A Multi-Dimensional Analysis of Topo-bathymetric Lidar Data of Paqtnkek Mi'kmaw First Nation Lands and Waters:

Assessment of Climate Change Vulnerability with Options for Adaptation

Year 1 Report

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Executive Summary

MAPS employed two community members to work on this project. AGRG worked with the Community Liaison Officer to conduct two community meetings, and with the GIS technician on fieldwork related to lidar ground truth data collection. A topographic lidar survey of Paqtnkek and the Afton River watershed was conducted on August 7, 2018. The survey was conducted at 1200 m altitude and measured elevations ranging from ~220 m elevation to ~-1 m (all elevations relative to CGVD28). A separate survey was conducted of the Afton River at 400 m elevation on August 6 using both the topographic and bathymetric lasers. Maximum elevation surveyed was 115 m and minimum was -10 m. The lidar data were processed from discrete unclassified points to finished lidar products such as digital elevation, colour shaded relief, and intensity models. A photo survey was conducted simultaneously with the lidar survey and resulted in 15 cm resolution orthophoto mosaics. GPS data were collected of the topography and river bathymetry to validate the lidar data.

A coastal erosion analysis was conducted using historical imagery. GIS modelling was used to estimate past erosion and project erosion into the future. The coastal portion of Paqtnkek Mi'kmaw Nation had a low vulnerability to erosion (max erosion rate per year of 0.05 m/yr at the We`lnek shore). A storm surge analysis was completed using recent observations of local storm surge, combined with astronomical high tides and recent sea-level rise predictions. The We`lnek shore was found to be vulnerable to total combined water levels of 2 m, with the lower section of shoreline inundated at those levels. Additionally, the land parcel south of Pomquet Harbour will flood at 2 m.

Project results were presented to the community at year-end. Following the presentation, meeting participants had a discussion facilitated by MAPS on possible adaptation solutions for the threatened church.

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1 Introduction

Paqtnkek Mi'kmaw Nation is located 24 km east of Antigonish, NS, and is comprised of 880 inland acres (Paqtnkek-Niktuek Reserve No. 23) plus 120 acres at the coastal outlet of the Pomquet River (We`lnek Reserve No. 38), (Figure 1.1). Climate change concerns within the community are focused on threats to coastal cultural sites due to sea level rise, storm surge flooding and erosion, and threats to infrastructure in the inland community due to overland flooding of the Afton River. This two-year project was a collaboration between Mi'kma'ki All Points Services (MAPS) and the Nova Scotia Community College's Applied Geomatics Research Group (NSCC AGRG) to conduct a Vulnerability Assessment and Adaptation Plan for both the coastal and inland regions of the community. This report documents progress on Year 1 of the project, which focused on an evaluation of coastal threats to the community and data collection for Year 2. Year 2 will focus on identification and collaborative adaptation for inland threats to the community.

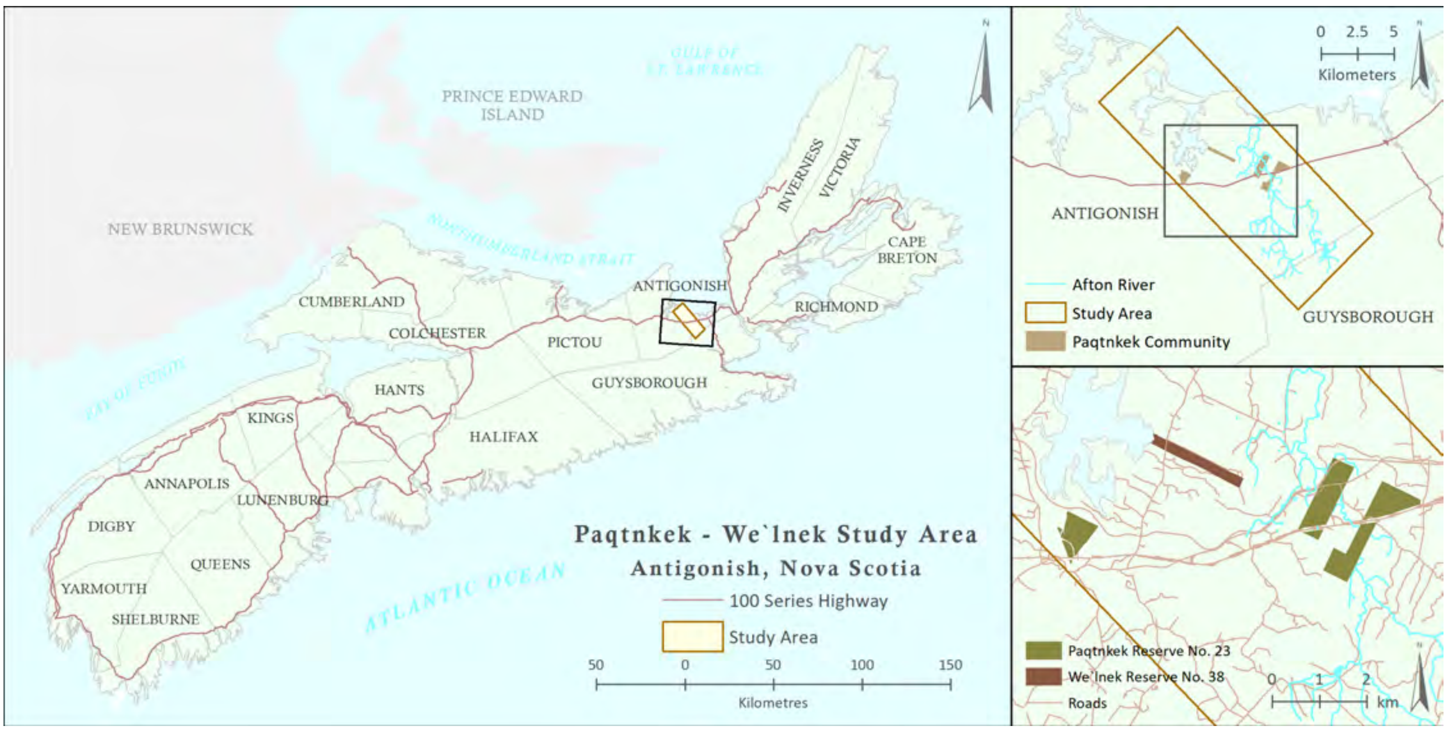

Figure 1.1: The project lidar study area in Antigonish County showing the Afton River, lidar study area, and the four land parcels that comprise the Paqtnkek community.

1.1 Coastal Threats

The coastal portion of Paqtnkek Mi'kmaq Nation has experienced heavy erosion of the shoreline of the We`lnek Reserve No. 38 (Figure 1.1, bottom right panel) during spring tides and other astronomically high tides, and occasional inundation of the land near the coast. A historic and culturally significant church and cemetery are located at the coast and are threatened by the continued erosion and sea-level rise, which, if combined with storm surge could cause irreparable damage to the site. Plans to develop fisheries-related infrastructure on this land are hampered due to the unknown and unquantified risks due to climate change and erosion.

Global sea-level rise, as predicted by climate change models, will increase the problem of flooding and erosion making more coastal areas vulnerable. The threat of erosion and sea-level rise along the shores of the Northumberland Strait are exacerbated by sediment composition; average annual erosion rate is 0.4 m/year (Finck, 2007; Government of New Brunswick, 2011; Lemmen et al., 2016; Shaw et al., 1998). For Antigonish, a 10-year storm could result in a sea-level of 3.32 m by 2025, 1.27 m higher than the largest astronomical tide, and a 100-year storm in 2055 would increase water level by 1.91 m above the largest astronomical tide (Richards and Daigle, 2011).

A climate change adaptation strategy to effectively plan for rising sea-level, increased erosion and storm surge was developed for this project through collaborative engagement between MAPS, NSCC, and the Paqtnkek community. The plan to quantify and map the risk to the community from flooding, erosion, and sea-level rise under climate change scenarios consisted of a vulnerability assessment based on lidar data and satellite imagery, and incorporation of Traditional Ecological Knowledge (TEK). An adaptation plan informed by the vulnerability assessment and by community discussions was developed. The plan suggests ways to minimize or mitigate damage to community infrastructure and to plan for future development.

1.2 Inland Threats

Year 2 of this project will be the development of a vulnerability assessment and adaptation plan for the Afton River to quantify and map the risk to the community from inland flooding and erosion under climate change scenarios.

The majority of the Paqtnkek First Nations lands lie in the Afton River floodplain which, in the past, was known to flood occasionally at spring breakup. Ice floating downstream would sometimes become blocked at bridges and culverts and cause overland flooding. However, community members have noticed that in recent years there are two or three freeze-thaw cycles in the river due to fluctuating temperatures, and the outlets at the bridges have become narrower/more constricted due to vegetation and sediment buildup; this has resulted in the river overtopping its banks more frequently than in the past. Exacerbating the issue is the high rate of erosion of the river, noted by community members to be on the order of one foot per year. The erosion has caused the bank to be undercut, trees to be toppled and new channels to be cut. This erosion has changed the path of the river, and it is slowly moving towards the community's sewage treatment plant, which is located on the edge of the floodplain. Community members state that the river has moved 100 yards towards the sewage treatment plant and a railway bridge over the past 40 years. There are five bridges over the Afton River within the Paqtnkek Mi'kmaq Nation Community.

The extent to which the infrastructure along the river is susceptible to flooding is expected to become more severe with changes to precipitation amounts and duration in the face of climate change. Richards and Daigle (2011) predicted an annual increase in precipitation for Antigonish; most of that increase is predicted to occur in the winter and spring, with minimal increase in summer and fall precipitation. Extreme rainfall events are predicted to occur more frequently (2003), and more precipitation is expected to fall as rain rather than snow in the future. Streamflow is expected to increase with temperature and precipitation in the Atlantic region (Najjar et al., 2000), and spring flood events could become more common due to changes in late-winter early-spring precipitation patterns (Berrang-Ford and Noble, 2006). This anticipated increase in the severity and extent of flooding will not only affect existing infrastructure near the Afton River, it may also limit future community housing infrastructure expansion and economic development, particularly regarding the Paqtnkek Mi'kmaw Nation's plans to acquire adjacent land parcels for future community development.

2 Community Engagement

The community of Paqtnkek has been actively involved in the project in Year 1. MAPS and AGRG presented a project overview to the Paqtnkek Band Council on March 26, 2018. In early summer two community members were hired to work on the project. Krista Thompson is the community liaison officer and Kara Pictou was hired to collect TEK and assist AGRG with fieldwork. Ms. Thompson and Ms. Pictou facilitated a community meeting on Oct. 22, 2018, for MAPS and AGRG to present the project overview and results to-date to the wider community. Ms. Pictou scheduled TEK interviews with community members during the meeting, and assisted MAPS with annotating a map with local knowledge of past river channels and erosion. Following the community meeting AGRG trained Ms. Pictou on measuring high water level in the Afton River. The final community meeting for Year 1 is scheduled for Feb. 20, 2019, to present the results of the vulnerability assessment and discuss possible solutions for adaptation planning. The meeting will be attended by MAPS, AGRG, Paqtnkek Band Council, elders, and community at large.

