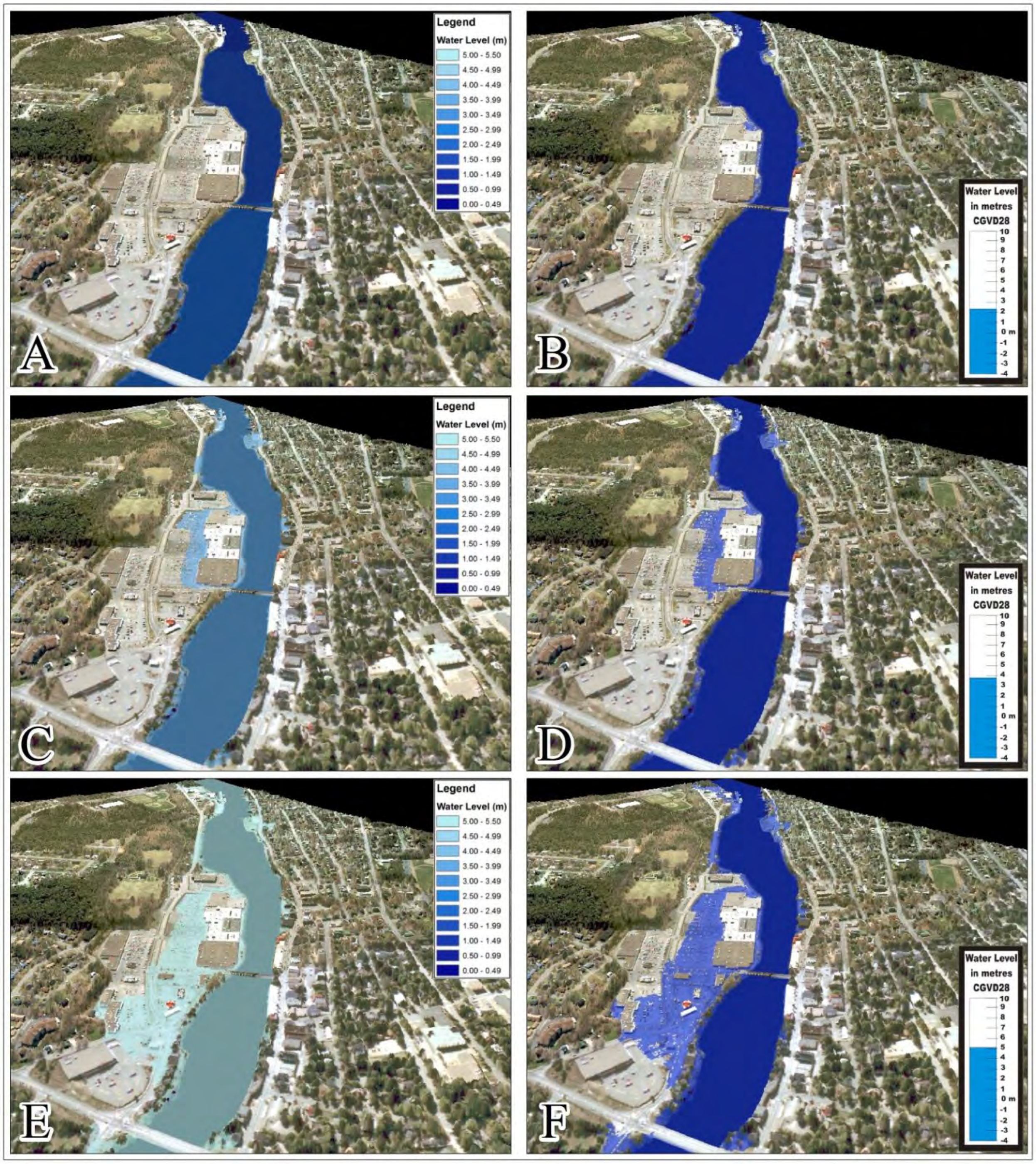

Figure 4:2 Comparison perspective views of the flood risk extents of different water levels from the combined hydrodynamic (HD) model (left panel) and still-water GIS method (right panel). A) Normal high tide HD model, B) GIS still-water level 2.2 m, C) Normal high tide + 2.2 m surge HD model, D) GIS still-water level 3.9 m, E) Normal high tide + 3.5 m surge HD model, F) GIS still-water level 5 m.

As mentioned above, the results of the HD model for each time-step is a water elevation and water depth raster layer. There may be cases where a given time step does not produce the maximum flood extent for all areas on the map as a result of the dynamic nature of the model and the gradient issues discussed. This makes the output of the hydrodynamic model problematic to represent as a single GIS layer on a map. As a result, we have examined the outputs from the HD model and constructed a mosaic, which takes the maximum water level, or water depth, from the output time steps and constructs a raster mosaic of the maximum water elevation and water depth for each of the simulations. A shape file of the extent of the maximum flood extent from the mosaic has been determined and is provided for each simulation.

The HD flood modeling was carried out using the bare-earth DEM from the lidar survey modified to include the bathymetry of the river channel. As a result, the flood extent does not include the buildings or other obstructions that are not represented in the DEM. For the various visualizations and maps, the buildings have been superimposed or projected vertically along with the trees and other objects using the lidar elevations from the DSM in the case of perspective views (Figure 4:1, Figure 4:2). In order to test the potential effect including the buildings in the flood simulation, we assigned elevations to the building footprints and included them in the 3.5 m storm surge simulation. The results indicate that the inclusion of the buildings did not significantly change the flood extent or the time to drain the water back into the river. This may be a result of the fact that a 3.5 m storm surge over a tidal cycle allows enough time for the water to inundate to a maximum level regardless of travel time. The buildings do have an effect on the water flow velocity that may result in increased erosion or other damage to the structures that was beyond the scope of this project (Figure 4:3). It is interesting to note that the dominant flow direction downstream for the river is constant even with a 3.5 m storm surge on high tide, although eddies appear in the current during the peak push of the tide-surge with the river discharge (Figure 4:3).

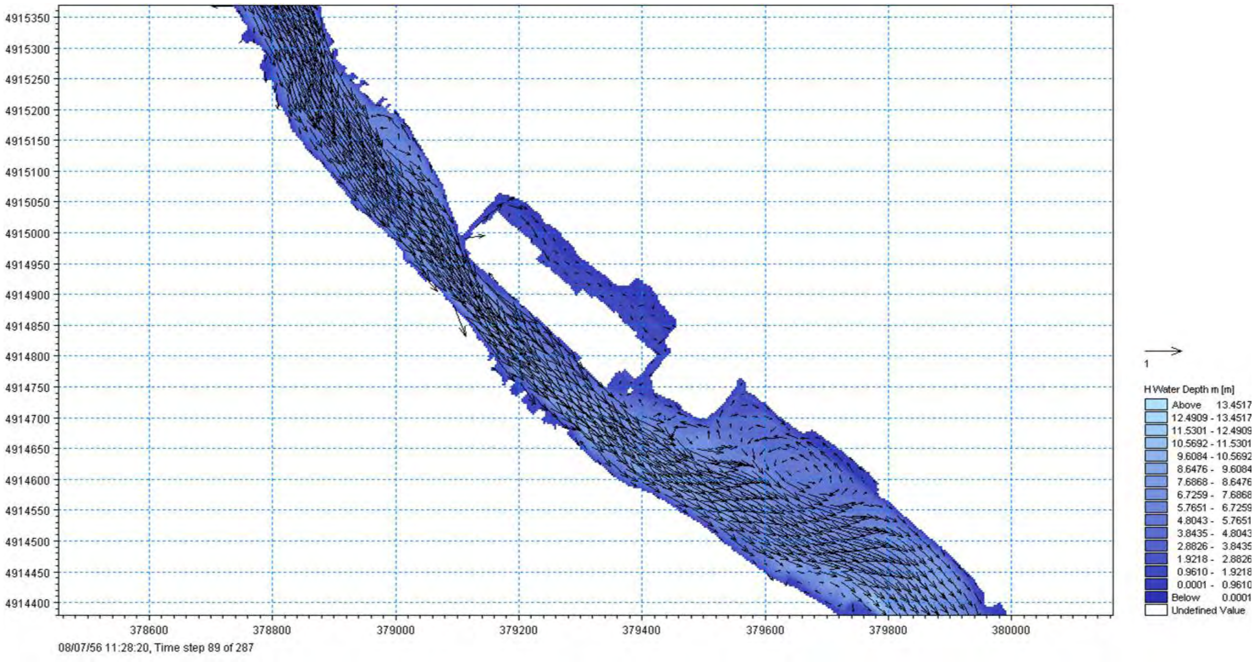

Figure 4:3 HD model output of water depth with current velocities denoted with larger arrows indicating increased velocity.

The inundation model for the 3.5 m storm surge indicates that the floodwater extends beyond the mall parking lot and floods the area west of Old Bridge Street and around the Eastside Plaza and remains flooded. We have not modeled underground storm drainage systems however, and as such this inundation may not accurately reflect the proper drainage system. However, if this area floods the elevation of the water in the river would be very high, thus prohibiting the drainage of this area through storm drains that empty into the river. In the case of the mall parking lot, after the storm surge water level subsides, the parking lot drains by surface runoff back into the river. This does not appear to be the case of the area west of the Old Bridge Street where the water appears to get trapped in a low lying area with no means of overland flow back into the river.

As mentioned earlier in the report, there are variable projections of sea-level rise under climate change. We have chosen two additional water levels to add to the normal high tide for our simulations which represent possible storm surge combined with relative sea level rise over the next 100 years. The combination of surge and sea level rise rates give us a range between 2.2 and 3.5 m of additional water level in the future. As a result we have used values of 2.2 m and 3.5 m on top of high tide to simulate flooding to encompass the variability in projections, including both a conservative sea level rise rate (ie. IPCC) and the worst case scenario from Richards and Daigle (2012). In their worst case scenario they take the worst storm surge on record from Hurricane Juan, measured at the Halifax tide gauge of 1.63 m and add it to the Lunenburg HHWLT with a RSL of 1.54 m by 2100 giving a total water level of 5.60 m CD (Table 2-4). Based on the CD-CGVD28 conversion for Halifax of 0.8 m, this worst case scenario is equal to 4.8 m CGVD28. This value (4.8 m CGVD28) is equivalent to the normal high tide plus a 3.5 m surge at the mouth of the LaHave. The surge value of 2.2 m on top of a high tide, culminating to a total water level of 3.5 m CGVD28, is roughly equivalent to a significant storm surge (Juan) in 100 years under conservative sea level rise estimates (73 cm/century, IPCC). In our model simulations, the boundary condition at the mouth of the LaHave River consists of a normal high tide level of 1.3 m CGVD28, then with the addition of a 2.2 m storm surge (3.5 m CGVD28) and then an addition of a 3.5 m storm surge (4.8 m CGVD28) is used. The GIS still-water levels can be used to determine areas at risk incrementally or if new projections become available related to SLR in the future.

Table 4-1: Explanation of water levels used for coastal hydrodynamic simulations considering storm surge and relative sea level rise.

Storm Surges	**Relative Sea Level Rise by 2100**	**Surge + RSL 2100**	**Total Water Level for Simulations (High tide plus Surge + RSL 2100)**
Juan (2003) ~ 1.5 m	IPCC 0.7 m	1.5 + 0.7 = **2.2 m**	3.5 m CGVD28
Saxby Gale (1869) ~ 2 m	Forbes et al. 1.5 m	2 + 1.5 = **3.5 m**	4.8 m CGVD28

In the case of changes to the atmospheric climate, the projections by Richards and Daigle (2012) only go to 2080 and they caution us about the model uncertainty with predicting extreme events. Although annual precipitation is expected to increase over time, the water surplus (runoff) is expected to decrease over time as a result of the increased temperature and thus increased evapotranspiration. The changes in short term precipitation (within a 24 hour period) are expected to increase by 16% by 2080. Given the uncertainty around this projection and its implications on flooding we have assumed this will translate into a 16% increase in discharge of the river. We have then used the extreme analysis to calculate what effect this 16% increase in discharge will have on events. For example, a 16% increase in the flow of the March 31, 2003 flood event results in the return period from this event changing from a 53 year return period at 65% probability to a 44 year return event. In order to calculate how a 16% increase will affect the return period of the flows previously calculated for the present day (Table 2-1 Return periods with 65% and 99.5% probability of the 50 and 100 year discharge events.) we first calculate the mean annual maximum flow of the LaHave River, so we are not looking at a single event but rather the average of the annual maximum runoff events. We then calculate what 16% of that flow is and use it as an average increase in river discharge by 2080. The current 50 year return period events drop by 3 years to a return period of 47 years in 2080 and the current 100 year return period events drop by 12 years to a return period of 88 years in 2080 (Table 4-2).

Table 4-2 Example of a 16% increase in short duration rainfall assumed to equal a 16% increase in the average annual maximum discharge. The current return period and discharge values for different probabilities and the return period projected to 2080 considering this 16% increase.

Event	**Return Period in Years**	**Discharge (m^3/s)**	**Return Period (2080)**
65% probability	50	652	47
65% probability	100	741	88
99.5% probability	50	441	47
99.5% probability	100	530	88

Given the uncertainty of the projected changes in water surplus and short term precipitation events and the fact that the downtown waterfront is more vulnerable to storm surge events, we did not generate a new set of simulations of runoff events for 2080 but rather show how the return period of specific events could become shorter in duration with increased runoff. Appendix 7 shows the new return periods for given discharge levels based on a 65% probability of occurrence and an average increase in maximum annual discharge of 16% by 2080. Appendix 8 shows the new return periods for given discharge levels based on a 99.5% probability of occurrence and an average increase in maximum annual discharge of 16% by 2080. Recall that the design level tables have a start date of 2000 and an end date of 2100. For Appendices 2 and 3, the date of a given flow is interpreted to represent the return period for a given probability (65 or 99.5%). For example a return period of 2040 is interpreted to be that the return period is 40 years starting from 2000. However, for Appendices 7 and 8 which represent an increase in the average annual maximum flow of 16% by 2080, a return period of 40 years is indicated by the date 2120 (631.28 cubic metres per second at 65% probability).

5. Implications for Municipal Planning and Infrastructure Management

The scope of this project was to simulate river discharge and storm surge events to predict areas at risk of flooding. Additionally we were to consider the possible impacts of climate change in terms of sea-level rise (SLR) and discharge on flooding. We offer these adaptation suggestions as areas for the town to consider. However, the details of specific adaption plans such as critical elevations for berms are beyond the scope of this project. In the future, if the town is interested in another research project to investigate the specifics of possible adaptation measures to determine their effectiveness to reduce flooding; AGRG has experience with altering the elevation, e.g. constructing a dyke of a certain elevation, and using the modeling techniques described in this report to test the results of this alteration on the extent of flooding.

Our modeling results suggest that the areas upstream of the Veterans Memorial Bridge are vulnerable to flooding from large river discharge events. Although there is limited infrastructure in these areas that appears to be affected by inundation (Fig. 3.11-3.13), erosion of the shoreline may occur under such conditions. The historical aerial photo analysis indicates some of the highest erosion rates occur in this area (Fig 3.18). LaHave Street may be at risk to erosion during high discharge events, especially where the road swings to the northeast at the western extent to join up with North Street. Armoring the shoreline at the bend on LaHave Street would reduce the risk of erosion and damage to the road, although it would not prevent it from being inundated during extreme discharge events.