3 Lidar Survey

3.1 Lidar Data Collection

AGRG utilized the Chiroptera II integrated topographic-bathymetric lidar sensor equipped with a 60 MPIX multispectral camera for this study. The system incorporates a 1064 nm near-infrared laser for ground returns and sea surface and a green 515 nm laser for bathymetric returns. The lasers scan in an elliptical pattern, which enables coverage from many different angles on vertical faces, causes less shadow effects in the data, and is less sensitive to water surface interaction (e.g., waves). The bathymetric laser is limited by depth and clarity and has a depth penetration rating of roughly 1.5 x the Secchi depth (a measure of turbidity or water clarity using a black and white disk). The Leica RCD30 camera co-aligned RGB+NIR motion compensated photographs which can be mosaicked into a single image in post-processing or analyzed frame by frame for maximum information extraction. The calibration of the lidar sensor and camera have been documented in an external report which is available upon request.

The lidar survey was conducted on August 6 and 7, 2018 (Table 3.1). The surveys were planned using Mission Pro software. The 71 flight lines are shown in Figure 3.1. The aircraft required ground-based high precision GPS data to be collected during the lidar survey in order to provide accurate positional data for the aircraft trajectory. The Nova Scotia Active

Control Stations (NSACS) cellular network was used to provide geodetic control and a GNSS base station was used to process the trajectory of the survey aircraft. The NSACS network was also used to establish base station coordinates for real-time kinematic collection of ground truth data within the study area. AGRG researchers conducted ground truth data collection including hard surface validation and river cross section measurements (Table 3.1 and Figure 3.2).

Survey	Lidar System	Survey Date	Survey Time (UTC)	Survey Duration	Number of Flight Lines	Flight Altitude	Validation (hard surface and cross section)
Afton River and Pomquet Bay Part 1	Bathy	Aug 6	13:15	3 hours 20 mins	32	400	Cross section measurements on Oct 23.
Afton River and Pomquet Bay Part 2	Bathy	Aug 6	17:15	2 hours 40 mins	22	400	
Afton River Watershed	Topo	Aug 7	13:25	2 hours 40 mins	16	1200	Road validation July 27

Table 3.1: Summary of lidar surveys. The Afton River and Pomquet Bay bathymetric surveys were conducted in two parts on August 6, and the entire topographic survey was conducted on Aug 7.

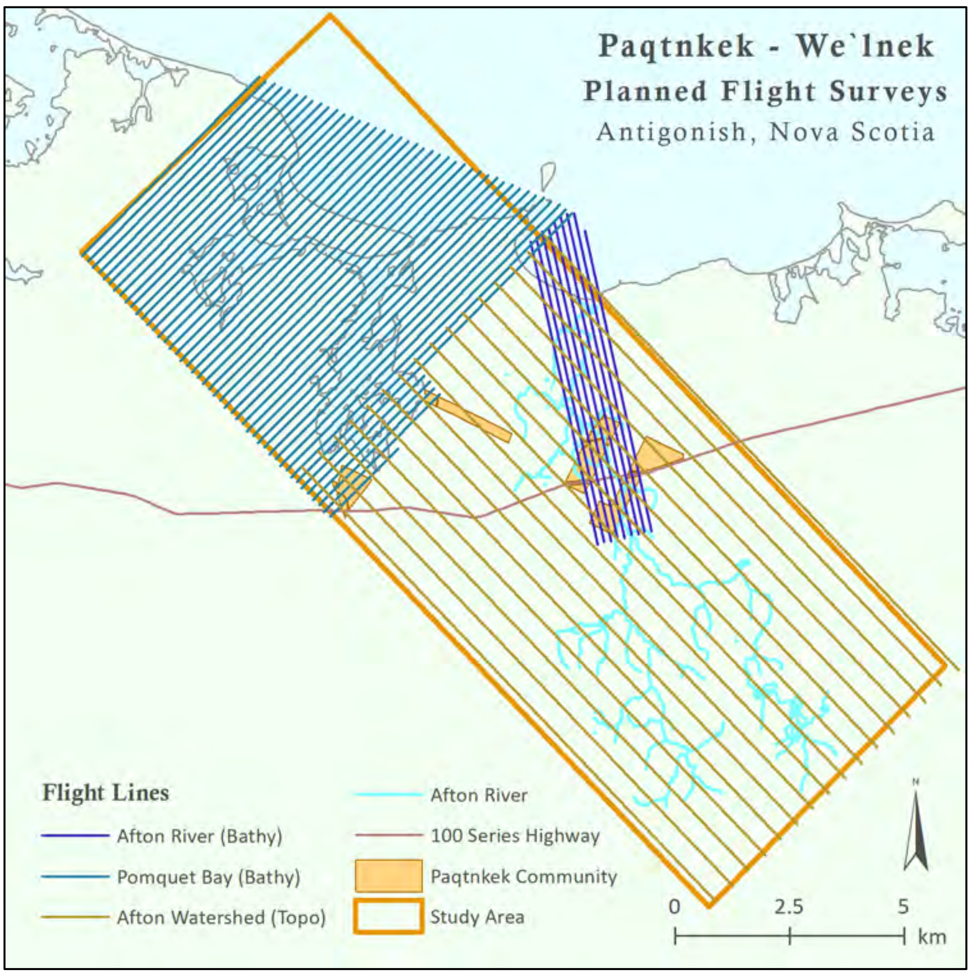

Figure 3.1: Flight lines for 2018 lidar surveys in Paqtnkek. A topographic lidar survey was conducted of the Afton River watershed, and bathymetric lidar surveys were conducted of the Afton River and Pomquet Harbour (for a separate project).

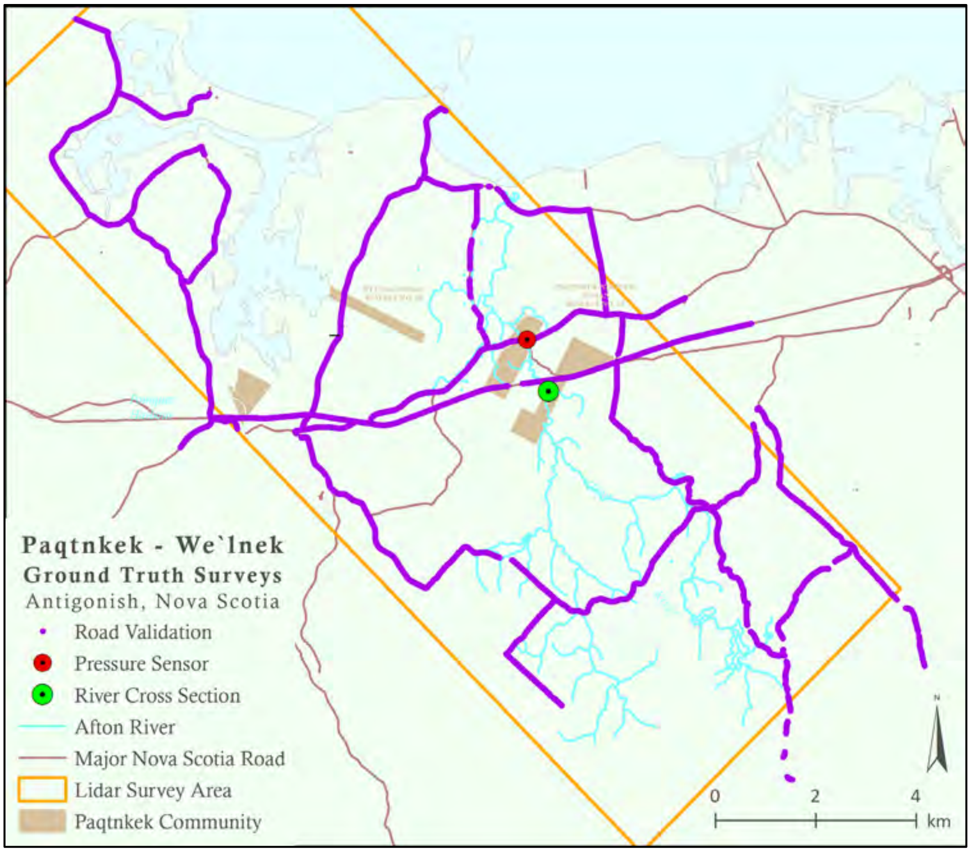

Figure 3.2: Lidar ground truth data collection for roads, cross sectional measurements for Afton River lidar validation to date, and location of pressure sensor in Afton River.

3.2 Lidar Data Processing

Aircraft GPS data were differentially corrected using base station observations, and the aircraft trajectory was calculated by linking the corrected GPS data with the aircraft attitude measured by an inertial measurement unit (IMU). Lidar Survey Studio (LSS) was used to process Chiroptera II waveforms, which were georeferenced into discrete points by linking laser returns to the processed aircraft trajectory to produce georeferenced point clouds in the LAS format. The data were inspected to ensure there was sufficient overlap (30%) and the AOI was fully covered by lidar returns.

The LAS files were read into TerraScan™ with the laser returns grouped by laser type so they could be easily separated, analyzed, and further refined. Points were classified into discrete classes based on their physical characteristics including relative geometry and reflective properties (Table 3.2).

Classification Value	*Meaning*
1	Unclassified
2	Ground
4	Medium vegetation
7	Low point (noise)
9	Topographic water surface
18	High noise
40	Bathymetric point

41	Bathymetric water surface
42	Derived water surface
80	Bathymetric vegetation

Table 3.2: Lidar point classification values and descriptions.

The classified LAS files were further processed using ESRI ArcGIS™ to produce a variety of raster surfaces at a 1 m^2 resolution. Surface products included: a digital surface model (DSM) comprised of valid lidar returns from vegetation, ground, and bathymetry; a digital elevation model (DEM) comprised of ground returns above and below the water line, and an intensity map of the lidar returns.

The RCD30 imagery was processed using Agisoft Photoscan Professional. Captured imagery was georeferenced using an aerial triangulation model. Where photo positions were unable to be resolved, imagery was directly georeferenced using the known camera position and orientation. Photo orientations were calculated by linking the exterior orientation (EO) extracted from the aircraft trajectory GPS position (X, Y, Z) and the IMU attitude (omega, phi, kappa) at shutter event to the engineered internal orientation (IO) of the RCD30 (CCD dimensions, focal length, lens curvature).

The original elevation of the lidar products were referenced to the same elevation model as the GPS unit they were collected with. This model is a theoretical Earth surface known as the ellipsoid, and elevations referenced to this surface are in ellipsoidal height (GRS80). To convert elevations to orthometric heights relative to the Canadian Geodetic Vertical Datum of 1928 (CGVD28) offsets were applied using the HT2 geoid-ellipsoid separation model from Natural Resources Canada.

Ground elevation measurements obtained using the RTK GPS system were used to validate the topographic lidar returns on areas of hard, flat surfaces (e.g., roads); the bathymetric sensor was validated using the cross sections measured with RTK GPS. The difference between the GPS elevation and the lidar elevation (ΔZ) was calculated by extracting the lidar elevation from the DEM and subtracting the lidar elevation from the GPS elevation. GPS points were subject to a quality control assessment before being included in the validation process. GPS measurements were required to have < 0.05 m of error in elevation at the time of their capture in order to limit bad GPS signal error.