The apparent more significant risk to the town infrastructure is from storm surge and SLR. Our modeling results suggest that with a 2.2 m storm surge on top of normal high tide at the mouth of the LaHave River today or a lesser surge in the future with SLR will inundate the Marine Terminal Wharf, the Bridgewater Mall parking lot and Ships landing Park along with affecting LaHave Street and Route 3 (Fig. 5.1). A possible adaptation solution to mitigate this risk is to build a protective barrier to the increased water levels in the river. The barrier could be in the form of a berm made of earth with armor stone on the river side of it to protect from erosion. There are areas at risk from flooding where this approach may be easier to implement than others based on the infrastructure and proximity to the river. For example, the area of LaHave Street at the east end of the town can accommodate the construction of a protective berm. However, the river is very close to the back of the mall, only separated by a service road which makes it challenging to raise the elevation and build a protective berm there. The area east of the mall may afford enough room to build such a structure. It is recommended that the details of the elevations be examined in this area to determine if a structure placed at this location would prevent flooding of the parking lot.

The sections of LaHave Street west of the mall are also close to the river but appear suitable for construction of such a barrier. Areas along the river west of Veterans Memorial Bridge along lower Elm Street are also close to the river bank where the construction of a barrier maybe challenging to construct as a result of the proximity of the road to the river (Fig. 5.1).

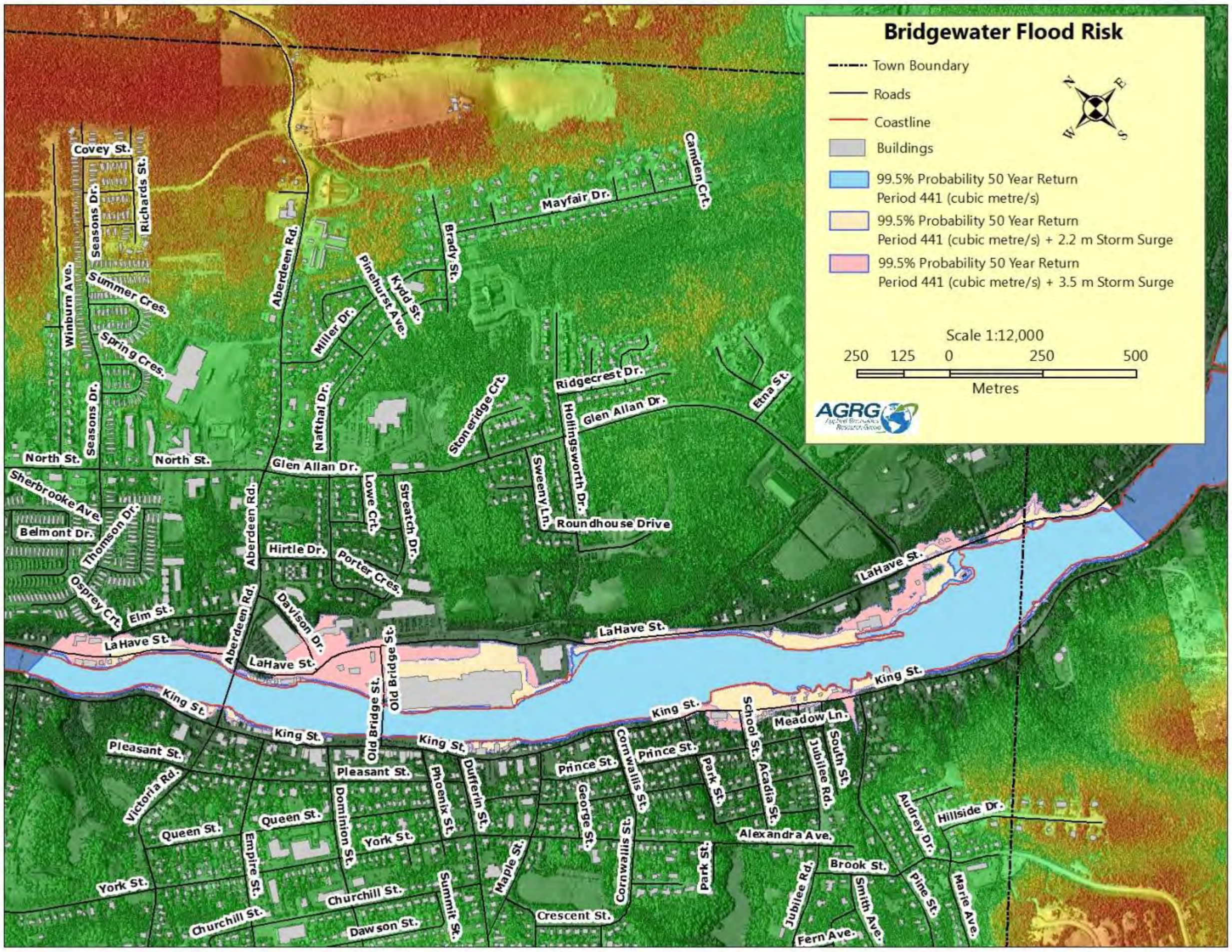

Figure 5:1 The extent of the three the modeled storm surge/relative sea level rise tidal conditions (Table 2-2) focusing on the downtown Bridgewater area.

The areas at risk of flooding from storm surge and SLR on the south side of the river include Ships landing Park and at extreme water levels (3.5 m surge today or lesser in the future under SLR), are King Street and the lower section of School Street. Without disturbing the park aesthetics or the public boat launch , constructing a protective berm will be very challenging in this area. At these higher water levels, flooding increases in the mall parking lot and extends to the Old Bridge Street and Davison Drive. If protective structures are built to mitigate the risk of flooding today, the elevations of such structures should be high enough to prevent overtopping from the river during these high water events in the future. Critical elevations could be determined by examining the water elevation and the current land elevation derived from the lidar DEM.

The flooding of streets by Wile and Hebb brook are an issue of undersized culverts and bridges for the drainage system. The “bottle neck” locations should be highlighted and larger culverts installed. In the case of bridges, consider excavating the channel to allow larger discharge through the system during high rain events.

As mentioned earlier, the models that have been constructed for this project provide the foundation for further adaptation studies to determine the location and critical elevations required for structures to mitigate flood risk. The elevation model can be altered to simulate the construction of a protective berm and the flood simulations re-run to determine the effectiveness on the reduction of flooding. Through this iterative process the location and critical elevation of such structures can be determined to aid in mitigating flooding.

6. Conclusions

A set of hydrodynamic and GIS based flood simulations have been conducted for the LaHave River and two small brooks within the town limits of Bridgewater. Past flooding events of the town and the LaHave River were researched and documented in this report. In order to conduct this work and support these modeling efforts, various field instruments were deployed including water level sensors at the Marine Terminal Wharf in the town and at Kraut Point near the mouth of the LaHave River. In addition to this, two weather stations were deployed to monitor rainfall and temperature - one was located in the central area of the LaHave watershed upstream of the town in Cherryfield and the other was located along the coast at Hirtle's Beach. In addition to the instrumentation, field surveys were conducted to measure the topography of the river bed in order to merge this information with data acquired by a lidar survey of the study area. The bathymetry was merged with the lidar elevations to construct a seamless elevation model that was the basis for the flood risk model simulations. Environment Canada measures the stage of the LaHave River upstream of the town and converts these measurements into daily flow values. The time-series of flows dating back to 1913 were analyzed and the annual maximum flow was extracted. The annual maximum flow was used to fit an extreme value model to the data in order to calculate the return period of specific flood events, such as March 31, 2003. In addition the 50 year and 100 year flow levels were extracted from these data under different probabilities of occurrence. For example a 65% probability of occurrence is equivalent to at least once occurrence within the given return period. The river flows for the 50 and 100 year return periods were calculated for the 65% and 99.5% probability. The flows associated with these return periods were used to define the river discharge boundary at the upstream section of the river for the modeling. Since Bridgewater is located at the tidal extent of the LaHave Estuary, we also incorporated a tidal and storm surge component into the modeling. A tidal boundary was established near the mouth of the LaHave Estuary and the predicted tide was calibrated against the water level observations obtained the AGRG water level sensor at Kraut Point. The tidal boundary used for the modeling consisted of a normal annual high tide (1.5 m) as well as the simulation of a 2.2 m and 3.5 m storm surge event. This resulted in twelve simulations by combining the 50 and 100 year discharge events at 65% and 99.5% probability with normal high tide as well as normal high tide plus 2.2 m surge and normal high tide plus a 3.5 m surge. The selection of storm surge levels was made to account for future sea-level rise predictions under climate change. In addition to the hydrodynamic modeling, a simpler GIS based still-water model was executed in order to compare to the results of the more complex hydrodynamic model. The results of the two models were similar in many aspects with the GIS based approach slightly overestimating the flood extent in some locations.

In addition to the flood risk modeling, a study was undertaken to examine past changes in the coastline position of the LaHave River to assess the degree of vulnerability to erosion. Aerial photos dating back to 1948, 1965, 1967, 1992, 2001 and 2009 were orthorectified so that direct measurements of the coastlines position could be interpreted and analyzed. The range of dates of these photos captured the significant event of in filling a marsh area to construct the Bridgewater Mall. The change in the coastline between the different dates of photos was used to calculate erosion and accretion rates. In general the downtown coastline does not appear to be significantly vulnerable to erosion. This in part is a result of the high degree of armoring that has taken place to protect the coastline. There are areas upstream of the Veteran's Memorial Bridge that do show areas of erosion however.

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 downtown area is vulnerable to SLR and storm surge flooding. 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. The flood extent expands for all these areas when the storm surge level is increased to 3.5 m and includes a significant area west of Old Bridge Street where the water appears to get trapped and does not easily drain back into the river once the storm surge levels subside.

Various GIS layers have been delivered to the town that accompany this report and are associated with the different modeling simulations and GIS-based still-water levels and historic coastlines and change rates. The most vulnerable infrastructure in the downtown water front is the Bridgewater Mall which only floods under extreme storm surge conditions. However, with SLR and possible increased storm intensity, the risk of such an event is possible. Other areas of the town at risk of flooding include Wile Brook and Hebb Brook which saw local flooding after extreme rainfall events. As part of our simulations these brooks were included and flood extents calculated. However, we did not have any instruments deployed in these brooks and our model was calibrated to match historic photos depicting flood events.

7. Acknowledgements

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9. Appendix 1: Design Risk - Gumbel EVM – 663 m^3/yr – yearly max discharge associated with the March 2003 event along the LaHave River

Date/Time	Cumulative Probability	Expected Number of Occurrences
1/1/2000 12:00	0.018755715	0.018755715
1/1/2001 12:00	0.037159652	0.037511429
1/1/2002 12:00	0.055218411	0.056267144
1/1/2003 12:00	0.072938465	0.075022858
1/1/2004 12:00	0.090326167	0.093778573
1/1/2005 12:00	0.107387749	0.112534288
1/1/2006 12:00	0.12412933	0.131290002
1/1/2007 12:00	0.14055691	0.150045717
1/1/2008 12:00	0.15667638	0.168801432
1/1/2009 12:00	0.172493517	0.187557146
1/1/2010 12:00	0.188013992	0.206312861
1/1/2011 12:00	0.20324337	0.225068575
1/1/2012 12:00	0.21818711	0.24382429
1/1/2013 12:00	0.23285057	0.262580005
1/1/2014 12:00	0.247239005	0.281335719
1/1/2015 12:00	0.261357576	0.300091434
1/1/2016 12:00	0.275211342	0.318847149
1/1/2017 12:00	0.288805271	0.337602863
1/1/2018 12:00	0.302144237	0.356358578
1/1/2019 12:00	0.31523302	0.375114292
1/1/2020 12:00	0.328076314	0.393870007
1/1/2021 12:00	0.340678723	0.412625722
1/1/2022 12:00	0.353044765	0.431381436

1/1/2023 12:00	0.365178873	0.450137151
1/1/2024 12:00	0.377085397	0.468892865
1/1/2025 12:00	0.388768605	0.48764858
1/1/2026 12:00	0.400232687	0.506404295
1/1/2027 12:00	0.411481751	0.525160009
1/1/2028 12:00	0.422519832	0.543915724
1/1/2029 12:00	0.433350885	0.562671439
1/1/2030 12:00	0.443978794	0.581427153
1/1/2031 12:00	0.454407369	0.600182868
1/1/2032 12:00	0.464640349	0.618938582
1/1/2033 12:00	0.474681402	0.637694297
1/1/2034 12:00	0.484534127	0.656450012
1/1/2035 12:00	0.494202058	0.675205726
1/1/2036 12:00	0.50368866	0.693961441
1/1/2037 12:00	0.512997334	0.712717156
1/1/2038 12:00	0.522131417	0.73147287
1/1/2039 12:00	0.531094184	0.750228585
1/1/2040 12:00	0.539888847	0.768984299
1/1/2041 12:00	0.548518561	0.787740014
1/1/2042 12:00	0.556986418	0.806495729
1/1/2043 12:00	0.565295454	0.825251443
1/1/2044 12:00	0.573448649	0.844007158
1/1/2045 12:00	0.581448924	0.862762872
1/1/2046 12:00	0.589299148	0.881518587
1/1/2047 12:00	0.597002136	0.900274302
1/1/2048 12:00	0.604560649	0.919030016
1/1/2049 12:00	0.611977397	0.937785731

1/1/2050 12:00	0.619255038	0.956541446
1/1/2051 12:00	0.626396182	0.97529716
1/1/2052 12:00	0.633403389	0.994052875
1/1/2053 12:00	0.64027917	1.012808589
1/1/2054 12:00	0.647025991	1.031564304
1/1/2055 12:00	0.653646271	1.050320019
1/1/2056 12:00	0.660142383	1.069075733
1/1/2057 12:00	0.666516655	1.087831448
1/1/2058 12:00	0.672771374	1.106587162
1/1/2059 12:00	0.67890878	1.125342877
1/1/2060 12:00	0.684931076	1.144098592
1/1/2061 12:00	0.690840419	1.162854306
1/1/2062 12:00	0.696638927	1.181610021
1/1/2063 12:00	0.702328681	1.200365736
1/1/2064 12:00	0.707911719	1.21912145
1/1/2065 12:00	0.713390044	1.237877165
1/1/2066 12:00	0.718765618	1.256632879
1/1/2067 12:00	0.72404037	1.275388594
1/1/2068 12:00	0.72921619	1.294144309
1/1/2069 12:00	0.734294934	1.312900023
1/1/2070 12:00	0.739278423	1.331655738
1/1/2071 12:00	0.744168442	1.350411453
1/1/2072 12:00	0.748966746	1.369167167
1/1/2073 12:00	0.753675054	1.387922882
1/1/2074 12:00	0.758295054	1.406678596
1/1/2075 12:00	0.762828403	1.425434311
1/1/2076 12:00	0.767276726	1.444190026

1/1/2077 12:00	0.771641617	1.46294574
1/1/2078 12:00	0.775924642	1.481701455
1/1/2079 12:00	0.780127335	1.500457169
1/1/2080 12:00	0.784251204	1.519212884
1/1/2081 12:00	0.788297727	1.537968599
1/1/2082 12:00	0.792268355	1.556724313
1/1/2083 12:00	0.79616451	1.575480028
1/1/2084 12:00	0.79998759	1.594235743
1/1/2085 12:00	0.803738966	1.612991457
1/1/2086 12:00	0.807419982	1.631747172
1/1/2087 12:00	0.811031958	1.650502886
1/1/2088 12:00	0.814576188	1.669258601
1/1/2089 12:00	0.818053945	1.688014316
1/1/2090 12:00	0.821466473	1.70677003
1/1/2091 12:00	0.824814997	1.725525745
1/1/2092 12:00	0.828100717	1.74428146
1/1/2093 12:00	0.831324811	1.763037174
1/1/2094 12:00	0.834488434	1.781792889
1/1/2095 12:00	0.837592722	1.800548603
1/1/2096 12:00	0.840638787	1.819304318
1/1/2097 12:00	0.84362772	1.838060033
1/1/2098 12:00	0.846560594	1.856815747
1/1/2099 12:00	0.84943846	1.875571462
1/1/2100 12:00	0.852262349	1.894327176

10. Appendix 2: 65% probability Design Level for the LaHave River Discharge

Date/Time	Design Level (Discharge m^3/s)
1/1/2000 12:00	139.4133524
1/1/2001 12:00	229.7933524
1/1/2002 12:00	282.6633524
1/1/2003 12:00	320.1733524
1/1/2004 12:00	349.2733524
1/1/2005 12:00	373.0433524
1/1/2006 12:00	393.1433524
1/1/2007 12:00	410.5633524
1/1/2008 12:00	425.9133524
1/1/2009 12:00	439.6533524
1/1/2010 12:00	452.0833524
1/1/2011 12:00	463.4333524
1/1/2012 12:00	473.8633524
1/1/2013 12:00	483.5333524
1/1/2014 12:00	492.5233524
1/1/2015 12:00	500.9433524
1/1/2016 12:00	508.8533524
1/1/2017 12:00	516.3033524
1/1/2018 12:00	523.3533524
1/1/2019 12:00	530.0433524
1/1/2020 12:00	536.4033524
1/1/2021 12:00	542.4733524
1/1/2022 12:00	548.2633524
1/1/2023 12:00	553.8133524
1/1/2024 12:00	559.1333524
1/1/2025 12:00	564.2533524
1/1/2026 12:00	569.1733524
1/1/2027 12:00	573.9133524
1/1/2028 12:00	578.4933524
1/1/2029 12:00	582.9133524
1/1/2030 12:00	587.1833524
1/1/2031 12:00	591.3233524
1/1/2032 12:00	595.3433524
1/1/2033 12:00	599.2333524
1/1/2034 12:00	603.0133524
1/1/2035 12:00	606.6833524
1/1/2036 12:00	610.2633524
1/1/2037 12:00	613.7333524

1/1/2038 12:00	617.1233524
1/1/2039 12:00	620.4233524
1/1/2040 12:00	623.6433524
1/1/2041 12:00	626.7833524
1/1/2042 12:00	629.8533524
1/1/2043 12:00	632.8533524
1/1/2044 12:00	635.7833524
1/1/2045 12:00	638.6533524
1/1/2046 12:00	641.4533524
1/1/2047 12:00	644.2033524
1/1/2048 12:00	646.8833524
1/1/2049 12:00	649.5233524
1/1/2050 12:00	652.1033524
1/1/2051 12:00	654.6333524
1/1/2052 12:00	657.1233524
1/1/2053 12:00	659.5533524
1/1/2054 12:00	661.9533524
1/1/2055 12:00	664.3033524
1/1/2056 12:00	666.6033524
1/1/2057 12:00	668.8733524
1/1/2058 12:00	671.1033524
1/1/2059 12:00	673.2933524
1/1/2060 12:00	675.4533524
1/1/2061 12:00	677.5733524
1/1/2062 12:00	679.6533524
1/1/2063 12:00	681.7133524
1/1/2064 12:00	683.7333524
1/1/2065 12:00	685.7233524
1/1/2066 12:00	687.6833524
1/1/2067 12:00	689.6133524
1/1/2068 12:00	691.5233524
1/1/2069 12:00	693.3933524
1/1/2070 12:00	695.2433524
1/1/2071 12:00	697.0733524
1/1/2072 12:00	698.8733524
1/1/2073 12:00	700.6433524
1/1/2074 12:00	702.3933524
1/1/2075 12:00	704.1233524
1/1/2076 12:00	705.8233524
1/1/2077 12:00	707.5033524
1/1/2078 12:00	709.1633524
1/1/2079 12:00	710.8133524
1/1/2080 12:00	712.4233524

1/1/2081 12:00	714.0233524
1/1/2082 12:00	715.6133524
1/1/2083 12:00	717.1733524
1/1/2084 12:00	718.7133524
1/1/2085 12:00	720.2433524
1/1/2086 12:00	721.7433524
1/1/2087 12:00	723.2333524
1/1/2088 12:00	724.7133524
1/1/2089 12:00	726.1633524
1/1/2090 12:00	727.6033524
1/1/2091 12:00	729.0333524
1/1/2092 12:00	730.4433524
1/1/2093 12:00	731.8333524
1/1/2094 12:00	733.2133524
1/1/2095 12:00	734.5833524
1/1/2096 12:00	735.9333524
1/1/2097 12:00	737.2733524
1/1/2098 12:00	738.5933524
1/1/2099 12:00	739.9033524
1/1/2100 12:00	741.2033524

11. Appendix 3: 99.5% probability Design Level for the LaHave River

Date/Time	Design Level (Discharge m^3/s)
1/1/2000 12:00	-71.6780816
1/1/2001 12:00	18.71191838
1/1/2002 12:00	71.58191838
1/1/2003 12:00	109.0919184
1/1/2004 12:00	138.1919184
1/1/2005 12:00	161.9619184
1/1/2006 12:00	182.0619184
1/1/2007 12:00	199.4819184
1/1/2008 12:00	214.8319184
1/1/2009 12:00	228.5719184
1/1/2010 12:00	241.0019184
1/1/2011 12:00	252.3519184
1/1/2012 12:00	262.7819184
1/1/2013 12:00	272.4519184
1/1/2014 12:00	281.4419184
1/1/2015 12:00	289.8619184
1/1/2016 12:00	297.7719184
1/1/2017 12:00	305.2219184
1/1/2018 12:00	312.2719184
1/1/2019 12:00	318.9619184
1/1/2020 12:00	325.3219184
1/1/2021 12:00	331.3919184
1/1/2022 12:00	337.1819184
1/1/2023 12:00	342.7319184
1/1/2024 12:00	348.0519184
1/1/2025 12:00	353.1719184
1/1/2026 12:00	358.0919184
1/1/2027 12:00	362.8319184
1/1/2028 12:00	367.4119184
1/1/2029 12:00	371.8319184
1/1/2030 12:00	376.1019184
1/1/2031 12:00	380.2419184
1/1/2032 12:00	384.2619184
1/1/2033 12:00	388.1519184
1/1/2034 12:00	391.9319184
1/1/2035 12:00	395.6019184
1/1/2036 12:00	399.1819184
1/1/2037 12:00	402.6519184
1/1/2038 12:00	406.0419184
1/1/2039 12:00	409.3419184

1/1/2040 12:00	412.5619184
1/1/2041 12:00	415.7019184
1/1/2042 12:00	418.7719184
1/1/2043 12:00	421.7719184
1/1/2044 12:00	424.7019184
1/1/2045 12:00	427.5719184
1/1/2046 12:00	430.3719184
1/1/2047 12:00	433.1219184
1/1/2048 12:00	435.8019184
1/1/2049 12:00	438.4419184
1/1/2050 12:00	441.0219184
1/1/2051 12:00	443.5519184
1/1/2052 12:00	446.0419184
1/1/2053 12:00	448.4719184
1/1/2054 12:00	450.8719184
1/1/2055 12:00	453.2219184
1/1/2056 12:00	455.5219184
1/1/2057 12:00	457.7919184
1/1/2058 12:00	460.0219184
1/1/2059 12:00	462.2119184
1/1/2060 12:00	464.3719184
1/1/2061 12:00	466.4919184
1/1/2062 12:00	468.5719184
1/1/2063 12:00	470.6319184
1/1/2064 12:00	472.6519184
1/1/2065 12:00	474.6419184
1/1/2066 12:00	476.6019184
1/1/2067 12:00	478.5319184
1/1/2068 12:00	480.4419184
1/1/2069 12:00	482.3119184
1/1/2070 12:00	484.1619184
1/1/2071 12:00	485.9919184
1/1/2072 12:00	487.7919184
1/1/2073 12:00	489.5619184
1/1/2074 12:00	491.3119184
1/1/2075 12:00	493.0419184
1/1/2076 12:00	494.7419184
1/1/2077 12:00	496.4219184
1/1/2078 12:00	498.0819184
1/1/2079 12:00	499.7319184
1/1/2080 12:00	501.3419184
1/1/2081 12:00	502.9419184
1/1/2082 12:00	504.5319184

1/1/2083 12:00	506.0919184
1/1/2084 12:00	507.6319184
1/1/2085 12:00	509.1619184
1/1/2086 12:00	510.6619184
1/1/2087 12:00	512.1519184
1/1/2088 12:00	513.6319184
1/1/2089 12:00	515.0819184
1/1/2090 12:00	516.5219184
1/1/2091 12:00	517.9519184
1/1/2092 12:00	519.3619184
1/1/2093 12:00	520.7519184
1/1/2094 12:00	522.1319184
1/1/2095 12:00	523.5019184
1/1/2096 12:00	524.8519184
1/1/2097 12:00	526.1919184
1/1/2098 12:00	527.5119184
1/1/2099 12:00	528.8219184
1/1/2100 12:00	530.1219184

12. Appendix 4: Halifax expected water level (CD) using the Gumbel EVM under different RSL conditions. ACAS community of the District of Lunenburg (CGVD28-CD Halifax = 0.8 m).

Year	Water Level (0.32 m RSL)	Water Level (0.73 m RSL)	Water Level (1.46 m RSL)
2010	2.05	2.05	2.05
2011	2.17	2.18	2.18
2012	2.25	2.25	2.26
2013	2.30	2.30	2.31
2014	2.34	2.34	2.36
2015	2.37	2.38	2.40
2016	2.40	2.41	2.43
2017	2.42	2.44	2.46
2018	2.44	2.46	2.49
2019	2.46	2.48	2.52
2020	2.48	2.50	2.54
2021	2.50	2.52	2.57
2022	2.51	2.54	2.59
2023	2.53	2.56	2.61
2024	2.54	2.57	2.63
2025	2.55	2.59	2.65
2026	2.56	2.60	2.67
2027	2.58	2.61	2.69
2028	2.59	2.63	2.71
2029	2.60	2.64	2.73

2030	2.61	2.65	2.74
2031	2.62	2.67	2.76
2032	2.63	2.68	2.78
2033	2.64	2.69	2.79
2034	2.64	2.70	2.81
2035	2.65	2.71	2.83
2036	2.66	2.72	2.84
2037	2.67	2.73	2.86
2038	2.68	2.74	2.88
2039	2.68	2.75	2.89
2040	2.69	2.76	2.91
2041	2.70	2.77	2.92
2042	2.71	2.78	2.94
2043	2.71	2.79	2.95
2044	2.72	2.80	2.97
2045	2.73	2.81	2.98
2046	2.73	2.82	3.00
2047	2.74	2.83	3.02
2048	2.74	2.84	3.03
2049	2.75	2.85	3.05
2050	2.76	2.86	3.06
2051	2.76	2.86	3.08
2052	2.77	2.87	3.09
2053	2.77	2.88	3.11

2054	2.78	2.89	3.12
2055	2.79	2.90	3.14
2056	2.79	2.91	3.15
2057	2.80	2.92	3.17
2058	2.80	2.92	3.18
2059	2.81	2.93	3.19
2060	2.81	2.94	3.21
2061	2.82	2.95	3.22
2062	2.82	2.96	3.24
2063	2.83	2.97	3.25
2064	2.83	2.97	3.27
2065	2.84	2.98	3.28
2066	2.84	2.99	3.30
2067	2.85	3.00	3.31
2068	2.85	3.01	3.33
2069	2.86	3.01	3.34
2070	2.86	3.02	3.36
2071	2.87	3.03	3.37
2072	2.87	3.04	3.39
2073	2.88	3.04	3.40
2074	2.88	3.05	3.42
2075	2.88	3.06	3.43
2076	2.89	3.07	3.44
2077	2.89	3.08	3.46

2078	2.90	3.08	3.47
2079	2.90	3.09	3.49
2080	2.91	3.10	3.50
2081	2.91	3.11	3.52
2082	2.92	3.11	3.53
2083	2.92	3.12	3.55
2084	2.92	3.13	3.56
2085	2.93	3.14	3.58
2086	2.93	3.14	3.59
2087	2.94	3.15	3.61
2088	2.94	3.16	3.62
2089	2.94	3.17	3.63
2090	2.95	3.18	3.65
2091	2.95	3.18	3.66
2092	2.96	3.19	3.68
2093	2.96	3.20	3.69
2094	2.97	3.21	3.71
2095	2.97	3.21	3.72
2096	2.97	3.22	3.74
2097	2.98	3.23	3.75
2098	2.98	3.23	3.77
2099	2.99	3.24	3.78
2100	2.99	3.25	3.80
2101	2.99	3.26	3.81

2102	3.00	3.26	3.82
2103	3.00	3.27	3.84
2104	3.00	3.28	3.85
2105	3.01	3.29	3.87
2106	3.01	3.29	3.88
2107	3.02	3.30	3.90
2108	3.02	3.31	3.91
2109	3.02	3.32	3.93
2110	3.03	3.32	3.94

13. Appendix 5: Flood risk maps from model simulations.

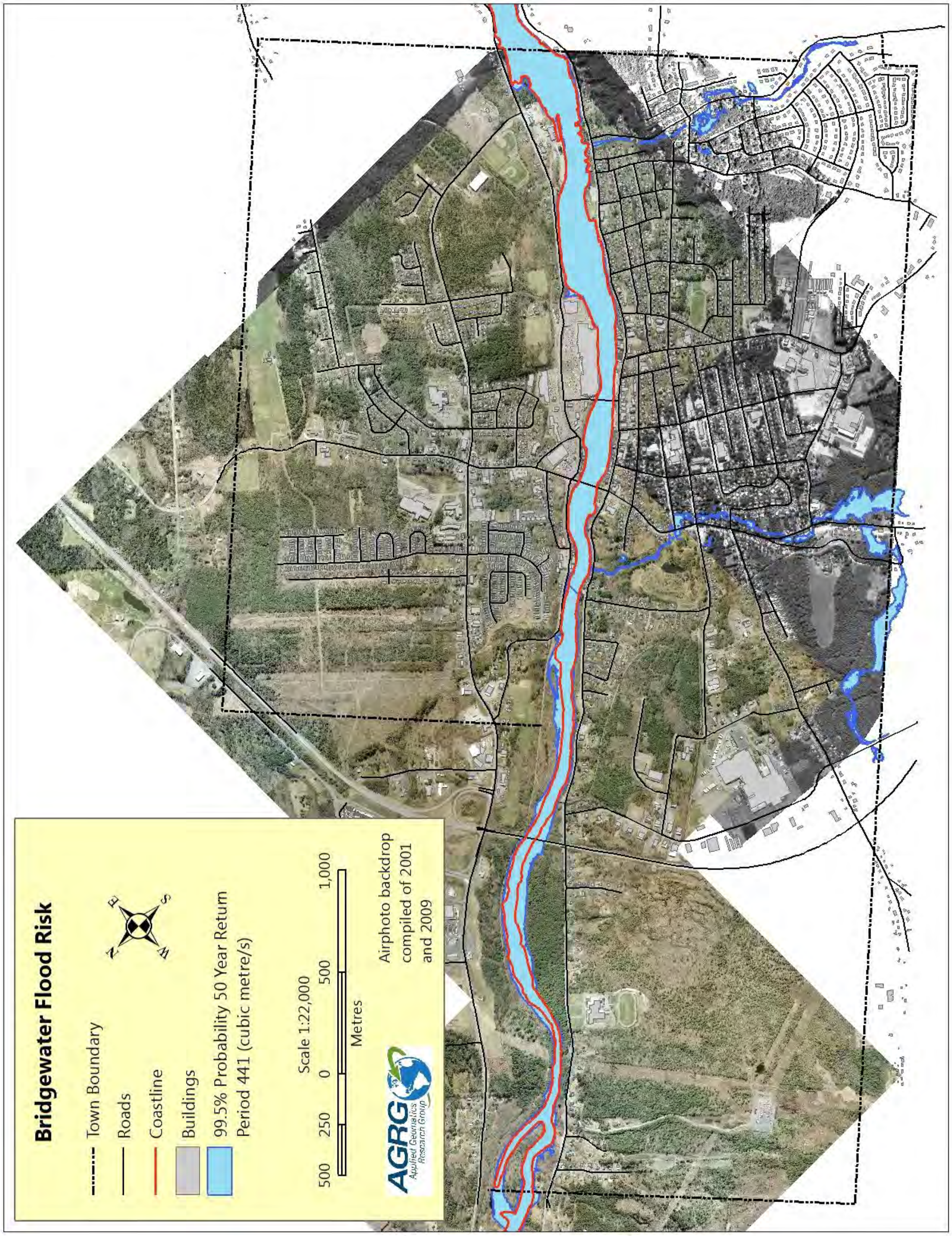

Figure 13:1 Maximum flood extent for **99.5%** probability for the **50 year** return period under **normal** high tide.