3.3 Lidar Results

The bathymetric lidar survey of the Afton River was processed into a DEM and DSM; these are presented as Colour Shaded Relief (CSR) models (Figure 3.3). The lidar surveyed a maximum elevation of ~115 m CGVD28 and penetrated to a depth of -10 m. The intensity model provides information on how much light was absorbed by the ground surface that the laser reflected off; bright areas in the intensity model indicate that the laser reflected strongly off the land (e.g., sand), while dark areas indicate a darker ground surface (e.g., trees, Figure 3.3 middle panel). The orthophoto mosaic draped over the DSM and DEM provide the reader with additional contextual information with which to view the image (Figure 3.3).

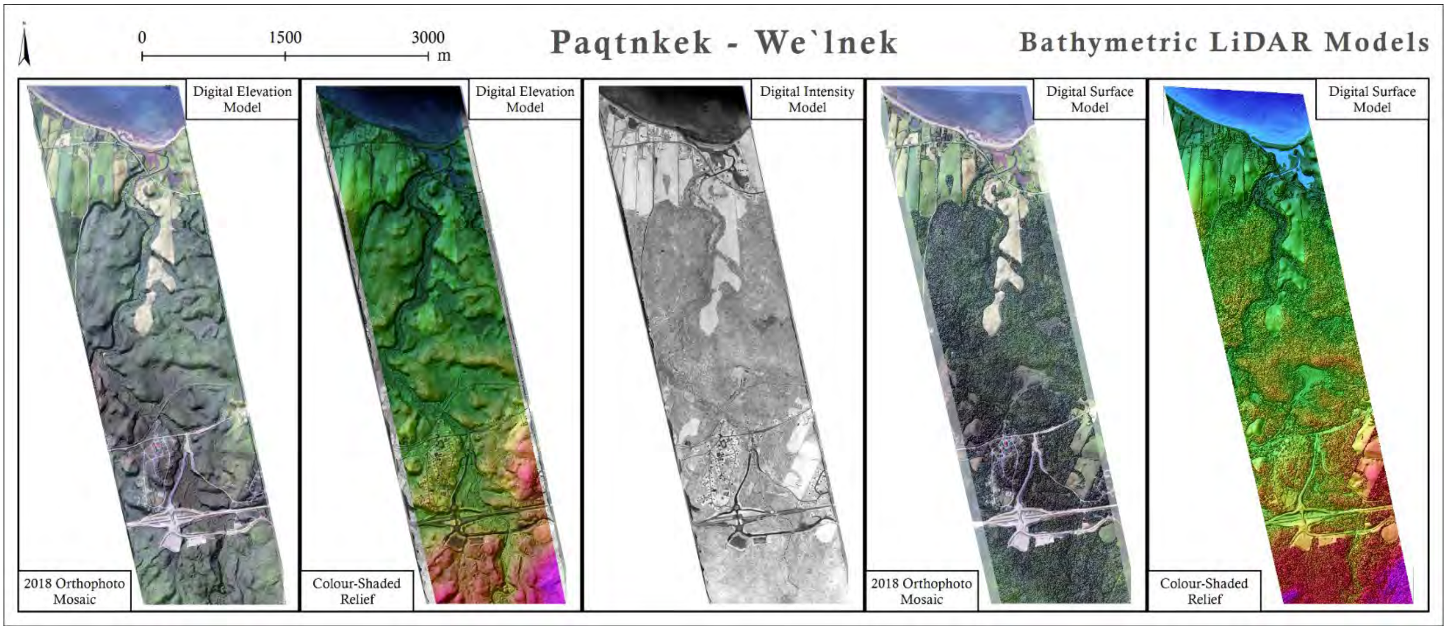

Figure 3.3: Lidar products for the August 6 bathymetric data collection of the Afton River. Panels show the orthophoto draped on the DEM, a CSR of the DEM, the intensity model, the orthophoto draped on the DSM, a CSR of the DSM, from left to right.

The August 7 topographic lidar survey of the Paqtnkek community was processed into a DEM and showed highest elevations in the southern portion of the study area (218 m CGVD28), then decreasing northwards to the shoreline (Figure 3.4). The Colour Shaded Relief (CSR) of the DSM shows buildings, trees, and other built infrastructure or vegetation within the study area (Figure 3.5). The RCD30 aerial orthophoto mosaic draped over the DEM (Figure 3.6) and over the DSM (Figure 3.7) shows the variety of land uses and vegetation cover throughout the watershed, including forests, lakes, agricultural use, roads, and residential areas.

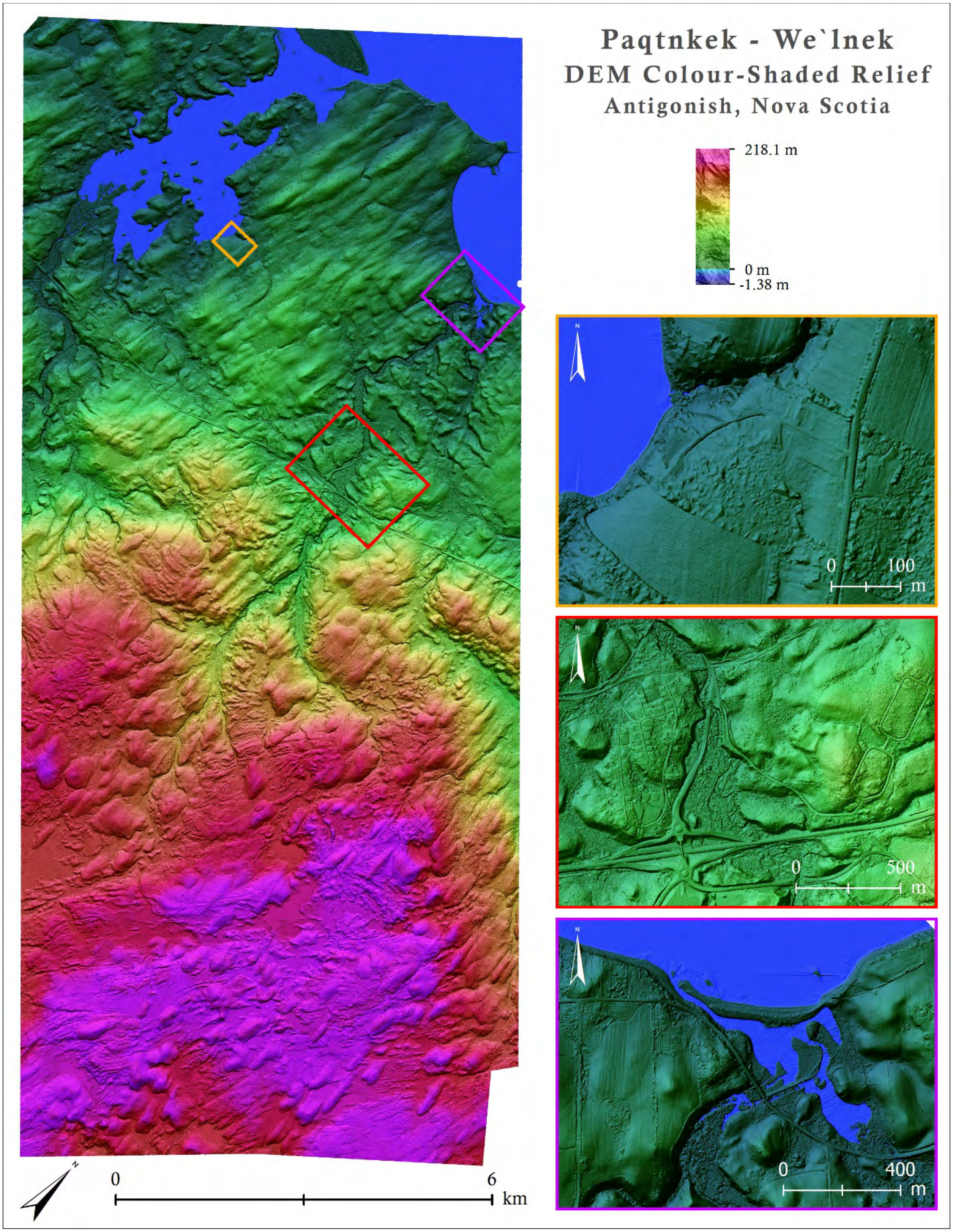

Figure 3.4: The colour-shaded relief of the DEM for Paqtnkek and surrounding area. Insets match to larger image by frame colour. Insets show the We`lnek shoreline, the new highway 104 interchange, and the mouth of the Afton River.

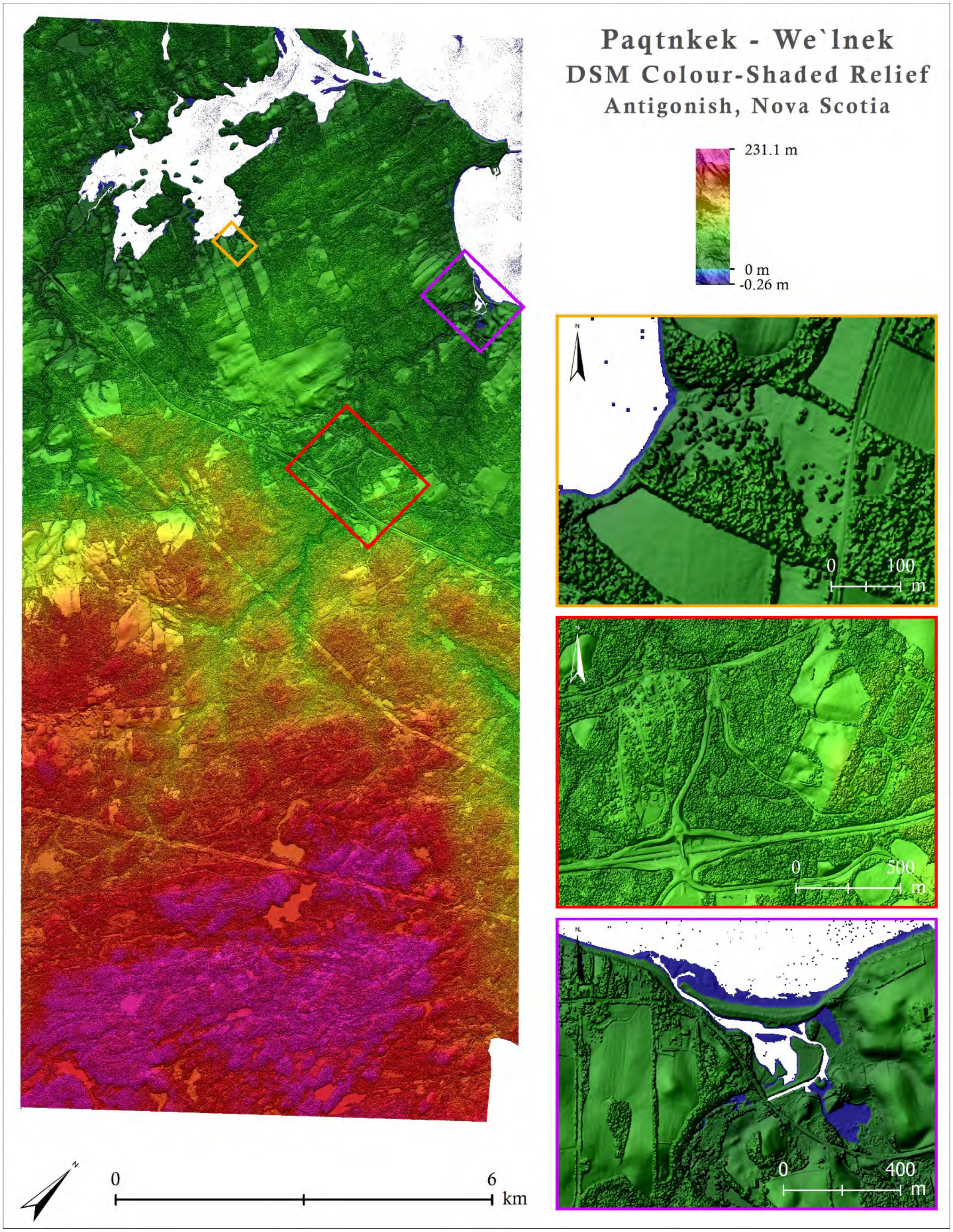

Figure 3.5: The colour-shaded relief of the DSM for Paqtnkek and surrounding area. Insets match to larger image by frame colour. Insets show the We`lnek shoreline, the new highway 104 interchange, and the mouth of the Afton River.

Figure 3.6: High-resolution true colour imagery of Paqtnkek and surrounding area collected simultaneously with the lidar draped on the DEM; insets match to larger imagery by frame colour. Insets show the We`lnek shoreline, the new highway 104 interchange, and the mouth of the Afton River.

Figure 3.7: High-resolution true colour imagery of Paqtnkek and surrounding area collected simultaneously with the lidar draped on the DSM; insets match to larger imagery by frame colour. Insets show the We`lnek shoreline, the new highway 104 interchange, and the mouth of the Afton River.

4 Coastal Threats

A 2017 assessment of climate change threats to the Paqtnkek community revealed a high level of vulnerability to sea-level rise, storm surge, and coastal erosion at the Welne'k shoreline (Mi'kmaw Conservation Group, 2017). The assessment was based on general information, and the report recommended that further evaluation of the Welne'k shoreline be undertaken using lidar and localized modelling. The evaluation of erosion and coastal threats presented in this section responds to those recommendations.

4.1 Erosion Analysis

4.1.1 Imagery

An analysis of historic coastal erosion at the We`lnek reserve was conducted using historical aerial photos, satellite imagery, National Air Photo digital imagery, and the lidar survey orthophoto mosaic (Table 4.1, Figure 4.1, Figure 4.2). Many images were acquired spanning 75 years for the coastal erosion portion of this project: six were used for the coastal erosion analysis, several were discarded due to poor georeferencing or distortion, and several are reserved for the river flooding analysis in Year 2. The two usable historic air photos were delivered as printed photographs and were scanned in at 2032 dpi resolution, two digital images were from the WorldView-2 satellite mission, one image was from the Nova Scotia Geomatics Center, and one image was from the National Resources Canada (NRCan) National Air Photo Library. The satellite images have a panchromatic band (sensitive to all visible colours of the light spectrum) and 4-band multispectral (RGB+NIR) and 0.5 m resolution, and the RCD30 RGB+NIR orthophoto mosaic has 0.15 m resolution. Each of the six images overlaps the We`lnek reserve parcel.

Image Date	Image Source	ID	Spectral Range	Scale	Medium	Resolution	Ground Control Points	Residual (m)
7/13/1945	HAP	Roll number A8469, photo number 22	B&W	15,000	Film	2032 dpi derived resolution	5	3.05
6/11/1954	HAP	Roll number A14090, photo number 80	B&W	15,000	Film	2032 dpi derived resolution	6	4.10
2003	GeoNOVA	N/A		N/A	Digital	0.6 m	6	0.89
10/03/2010	SAT	Catalog ID: 1030010006B34800	Pan+4 band MS	N/A	Digital	0.5 m	6	6.45
06/12/2011	SAT	Catalog ID: 103001000B8E5600	Pan+4 band MS	N/A	Digital	0.5 m	3	1.5×10^{-6}
05/22/2017	NAPL			N/A	Digital	0.6 m	N/A	N/A
08/07/2018	RCD30	N/A	RGB + NIR	N/A	Digital	0.15 m	N/A	N/A

Table 4.1: Summary of imagery used for coastal erosion analysis. HAP = Historic Air Photos, GeoNOVA = Nova Scotia Geomatics Center NAPL = National Air Photo Library, SAT = WorldView-2 Satellite, RCD30 = orthophoto mosaic from 2018, Pan+4 band MS = panchromatic band and 4-band multispectral.

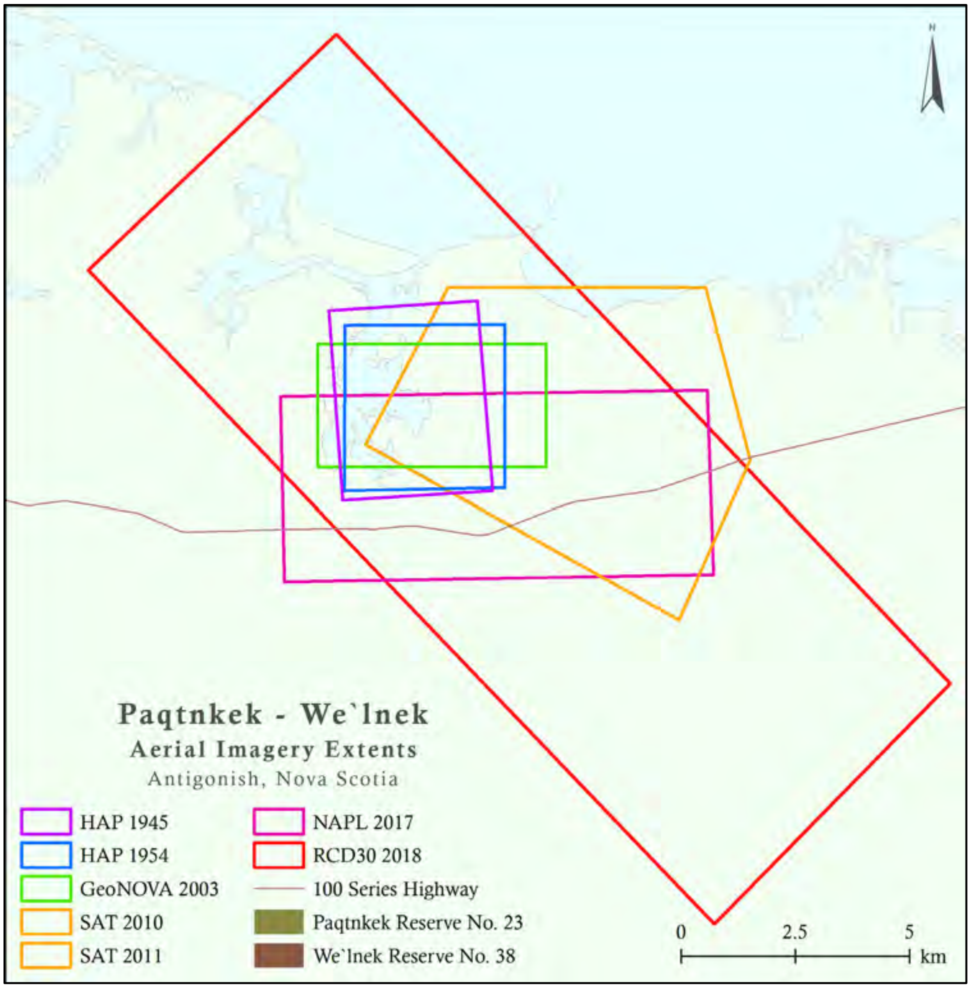

Figure 4.1: Boundaries of aerial imagery used for the coastal erosion analysis.

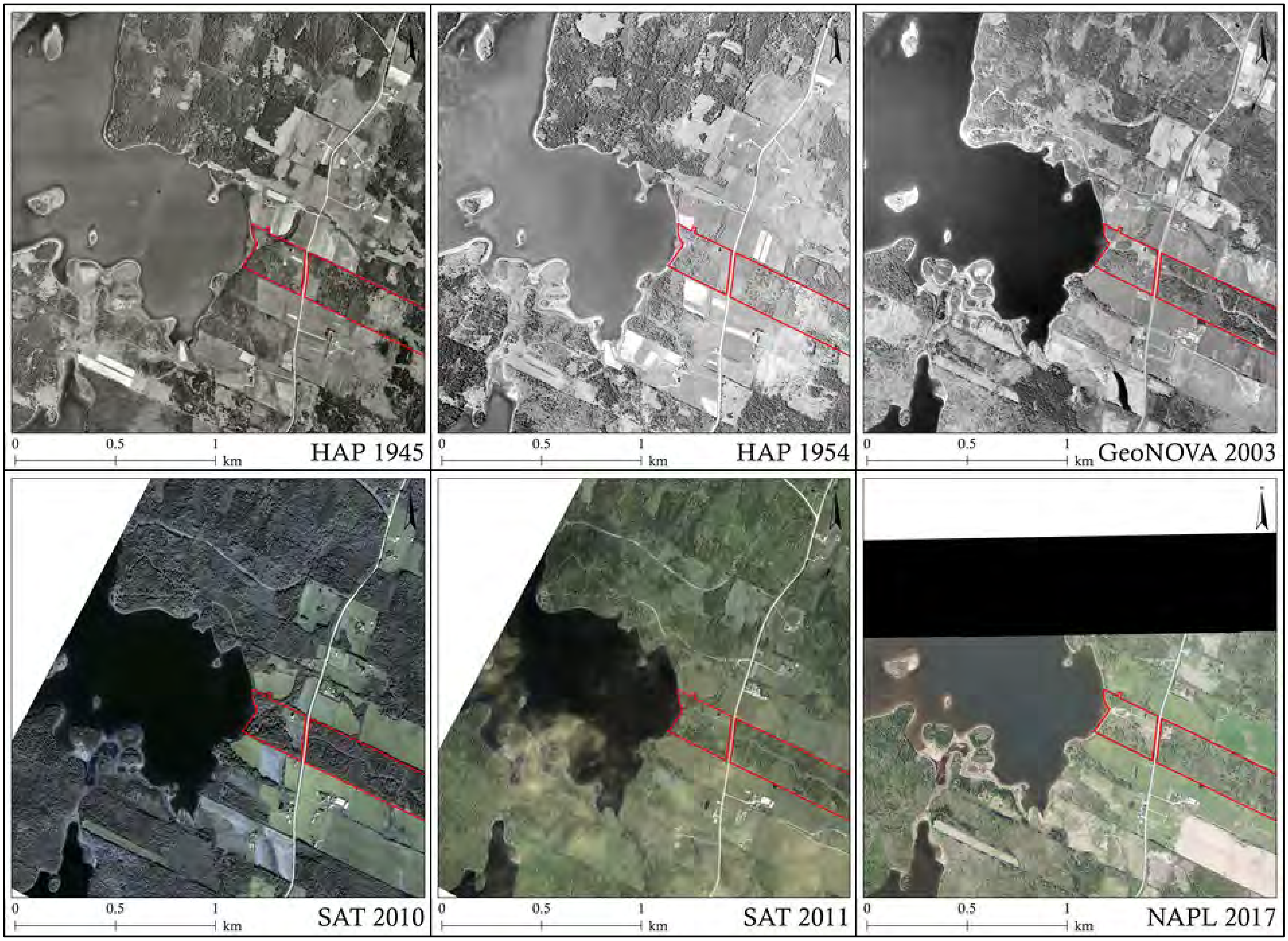

Figure 4.2: Aerial imagery used for coastal erosion analysis.