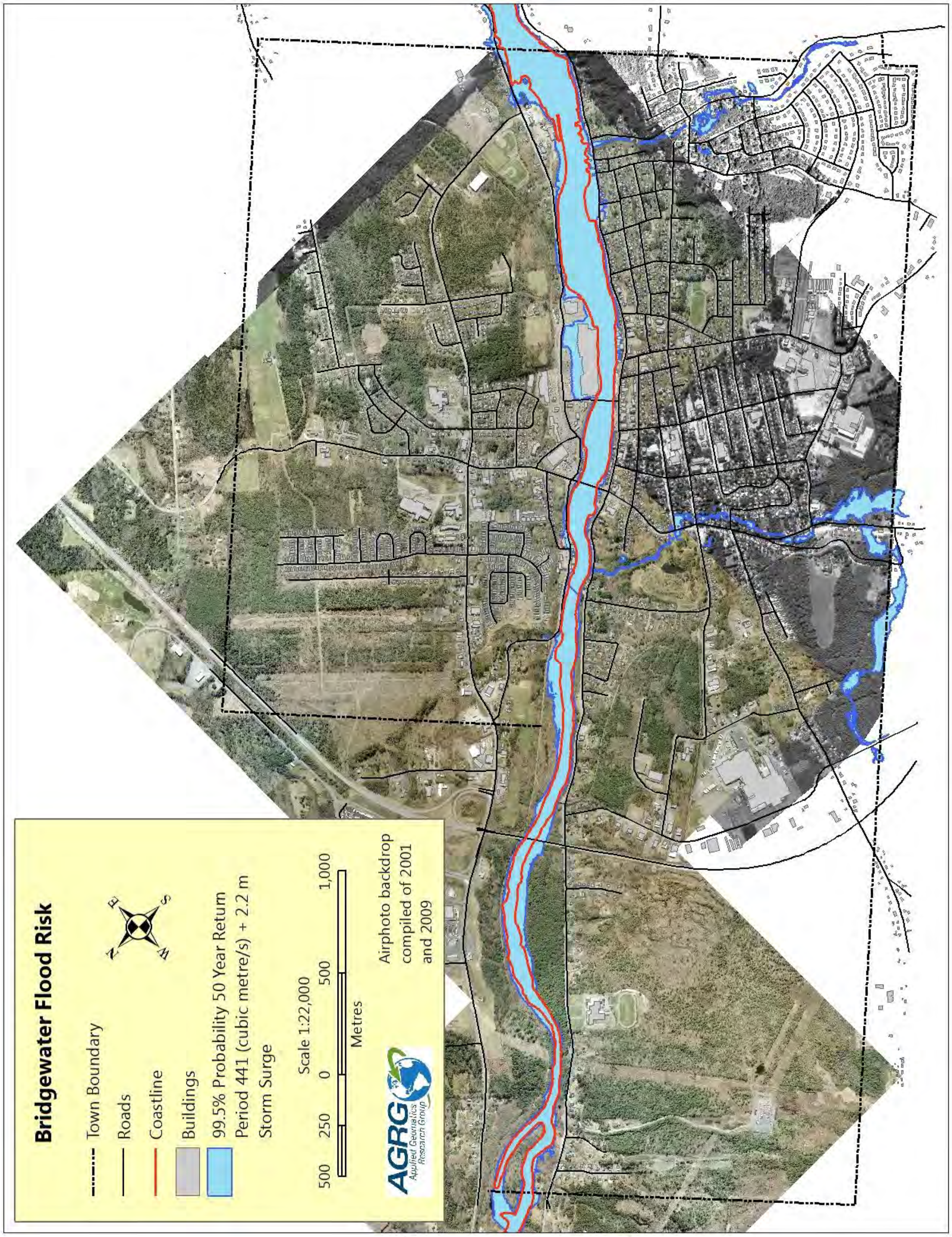

Figure 13:2 Maximum flood extent for **99.5%** probability for the **50 year** return period under normal high tide + **2.2 m** surge.

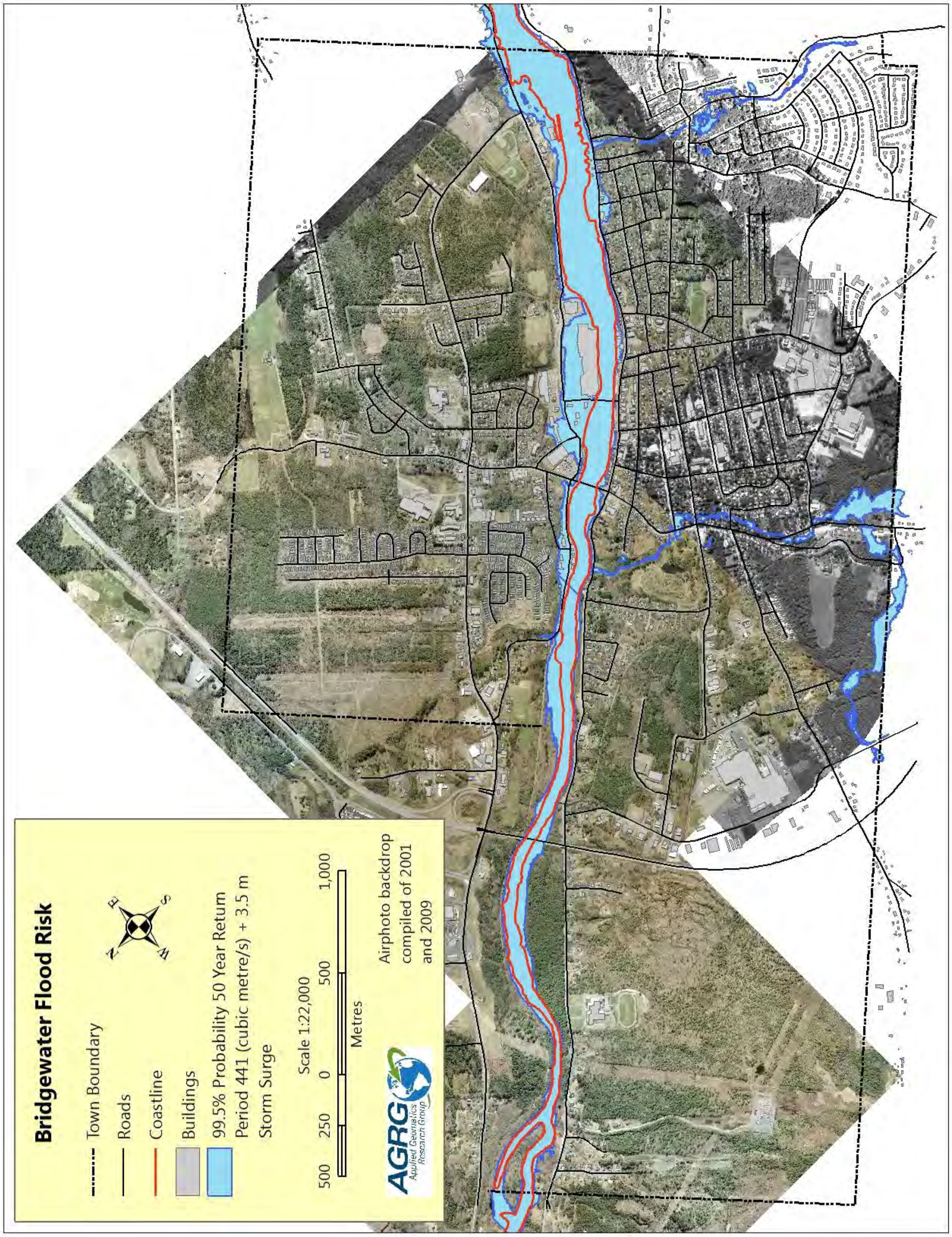

Figure 13:3 Maximum flood extent for **99.5%** probability for the **50 year** return period under normal high tide + **3.5 m** surge.

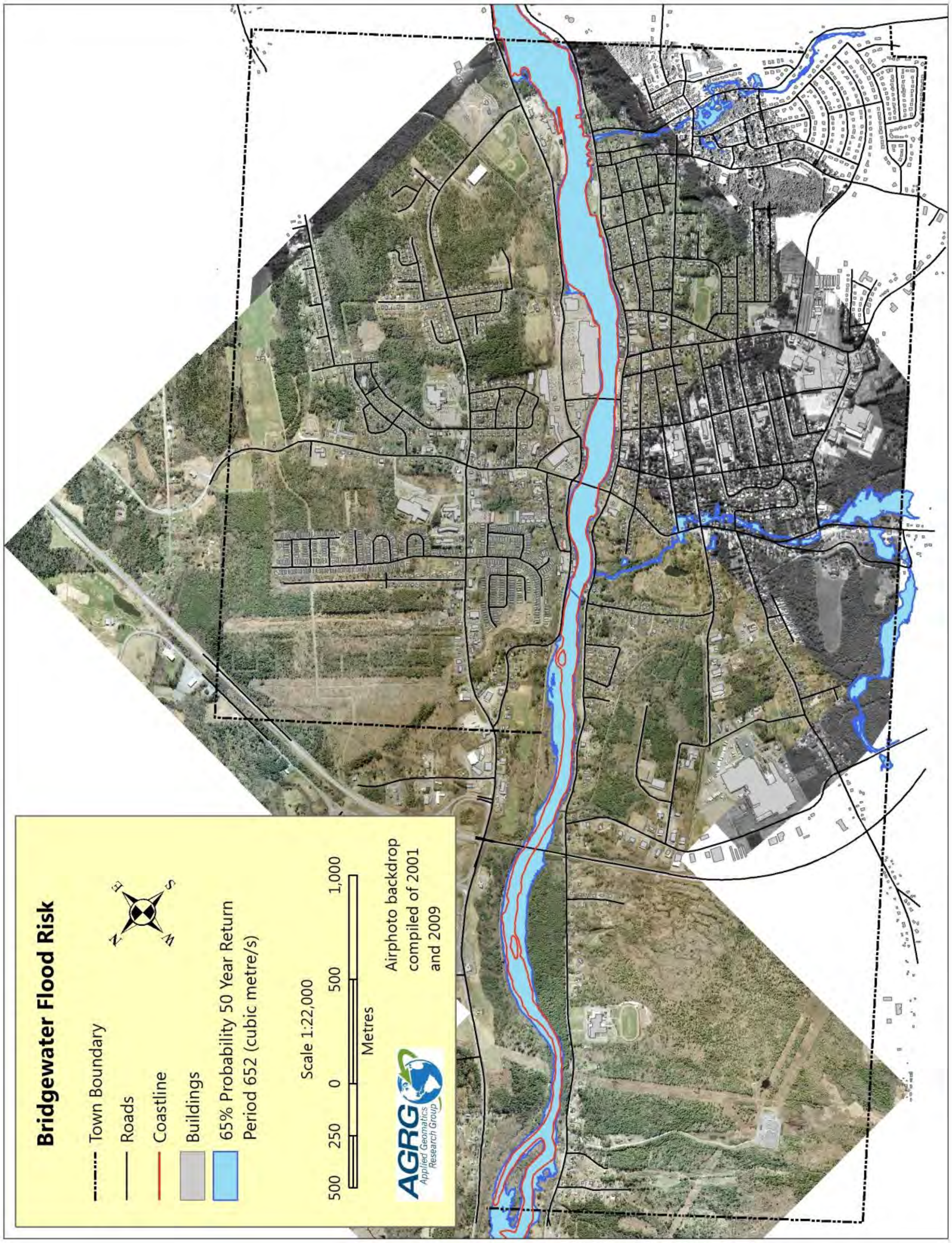

Figure 13:4 Maximum flood extent for **65%** probability for the **50 year** return period under **normal** high tide.