4.1.2 Georeferencing

The coastal erosion analysis followed the procedures developed by MacDonald and Webster (2014) which requires comparing images from different years in a Geographic Information System (GIS) and estimating past erosion rates. This process requires all the imagery to be referenced to the same geospatial reference system. The historic air photos and satellite images did not contain a spatial reference system and needed to be georeferenced in order to be used for the erosion analysis. Georeferencing is a process in which imagery with no spatial reference, such as a scanned hard-copy aerial photo, is assigned a spatial reference system. To georeference an image, features common to both the spatial and non-spatial images must be connected in the process of generating ground control points (GCPs). Features such as road intersections, bridges and building foundations can be used as GCPs, provided the feature is a ground feature and that the same feature is present in the same location in both images.

The 2018 orthophoto mosaic (RCD30) was used as the real-world reference to georeference the other images for several reasons. The air photos were collected concurrent with AGRG's topo-bathymetric lidar survey, which uses survey grade differential GPS and advanced inertial measurement hardware to track the movement of the plane and its survey-grade location. These data are incorporated into the spatial referencing of the RCD30 air photos, in combination with the lidar-derived ground terrain model, to produce a very high resolution (0.15 m) orthomosaic with a horizontal accuracy similar to that of the lidar dataset.

Up to six GCPs were used for georeferencing and a residual error estimate was computed for each image (Table 4.1). The residual error shows how accurately the image 'fits' to the reference dataset by comparing coordinates of the same GCP and ranged from high accuracy ($1.5x10^{-6}$) for the 2011 satellite imagery to lower accuracy for the historic air photos (up to 6 m).

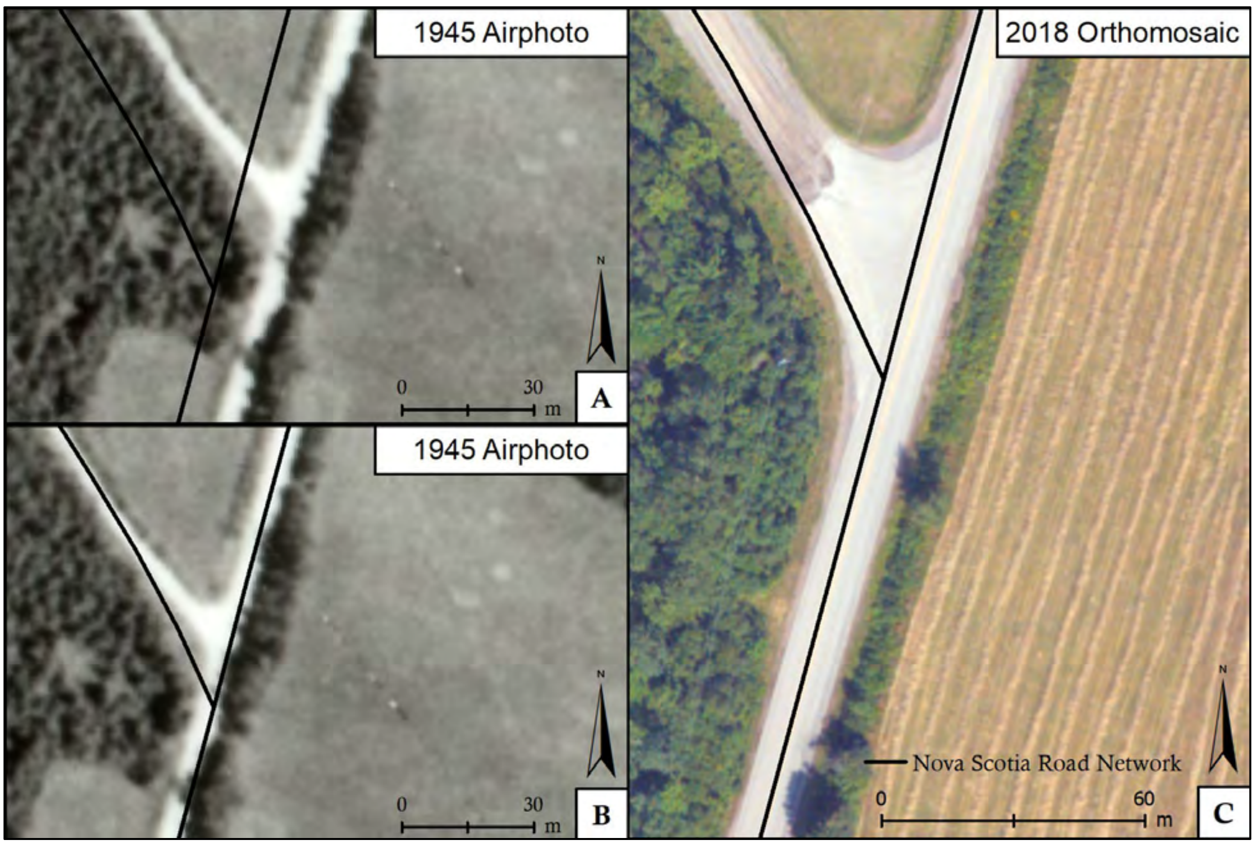

Figure 4.3: A road intersection that was used as a ground control point to georeference the 1945 air photo. The use of the road as a GCP improved the georeferencing from a poor fit (A) to a good fit (B); the 1945 air photo is now georeferenced as well as imagery georeferenced with aircraft trajectories (C).

4.1.3 Coastline Change Detection

The coastline in each georeferenced image from 1945 to 2018 was digitized in ArcMap using "the most landward evidence of tidal inundation" as the definition for coastline. The coastline was digitized for all of Church Cove, the small bay where the We`lnek reserve is located (Figure 4.4). In some areas the coastline appeared at the bottom of a steep bank, and in other areas the extent of tidal inundation was indicated by a wrack line visible in the imagery.

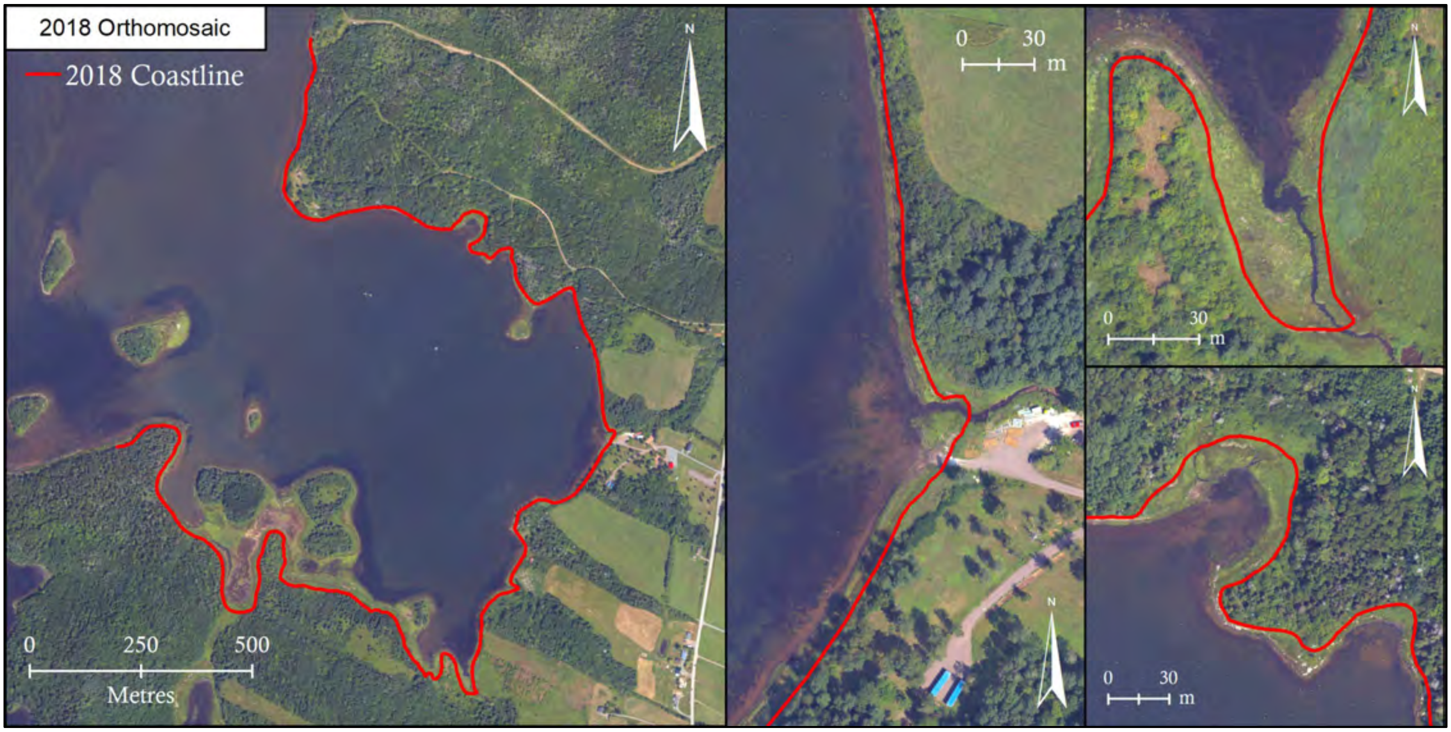

Figure 4.4: The 15 cm resolution 2018 RCD30 imagery of Church Cove, Pomquet Harbour, 2018. The left shows the extent of the digitized coastline in red. The zoomed in panels on the right show how the coastline was defined differently depending on the type of coastline (steep bank, marshy area, etc.).

The digitized coastline appears in different locations in different years of imagery where there has been erosion, accretion, or other changes to the coastline (Figure 4.5). The rate of shoreline change between 2018 and each historic image was calculated by first dividing the 2018 coastline into 1 m segments. The distance between the 2018 image and each historic image was calculated for the 1 m segments and divided by the number of years between images. This process resulted in a rate of coastline change for each 1 m segment for each historic image in meters per year (Figure 4.6Figure 4.7). Mean erosion rates were calculated for each year compared to 2018 (Table 4.2) and varied between 0.02 meters of erosion per year (1945) and -0.11 m of accretion per year (2017). Excluding the 2017 rate, there was an overall mean erosion rate of 0.036 m/yr, with a standard deviation of 0.013 m/yr. Likely the 2017 image was an unsuitable candidate due to its close proximity in time to the baseline (2018).