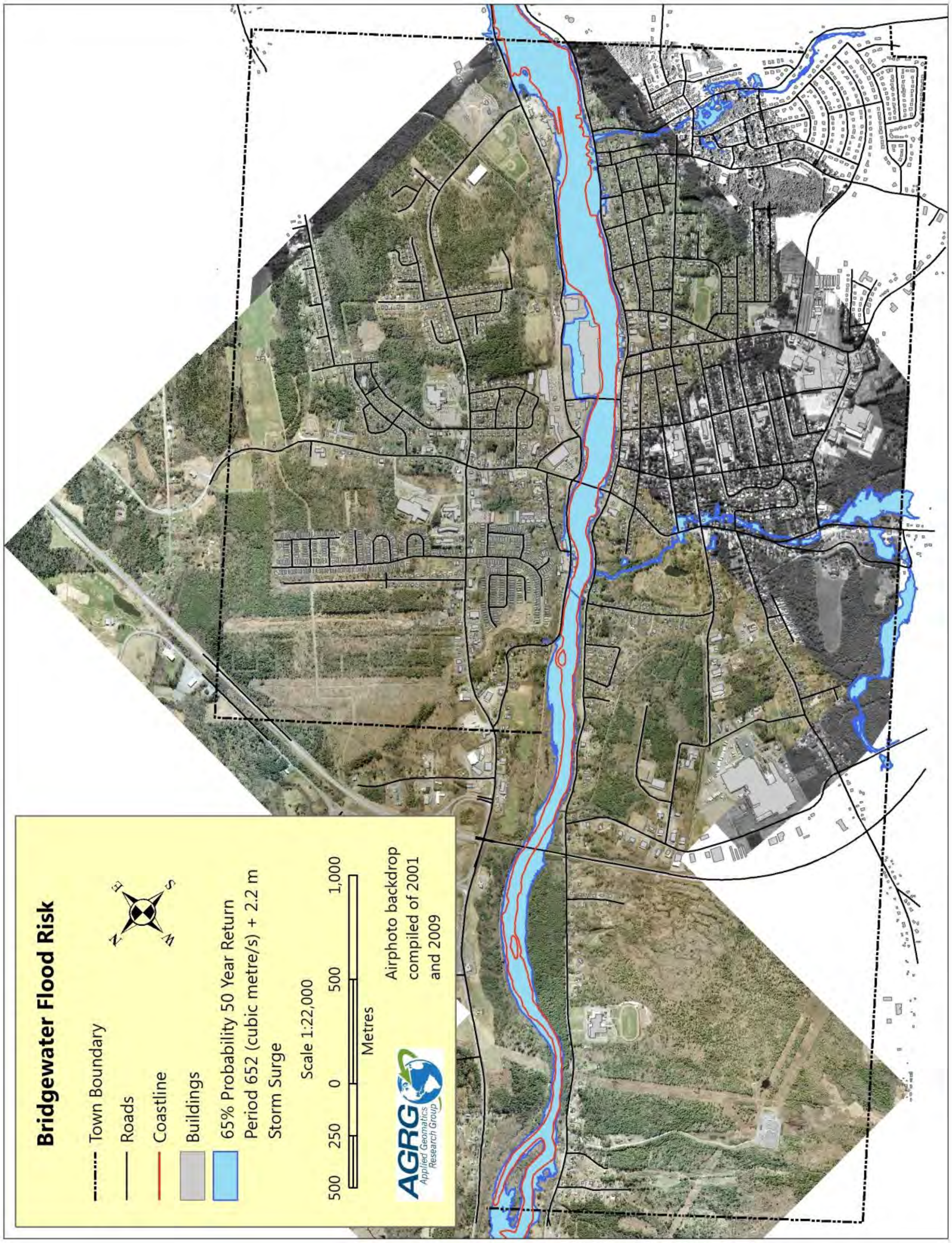

Figure 13:5 Maximum flood extent for **65%** probability for the **50 year** return period under normal high tide + **2.2 m** surge.

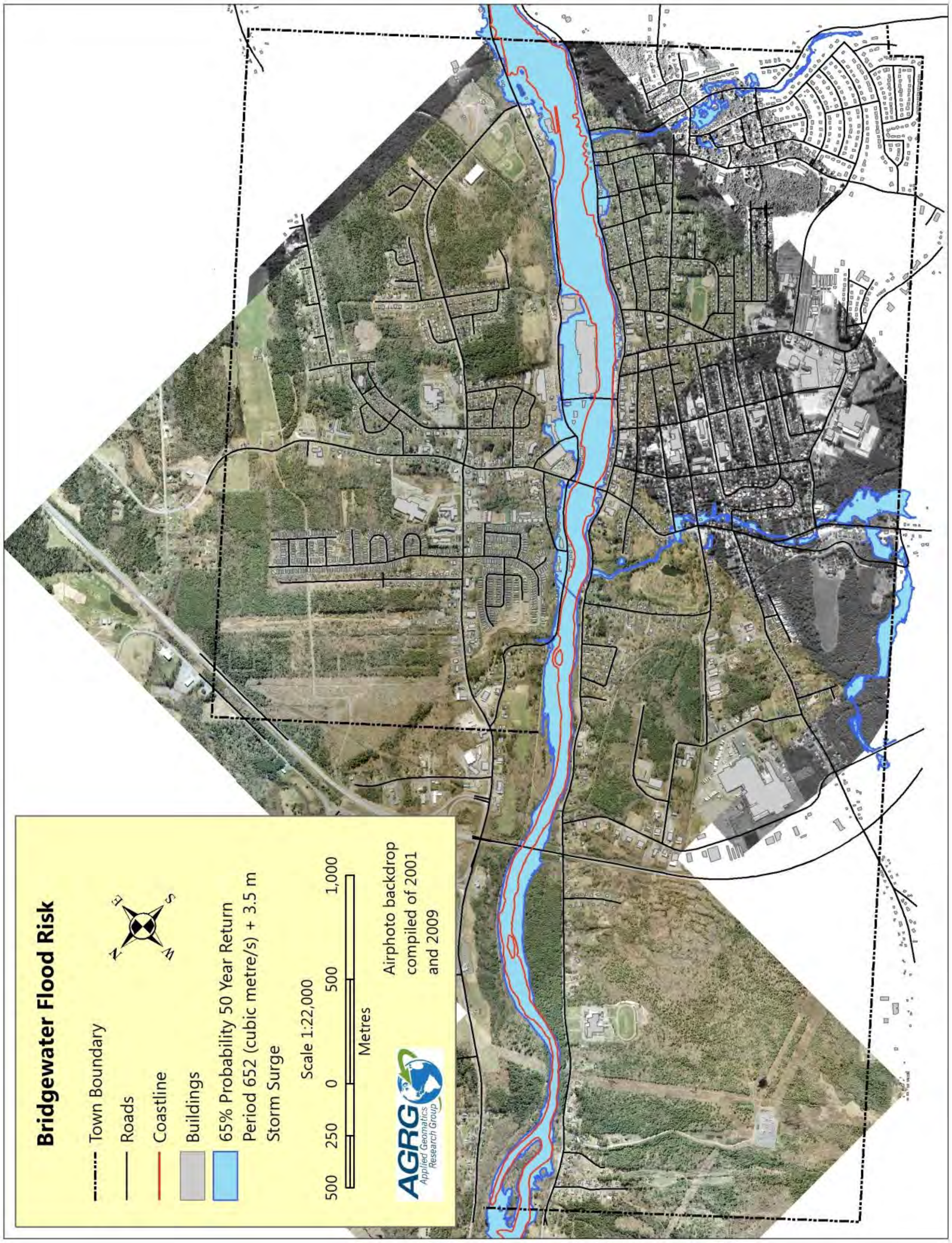

Figure 13:6 Maximum flood extent for **65%** probability for the **50 year** return period under normal high tide + **3.5 m** surge.

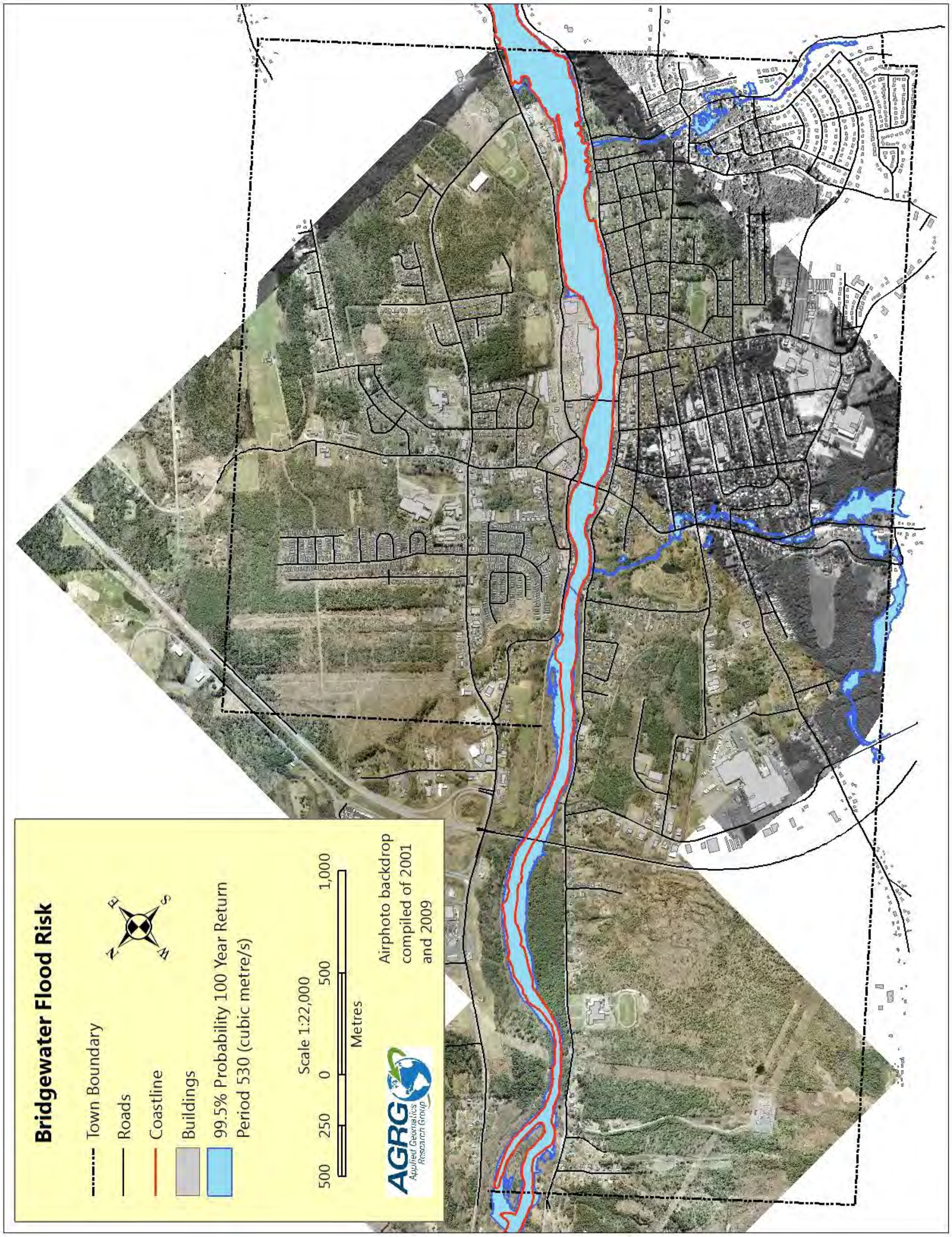

Figure 13:7 Maximum flood extent for **99.5%** probability for the **100 year** return period under **normal** high tide**.**

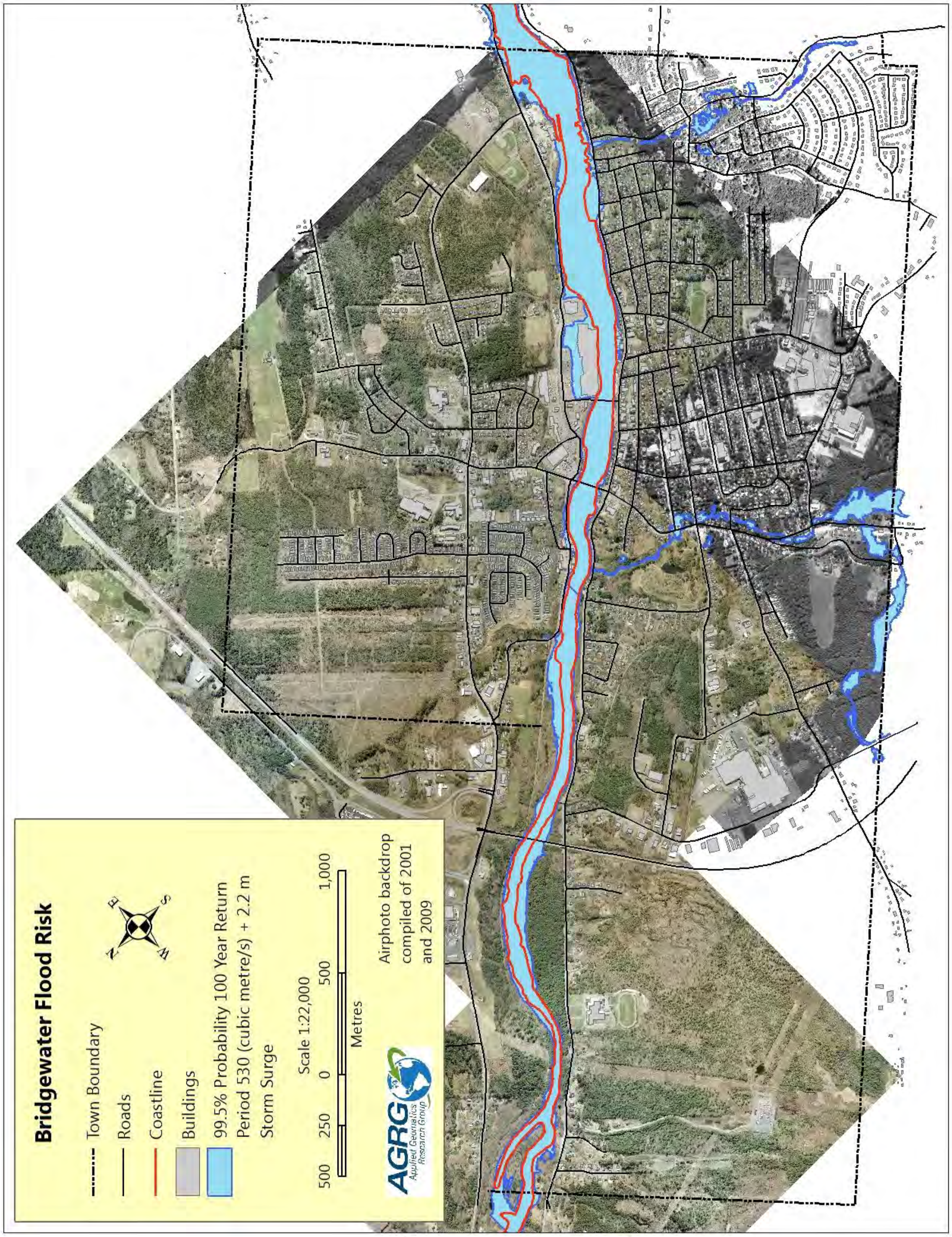

Figure 13:8 Maximum flood extent for **99.5%** probability for the **100 year** return period under normal high tide + **2.2 m** surge.

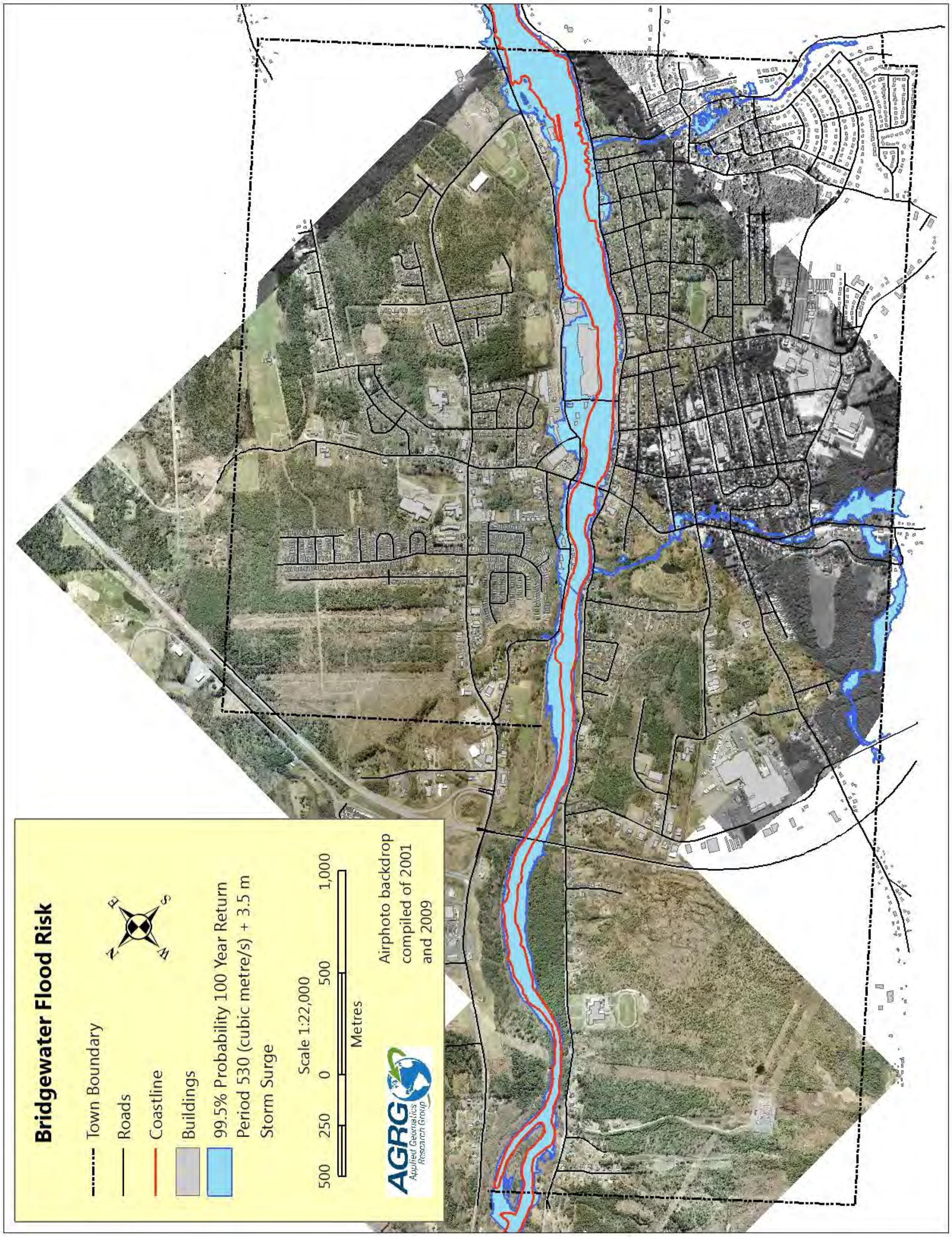

Figure 13:9 Maximum flood extent for **99.5%** probability for the **100 year** return period under normal high tide + **3.5 m** surge.

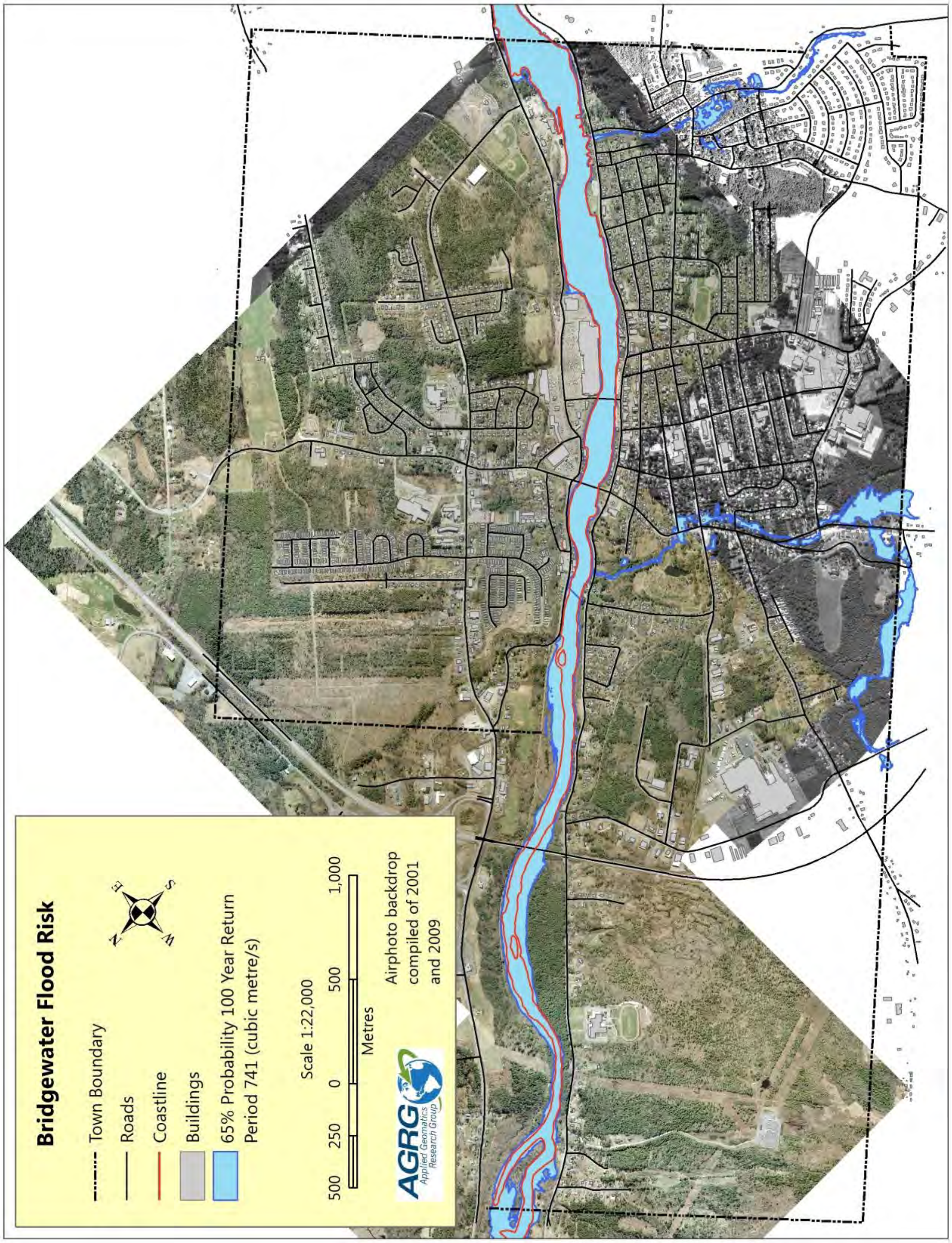

Figure 13:10 Maximum flood extent for **65%** probability for the **100 year** return period under **normal** high tide.

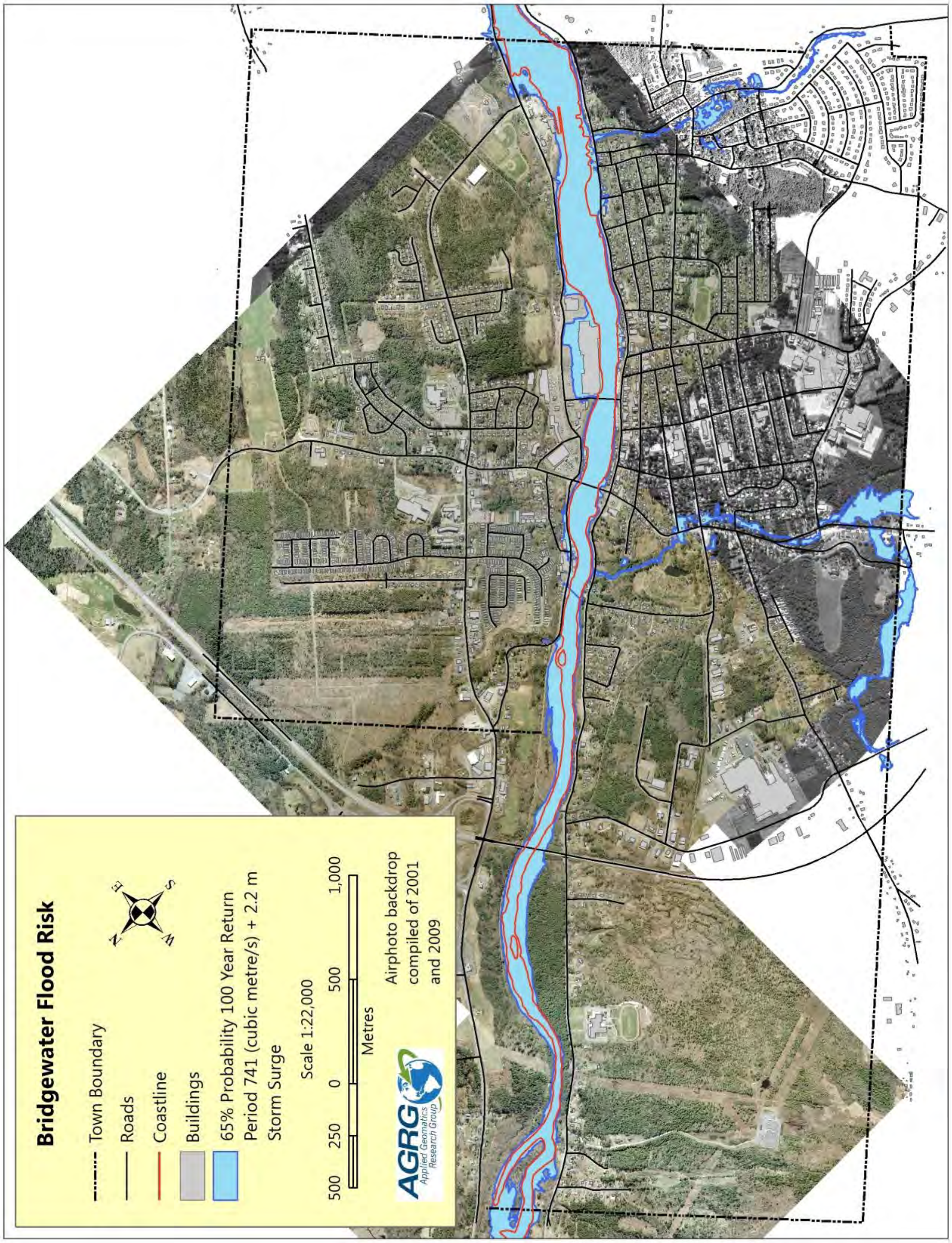

Figure 13:11 Maximum flood extent for **65%** probability for the **100 year** return period under normal high tide + **2.2 m** surge.

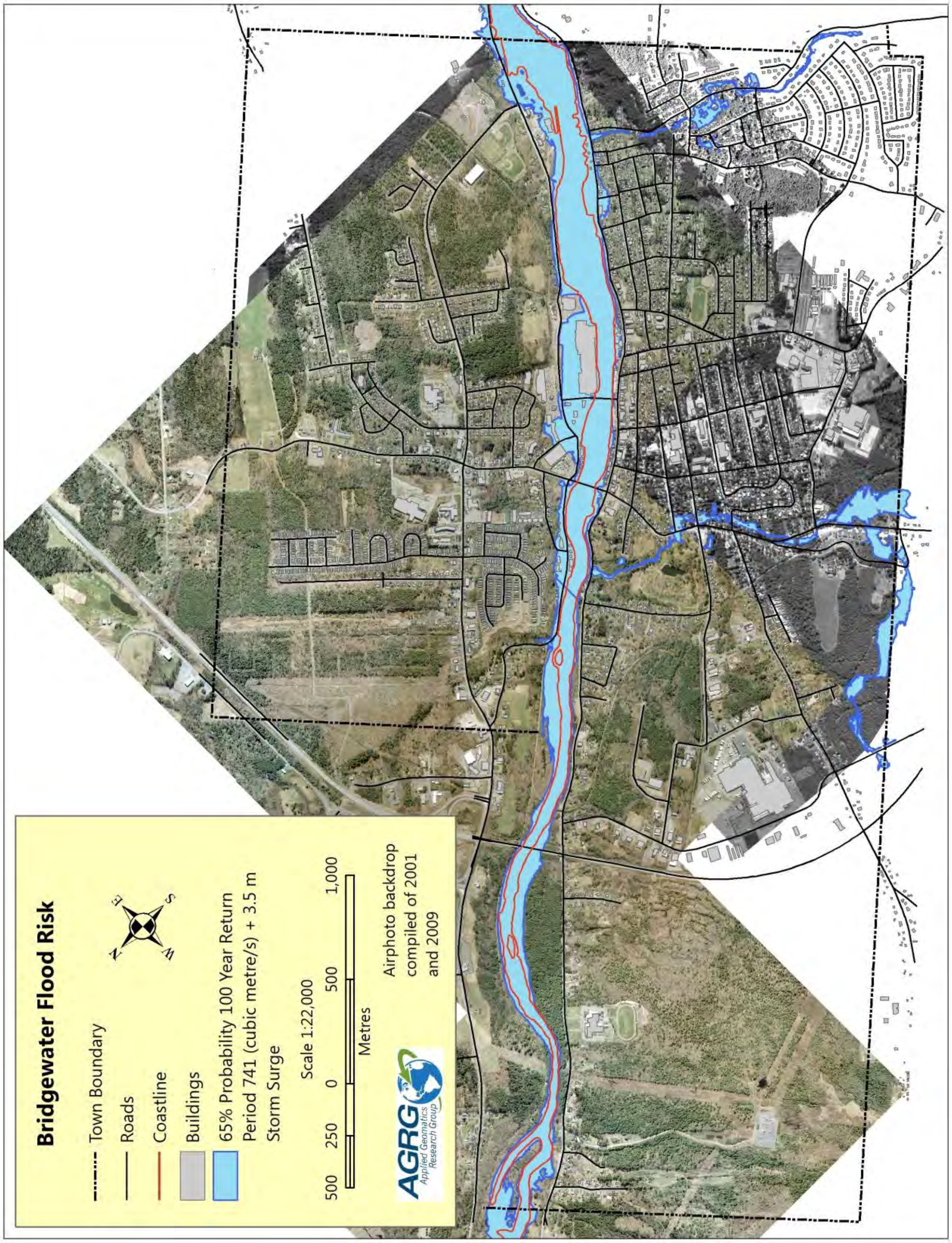

Figure 13:12 Maximum flood extent for **65%** probability for the **100 year** return period under normal high tide + **3.5 m** surge.