Year of Imagery	Mean Erosion Rate Compared to 2018 Imagery, in meters per year
1945	0.02
1954	0.03
2003	0.05
2010	0.03
2011	0.05
2017	-0.11

Table 4.2: Mean erosion rates in meters per year (m/yr) for Church Cove for each year of imagery compared to 2018 were between 0.02 and 0.05 m/yr while the 2017 dataset is very different at -0.11 m/yr. Positive values indicate erosion and negative values indicate accretion.

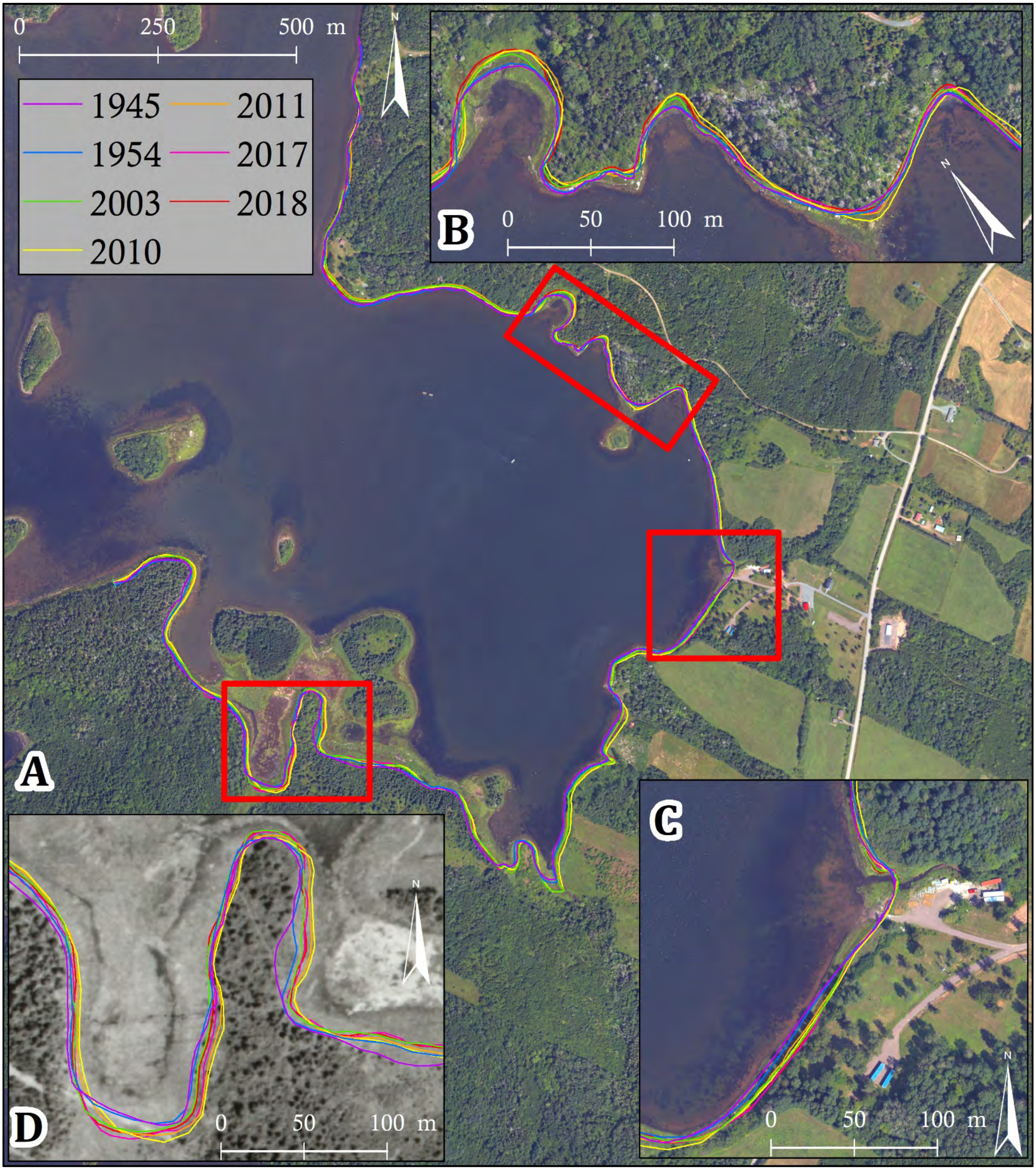

Figure 4.5: The digitized coastline for each image shown on the 2018 imagery for the entire bay (A), a section of the northeast shore (B), the coastline owned by Paqtnkek (C), and a section of somewhat sheltered coastline (D), shown on the 1945 historic air photo.

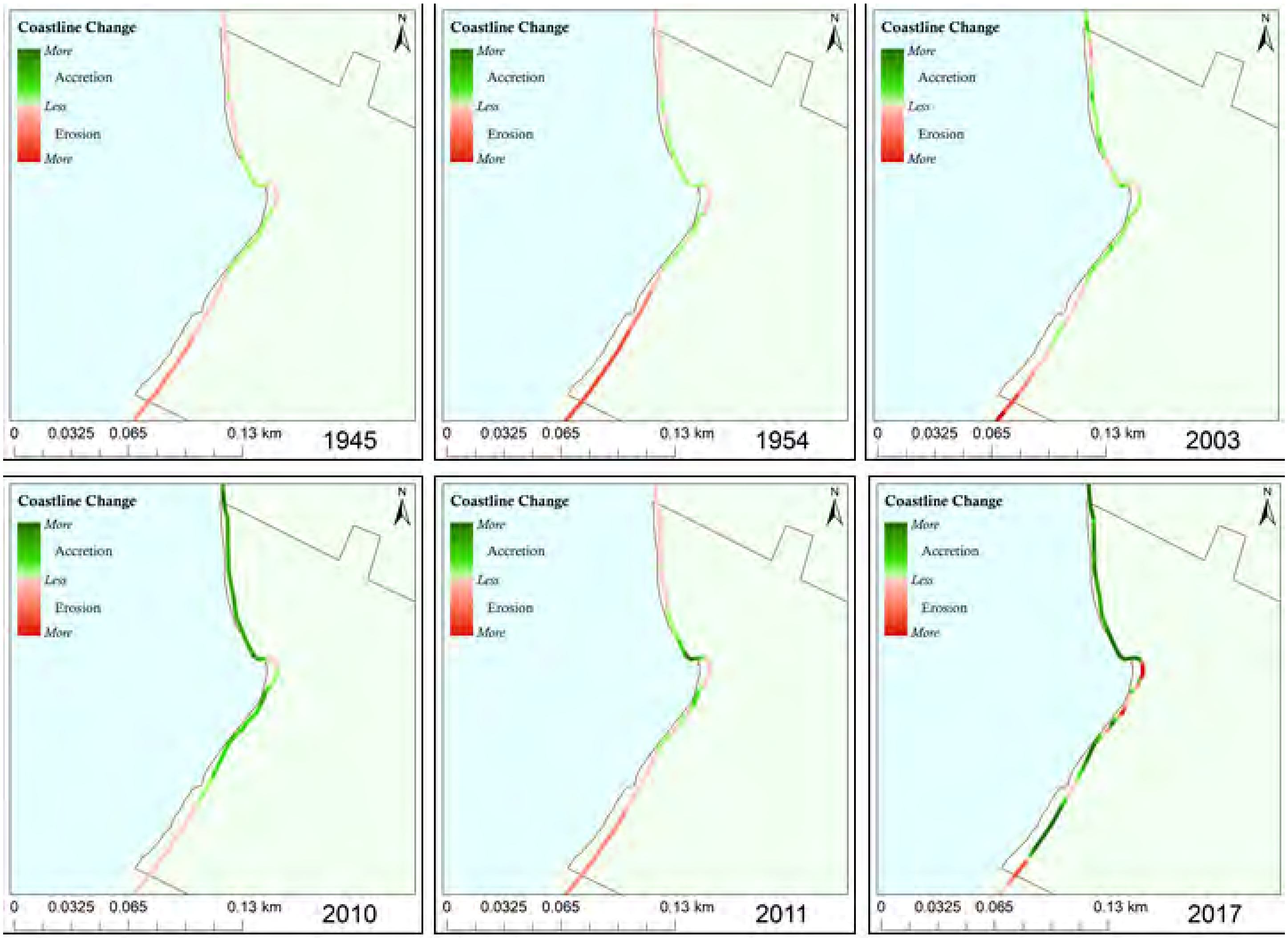

Figure 4.6: Relative rate of coastline change between each historic image and 2018 at the We`lnek coastline.

4.1.4 Coastline Change Projection

Future coastline change for Church Cove was projected based on past erosion and accretion rates for 2020 to 2120 in 20-year increments. The erosion projection method outlined in MacDonald & Webster (2014) projects future coastlines based on a given rate of past coastline change, using the most recent coastline as the baseline/starting point. The rate of past coastal change between 2003 and 2018 (Figure 4.7, Figure 4.8) was selected as the most appropriate rate for the projection analysis primarily because both imagery datasets have very good resolution and the 2003 georeferencing process had very low residual error (Table 4.1). The high resolution made it easier to identify the coastline, and the low residual error meant that imagery more accurately models the location of the coastline. Additionally, the period between 2003 and 2018 included several large storms that caused significant erosion along the Northumberland Strait. It was concluded that the 2003-2018 interval was the most appropriate as it would best represent the recent effects of climate change, such as increased intensity and frequency of damaging storms, reduced sea ice, and increasing sea temperatures.