14. Appendix 6: Historical orthophotos and coastlines.

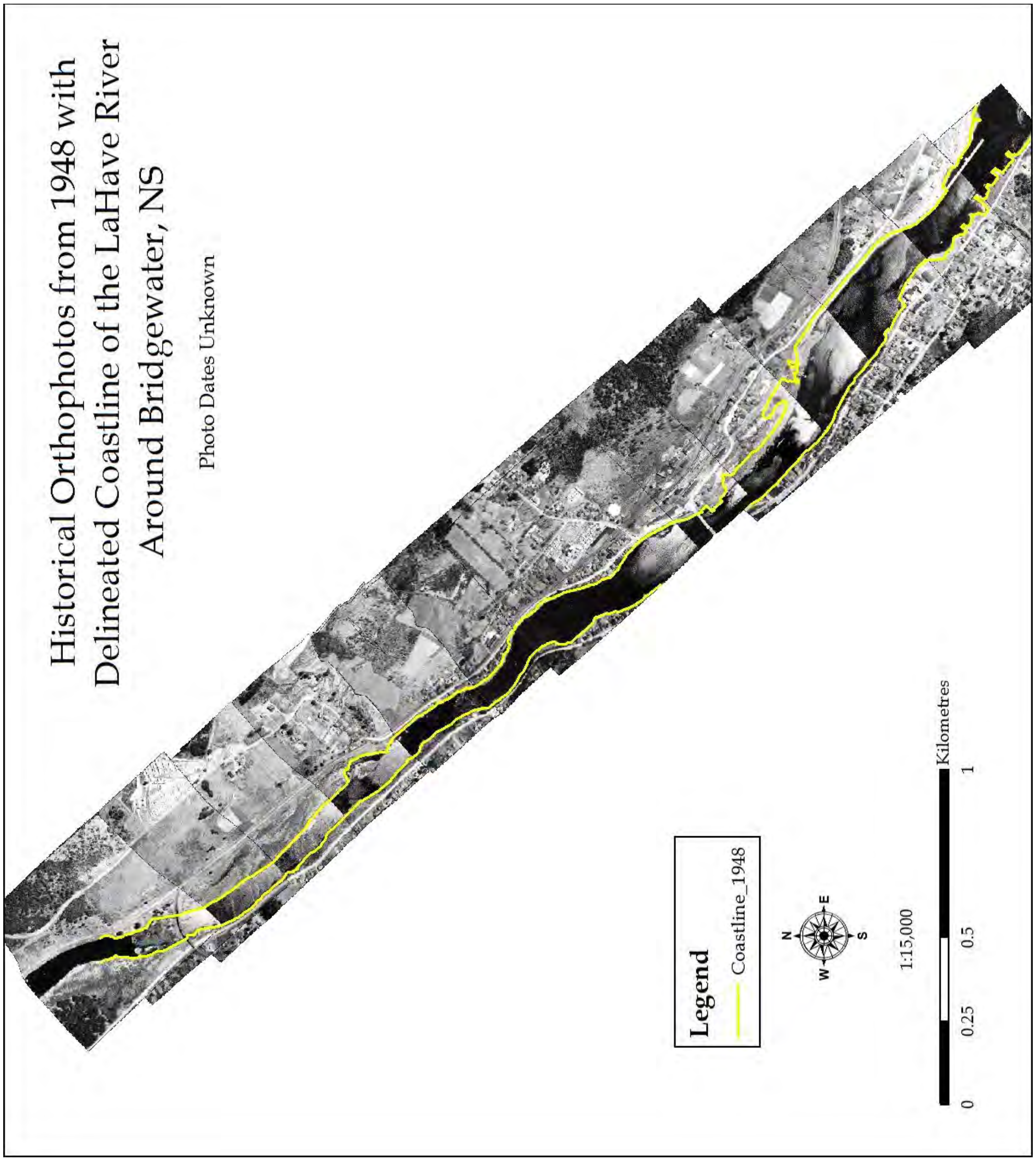

Figure 14:1 1948 orthophoto with coastline interpreted.

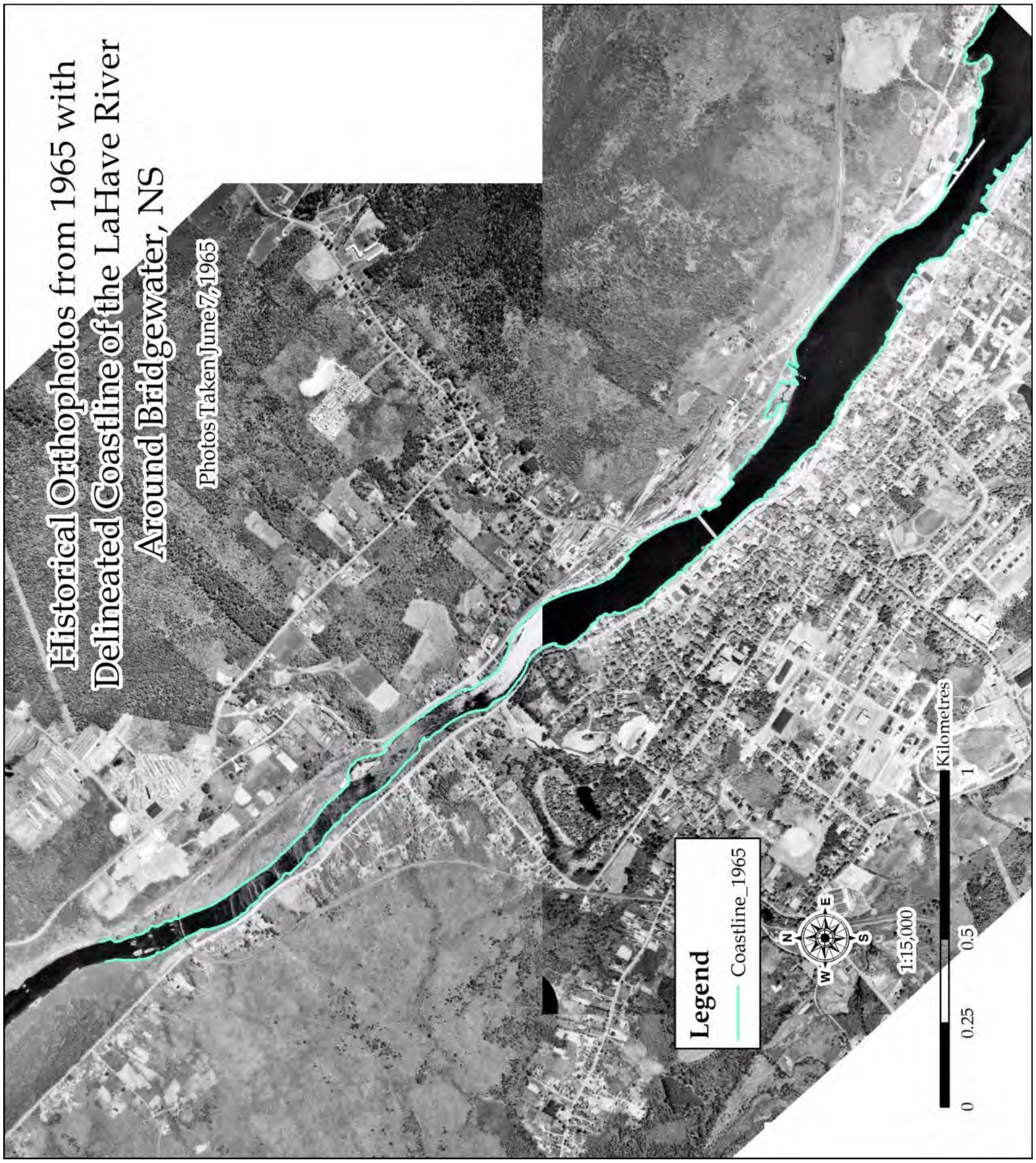

Figure 14:2 1965 orthophoto with coastline interpreted.

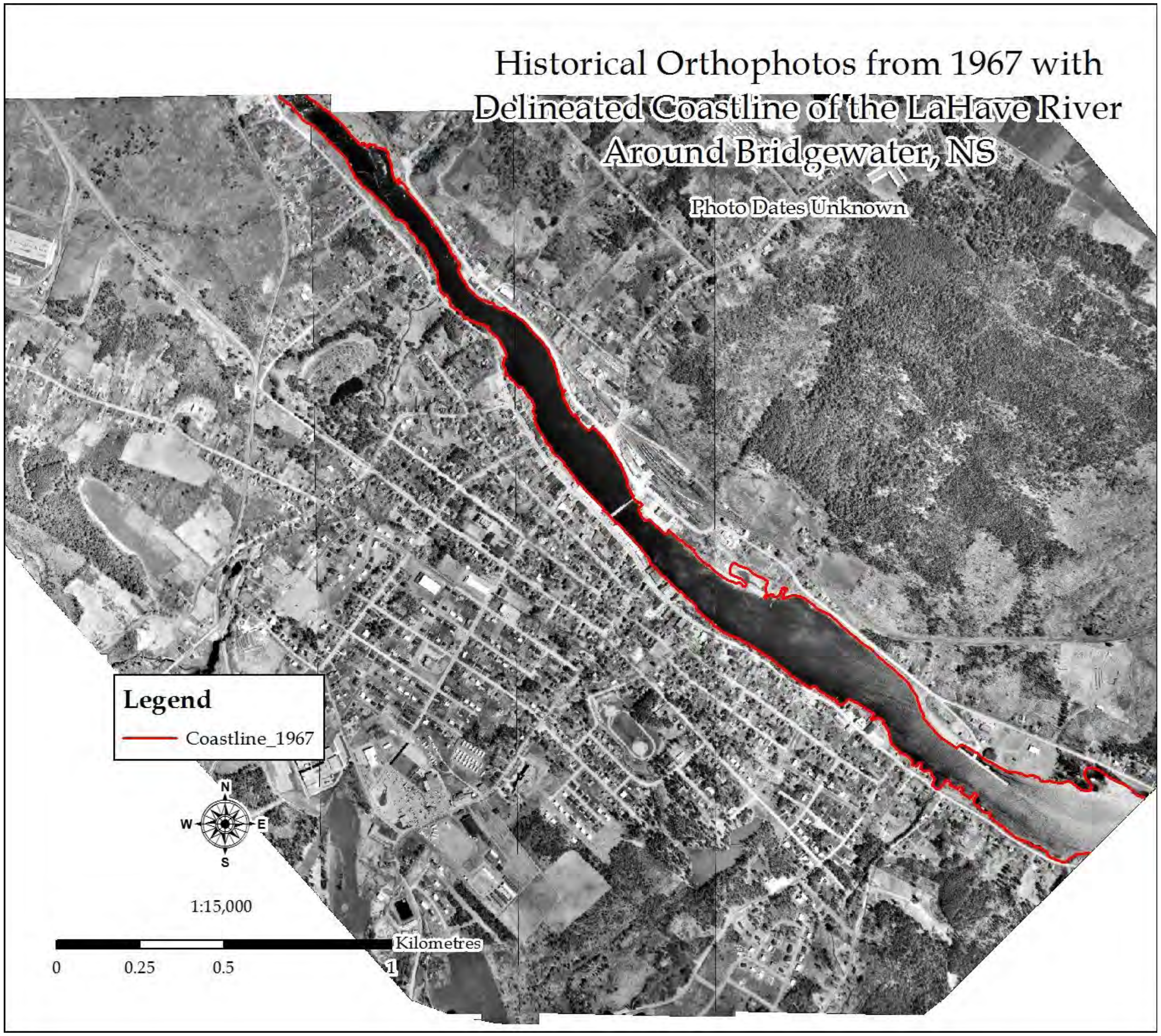

Figure 14:3 1967 orthophoto with coastline interpreted.

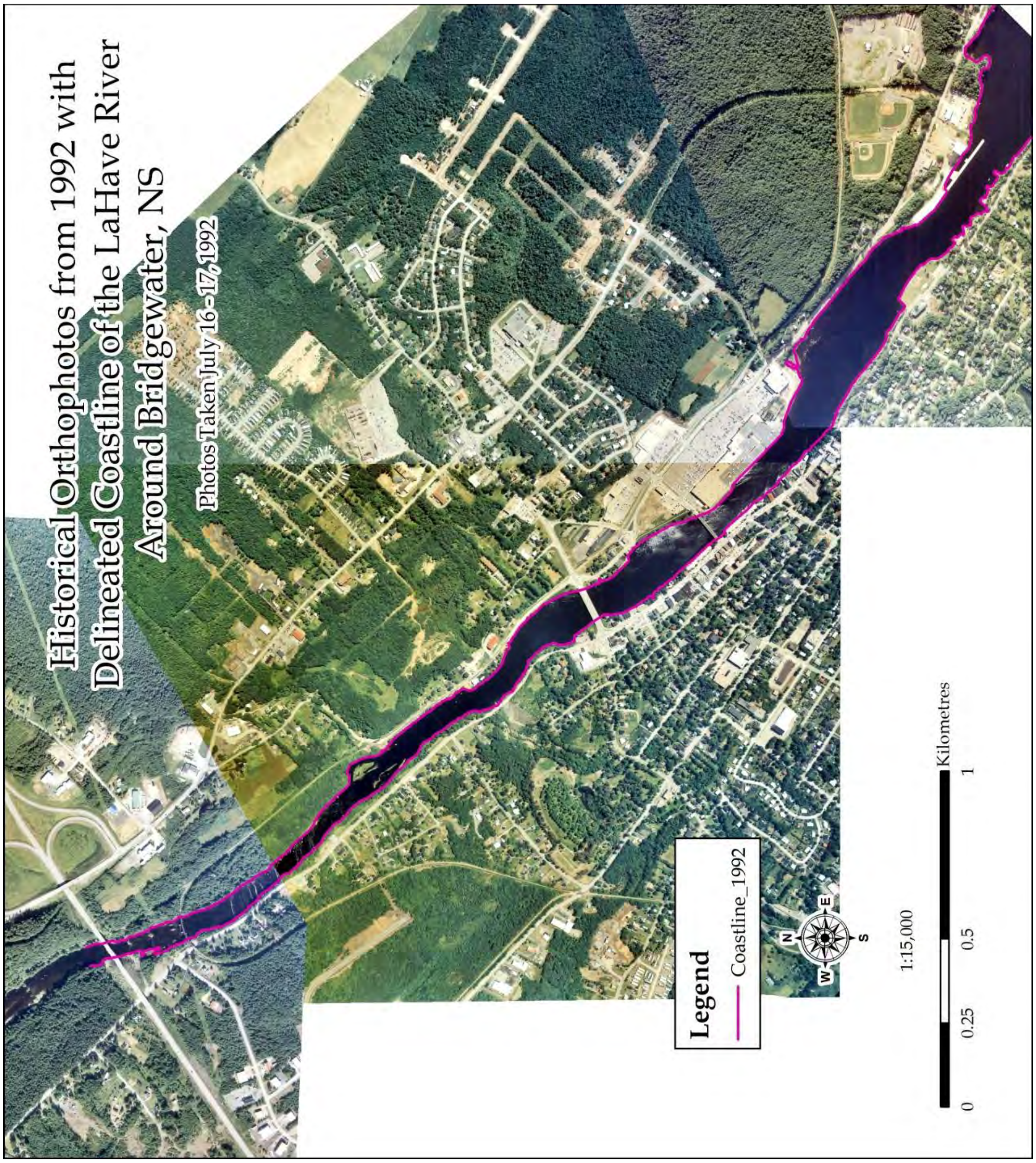

Figure 14:4 1992 orthophoto with coastline interpreted.

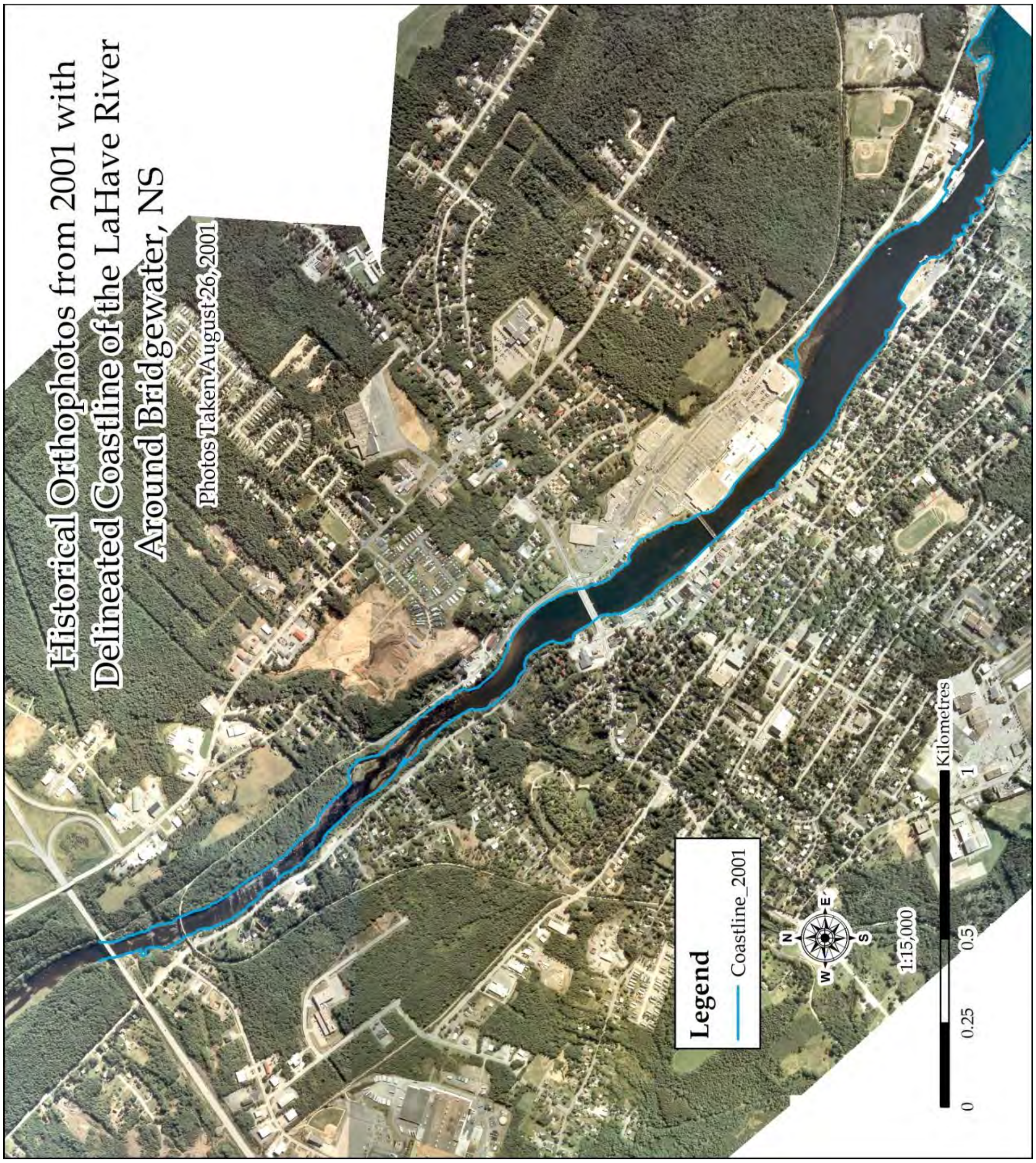

Figure 14:5 2001 orthophoto with coastline interpreted.

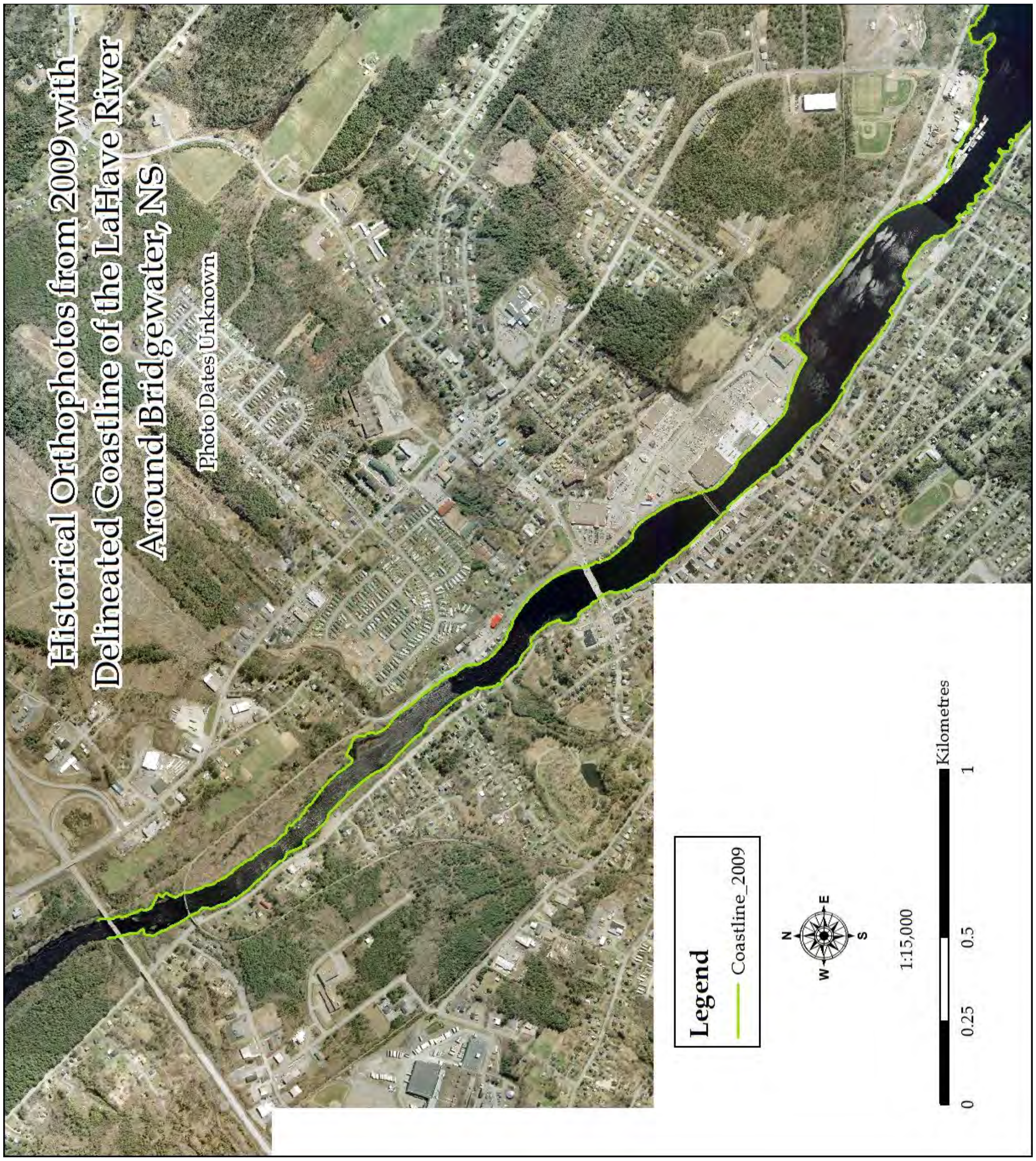

Figure 14:6 2009 orthophoto with coastline interpreted.

15. Appendix 7: 65% probability Design Level for the LaHave River assuming 16% increase in discharge by 2080

Date/Time	Design Level (Discharge
1/1/2080 1:01	139.4133524
1/1/2081 1:01	229.9833524
1/1/2082 1:01	283.0433524
1/1/2083 1:01	320.7433524
1/1/2084 1:01	350.0333524
1/1/2085 1:01	373.9933524
1/1/2086 1:01	394.2833524
1/1/2087 1:01	411.8833524
1/1/2088 1:01	427.4333524
1/1/2089 1:01	441.3633524
1/1/2090 1:01	453.9833524
1/1/2091 1:01	465.5133524
1/1/2092 1:01	476.1433524
1/1/2093 1:01	486.0033524
1/1/2094 1:01	495.1833524
1/1/2095 1:01	503.7933524
1/1/2096 1:01	511.8933524
1/1/2097 1:01	519.5333524
1/1/2098 1:01	526.7733524
1/1/2099 1:01	533.6533524
1/1/2100 1:01	540.2033524
1/1/2101 1:01	546.4633524
1/1/2102 1:01	552.4533524
1/1/2103 1:01	558.1933524
1/1/2104 1:01	563.7033524
1/1/2105 1:01	569.0133524
1/1/2106 1:01	574.1233524
1/1/2107 1:01	579.0533524
1/1/2108 1:01	583.8233524
1/1/2109 1:01	588.4333524
1/1/2110 1:01	592.9033524
1/1/2111 1:01	597.2333524
1/1/2112 1:01	601.4433524
1/1/2113 1:01	605.5233524
1/1/2114 1:01	609.5033524
1/1/2115 1:01	613.3633524
1/1/2116 1:01	617.1333524
1/1/2117 1:01	620.8033524
1/1/2118 1:01	624.3833524
1/1/2119 1:01	627.8733524

1/1/2120 1:01	631.2833524
1/1/2121 1:01	634.6233524
1/1/2122 1:01	637.8833524
1/1/2123 1:01	641.0733524
1/1/2124 1:01	644.1933524
1/1/2125 1:01	647.2533524
1/1/2126 1:01	650.2533524
1/1/2127 1:01	653.1933524
1/1/2128 1:01	656.0733524
1/1/2129 1:01	658.9033524
1/1/2130 1:01	661.6833524
1/1/2131 1:01	664.4033524
1/1/2132 1:01	667.0833524
1/1/2133 1:01	669.7133524
1/1/2134 1:01	672.3033524
1/1/2135 1:01	674.8433524
1/1/2136 1:01	677.3433524
1/1/2137 1:01	679.8133524
1/1/2138 1:01	682.2333524
1/1/2139 1:01	684.6233524
1/1/2140 1:01	686.9733524
1/1/2141 1:01	689.2833524
1/1/2142 1:01	691.5633524
1/1/2143 1:01	693.8133524
1/1/2144 1:01	696.0333524
1/1/2145 1:01	698.2133524
1/1/2146 1:01	700.3733524
1/1/2147 1:01	702.5033524
1/1/2148 1:01	704.6033524
1/1/2149 1:01	706.6733524
1/1/2150 1:01	708.7133524
1/1/2151 1:01	710.7333524
1/1/2152 1:01	712.7333524
1/1/2153 1:01	714.7033524
1/1/2154 1:01	716.6433524
1/1/2155 1:01	718.5733524
1/1/2156 1:01	720.4733524
1/1/2157 1:01	722.3433524
1/1/2158 1:01	724.2033524
1/1/2159 1:01	726.0433524
1/1/2160 1:01	727.8533524
1/1/2161 1:01	729.6533524
1/1/2162 1:01	731.4333524
1/1/2163 1:01	733.1933524
1/1/2164 1:01	734.9333524

1/1/2165 1:01	736.6533524
1/1/2166 1:01	738.3533524
1/1/2167 1:01	740.0433524
1/1/2168 1:01	741.7133524
1/1/2169 1:01	743.3733524
1/1/2170 1:01	745.0033524
1/1/2171 1:01	746.6333524
1/1/2172 1:01	748.2333524
1/1/2173 1:01	749.8333524
1/1/2174 1:01	751.4033524
1/1/2175 1:01	752.9733524
1/1/2176 1:01	754.5233524
1/1/2177 1:01	756.0533524
1/1/2178 1:01	757.5733524
1/1/2179 1:01	759.0833524
1/1/2180 1:01	760.5833524

16. Appendix 8: 99.5% probability Design Level for the LaHave River assuming 16% increase in discharge by 2080

Date/Time	Design Level (Discharge
1/1/2080 1:01	-71.67808162
1/1/2081 1:01	18.90191838
1/1/2082 1:01	71.96191838
1/1/2083 1:01	109.6619184
1/1/2084 1:01	138.9519184
1/1/2085 1:01	162.9119184
1/1/2086 1:01	183.2019184
1/1/2087 1:01	200.8019184
1/1/2088 1:01	216.3519184
1/1/2089 1:01	230.2819184
1/1/2090 1:01	242.9019184
1/1/2091 1:01	254.4319184
1/1/2092 1:01	265.0619184
1/1/2093 1:01	274.9219184
1/1/2094 1:01	284.1019184
1/1/2095 1:01	292.7119184
1/1/2096 1:01	300.8119184
1/1/2097 1:01	308.4519184
1/1/2098 1:01	315.6919184
1/1/2099 1:01	322.5719184
1/1/2100 1:01	329.1219184
1/1/2101 1:01	335.3819184
1/1/2102 1:01	341.3719184
1/1/2103 1:01	347.1119184
1/1/2104 1:01	352.6219184
1/1/2105 1:01	357.9319184
1/1/2106 1:01	363.0419184
1/1/2107 1:01	367.9719184
1/1/2108 1:01	372.7419184
1/1/2109 1:01	377.3519184
1/1/2110 1:01	381.8219184
1/1/2111 1:01	386.1519184
1/1/2112 1:01	390.3619184
1/1/2113 1:01	394.4419184
1/1/2114 1:01	398.4219184
1/1/2115 1:01	402.2819184
1/1/2116 1:01	406.0519184
1/1/2117 1:01	409.7219184

1/1/2118 1:01	413.3019184
1/1/2119 1:01	416.7919184
1/1/2120 1:01	420.2019184
1/1/2121 1:01	423.5419184
1/1/2122 1:01	426.8019184
1/1/2123 1:01	429.9919184
1/1/2124 1:01	433.1119184
1/1/2125 1:01	436.1719184
1/1/2126 1:01	439.1719184
1/1/2127 1:01	442.1119184
1/1/2128 1:01	444.9919184
1/1/2129 1:01	447.8219184
1/1/2130 1:01	450.6019184
1/1/2131 1:01	453.3219184
1/1/2132 1:01	456.0019184
1/1/2133 1:01	458.6319184
1/1/2134 1:01	461.2219184
1/1/2135 1:01	463.7619184
1/1/2136 1:01	466.2619184
1/1/2137 1:01	468.7319184
1/1/2138 1:01	471.1519184
1/1/2139 1:01	473.5419184
1/1/2140 1:01	475.8919184
1/1/2141 1:01	478.2019184
1/1/2142 1:01	480.4819184
1/1/2143 1:01	482.7319184
1/1/2144 1:01	484.9519184
1/1/2145 1:01	487.1319184
1/1/2146 1:01	489.2919184
1/1/2147 1:01	491.4219184
1/1/2148 1:01	493.5219184
1/1/2149 1:01	495.5919184
1/1/2150 1:01	497.6319184
1/1/2151 1:01	499.6519184
1/1/2152 1:01	501.6519184
1/1/2153 1:01	503.6219184
1/1/2154 1:01	505.5619184
1/1/2155 1:01	507.4919184
1/1/2156 1:01	509.3919184
1/1/2157 1:01	511.2619184
1/1/2158 1:01	513.1219184
1/1/2159 1:01	514.9619184

1/1/2160 1:01	516.7719184
1/1/2161 1:01	518.5719184
1/1/2162 1:01	520.3519184
1/1/2163 1:01	522.1119184
1/1/2164 1:01	523.8519184
1/1/2165 1:01	525.5719184
1/1/2166 1:01	527.2719184
1/1/2167 1:01	528.9619184
1/1/2168 1:01	530.6319184
1/1/2169 1:01	532.2919184
1/1/2170 1:01	533.9219184
1/1/2171 1:01	535.5519184
1/1/2172 1:01	537.1519184
1/1/2173 1:01	538.7519184
1/1/2174 1:01	540.3219184
1/1/2175 1:01	541.8919184
1/1/2176 1:01	543.4419184
1/1/2177 1:01	544.9719184
1/1/2178 1:01	546.4919184
1/1/2179 1:01	548.0019184
1/1/2180 1:01	549.5019184