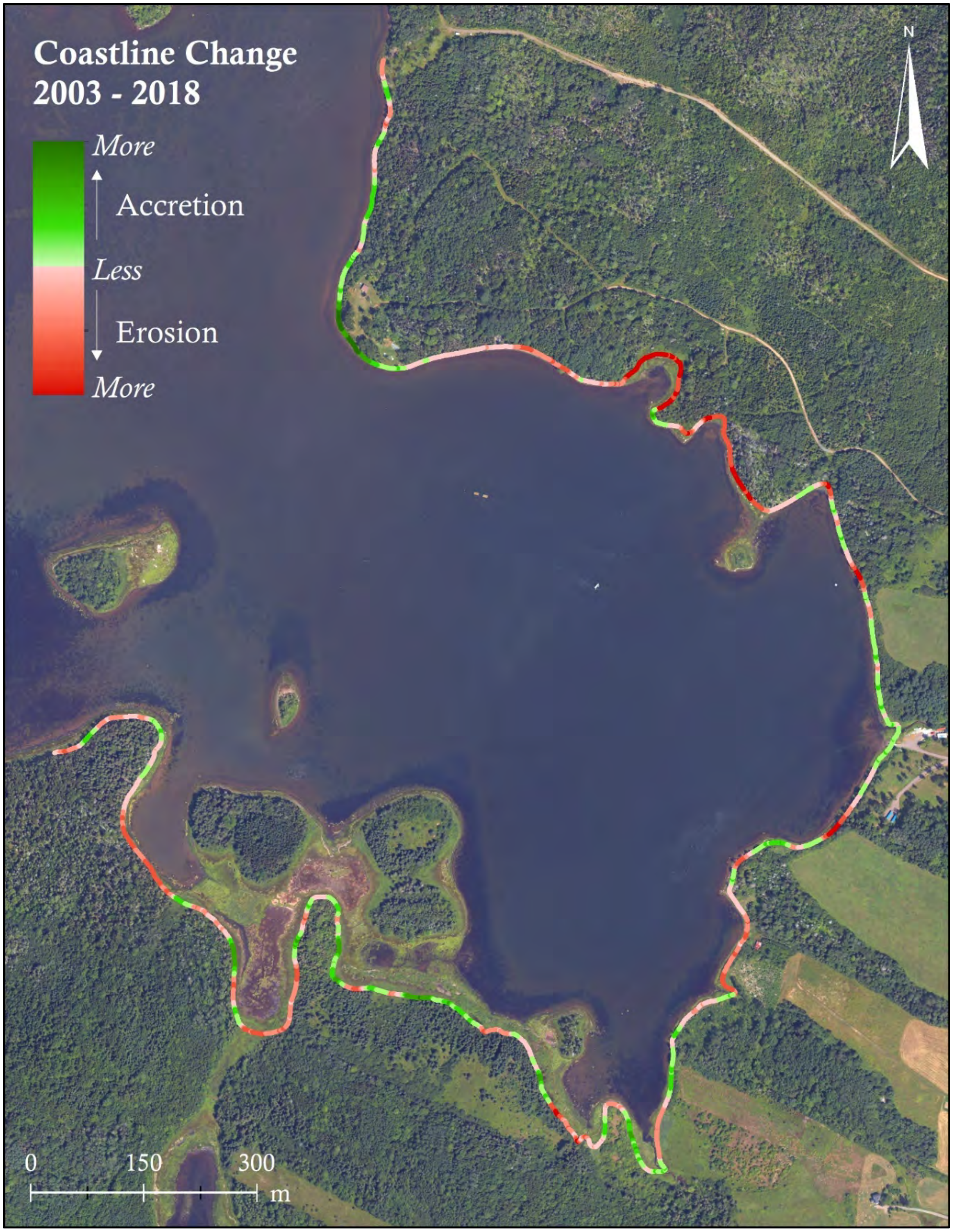

Figure 4.7: Qualitative visualization of erosion and accretion rates derived from a 15-year change detection (2003 to 2018) shows areas of mild (light red) and more extreme (dark red) erosion interspersed with areas of mild (light green) to more extreme (dark green) accumulation. The northeast shoreline exhibits more overall erosion while the southwest shore exhibits more overall accretion.

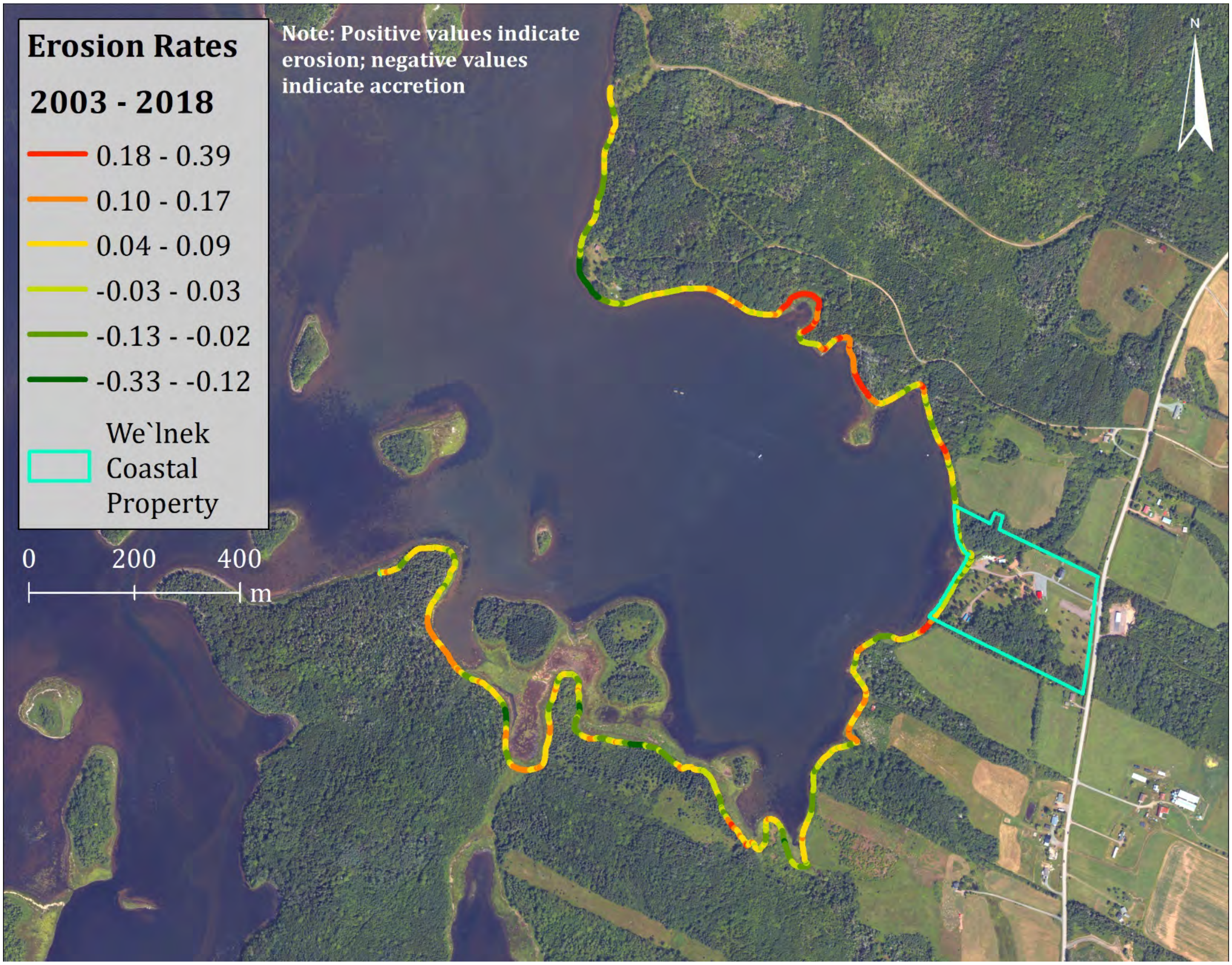

Figure 4.8: Quantitative visualization of erosion rates (in meters per year) from the 2003 - 2018 change detection, where a positive value means erosion and a negative value means accretion, as well as Paqtnkek's coastal property (in aqua).

The erosion projection method projects each future coastline directly from the 2018 coastline, and not from the previous projected coastline. The future coastline is projected for each 1 m segment from the 2018 coastline using the rate of change (from Figure 4.8, in metres per year) multiplied by the number of years between 2018 and the year of the projection. For example, the projection for the location of the coastline in 2080 used the 2003-2018 rate of coastal change multiplied by 62 years (2080 – 2018 = 62).

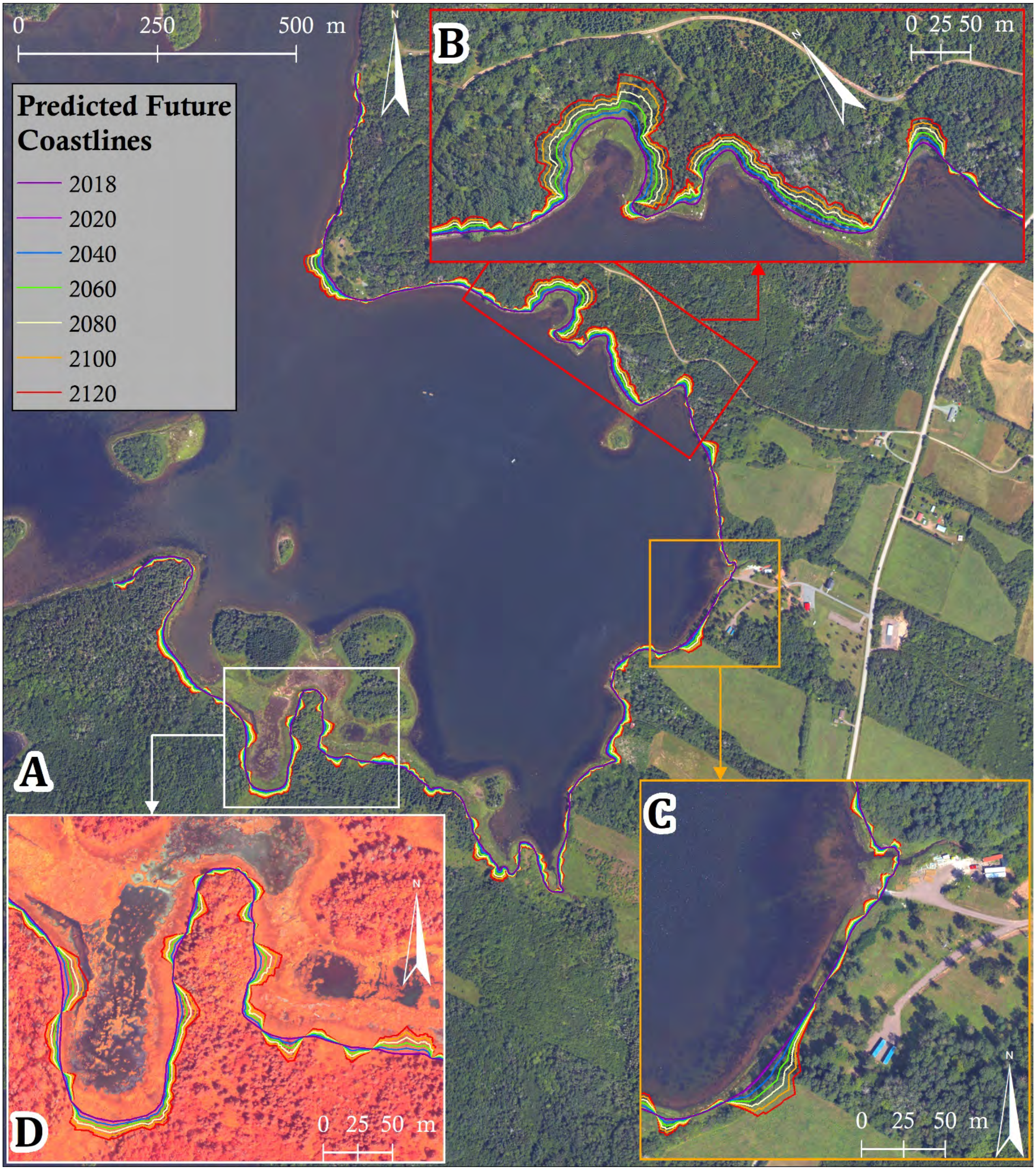

Figure 4.9: (A) Predicted future coastlines (various colours) around Church Cove shown on true colour 2018 RCD30 imagery details (B) some large areas of projected erosion on the northeast shoreline, (C) Paqtnkek First Nation's coastal property has some accumulation and erosion over time, and (D) complex areas with accumulation and erosion are alternating on a sheltered coastline on the southwestern shore of the cove.

The projections of the coastline in Church Cove according to local erosion and accretion rates suggest that portions of the Church Cove coastline that were susceptible to past erosion will see continued erosion, while areas of the coastline that have seen accretion in the past will continue to advance seaward (Figure 4.9). Frequently, sections of eroding coastline were adjacent to sections of advancing coastline, often with a zone of no change between or nearby. These segments of coastline with zero rate of past change were projected to remain constant in the future. Small bays and inlets around Church Cove presently cutting landward continue to erode (Figure 4.9B) while other areas show slight accumulation over time, such as coastline adjacent to the mouth of the small river which runs behind the church on Paqtnkek's coastal land parcel. If the rate of coastline change continues at the same pace it has for the last fifteen years, most of the coastline directly along Paqtnkek's coastal property should see moderate accumulation, except for a section of coastline along the western edge of the property (Figure 4.10).

Figure 4.10: Predicted future coastlines (various colours) along the Paqtnkek First Nation's coastal property (in aqua) shows accumulation over time near the river mouth, and erosion over time on the west end of the parcel.

4.2 Storm Surge Analysis

Storm surge flood layers were generated using an AGRG proprietary GIS tool that raises flood water on a flat plane (known as "still-water") to inundate low areas that are hydraulically connected to the coast as described in Webster *et al.* (2006). The DEM produced from the lidar represents the elevation of the top-most feature of the land, where the laser makes contact, and therefore provides no information on sub-surface features such as culverts, where rivers flow under roads. The DEM also represents bridges but cannot show any information on the water surface below the bridge. The tool works by allowing water to flood the DEM as it would in reality, passing through culverts and under bridges. To accomplish this, the DEM was modified to represent culverts or bridges as low areas in the DEM; this is known as a hydraulically corrected DEM. Culverts were generated manually, as there are no publicly available culvert datasets, by intersecting the roads GIS layer with the streams GIS layer, and adjusting the intersecting elevation; the DEM was modified manually to match the water surface elevation under the major Afton River bridges. The datasets used for this analysis included the National Road Network (NRN), which is the most complete and publicly available spatial road database, and the river/stream spatial dataset provided by the Nova Scotia Topographic Database (NSTDB) of 2012. The resulting hydraulically connected DEM used for the culvert and subsequent flooding analysis was 1 m resolution, thus the resulting flood layers are 1 m resolution.

Four storm surge scenarios were modelled based on past storm events, astronomical extreme tides, sea-level rise predictions, and tsunamis (Table 4.3). A storm surge was observed across a large extent of the Northumberland Strait on October 11, 2016; AGRG pressure sensors installed at three locations measured storm surges up to 1.6 m. Merigomish Harbour (west of Pomquet) and Mabou Harbour (east of Pomquet) are similar in coastal morphology to Pomquet, and measured storm surges near 1 m (Figure 4.11). Flood layers were generated for scenarios in which (1) a 1 m storm surge occurred at Higher High Water Large Tide (HHWLT, 1 m CGVD28 for Pomquet), resulting in flooding up to 2 m elevation relative to CGVD28, (2) if that same storm occurred in the future and included a conservative sea-level rise of 1 m, resulting in flooding up to 3 m, (3) future sea-level rise was extreme (5 m), resulting in flooding up to 7 m, and (4) a large tsunami occurred and flooded up to 10 m CGVD28. The flood layers were generated for the eastern shore of Pomquet Harbour and figures were generated at various scales to highlight flood extents at different shorelines (Figure 4.12 - Figure 4.17).

Water Level (relative to CGVD28)	**Significance**
2 m	October 2016 storm surge at HHWLT (1 m + 1 m)
3 m	October 2016 storm surge at HHWLT + conservative 100-year sea-level rise of 1 m (1 m + 1 m + 1 m)
7 m	October 2016 storm surge at HHWLT + extreme 100-year sea-level rise of 5 m (1 m + 1 m + 5 m)
10 m	Large tsunami

Table 4.3: Modelled flood scenarios.

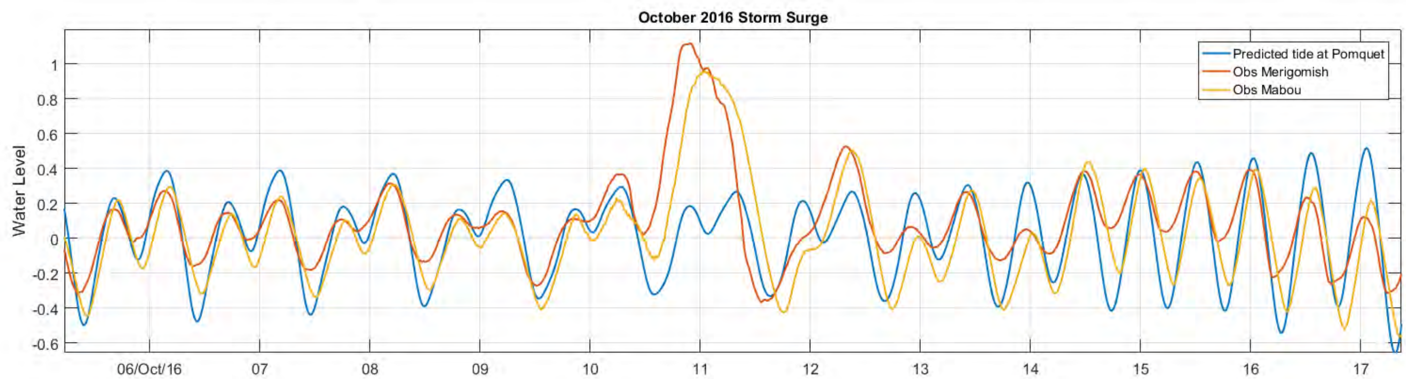

Figure 4.11: A ~1 m storm surge observed at Merigomish Harbour and Mabou Harbour on Oct 11, 2016. Predicted tides at Pomquet.

The results of the storm surge show the flooding extent of each of the major scenarios modelled. Upon reviewing these extents, four areas of interest were noticed to be the most affected by flooding (Figure 4.12). Along the coast of Bayfield beach where the Afton River begins (Figure 4.13) it can be observed at the 3m flood level the wharf will be underwater. At the 7m and 10m flood levels there will be many houses and roads underwater as well as major flooding around the Afton River. The Church Cove area (Figure 4.14) at 2m and 3m levels affect areas of wetlands or water tributaries but will be most affected at the 7m and 10m flood levels, with many islands disappearing. The coastal We`lnek property is a concern due to the reported cultural significance in the wooded area behind the church and cemetery. Figure 4.15 and Figure 4.16 show the extent of flooding on the We`lnek coastal property. Along the coast of the We`lnek property, the 2m and 3m flood levels show some flooding of the brook itself but will also flood the lower section of water access. At the 7m level, there is significant flooding of the brook and surrounding wooded area as well the lower half of the water access. The 10m flood level shows flooding to reach the extent of the back corner of the graveyard, located beside the church. This level also floods far up the brook and surrounding wooded area aside from a small portion of the property, adjacent to a hay field north of the property. The Paqtnkek property parcel south of Pomquet Harbour Figure 4.17, consists mostly of marsh lands and higher elevations. Though this area will flood at the 2m and 3m levels, it will be most affected by 7m and 10m flood levels which cause concern for the portion of highway and bridge located on the southern tip of the property.

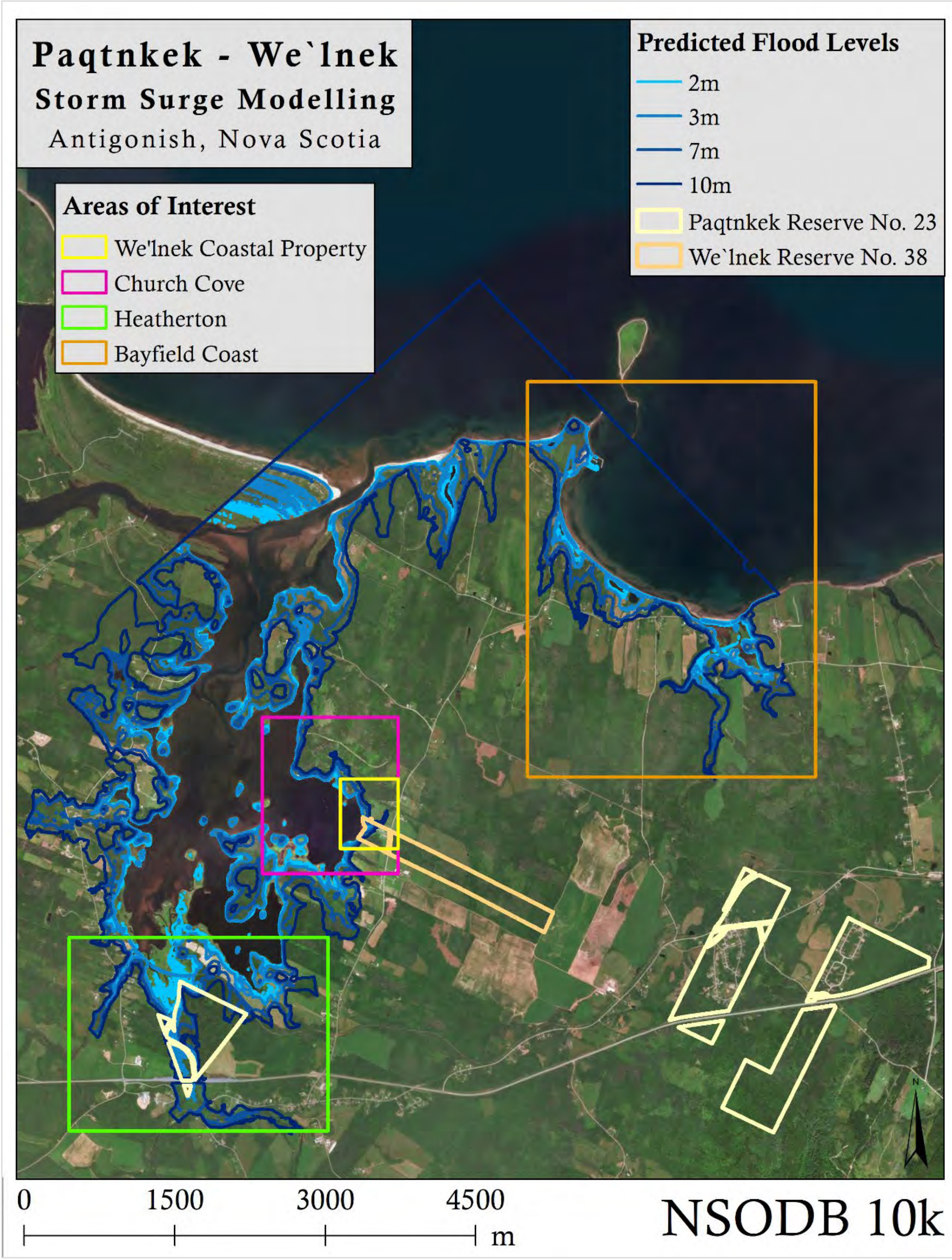

Figure 4.12: An overview of the areas of interest identified by reviewing the extent of flooding for each major flooding scenario detailed in Table 3.3.

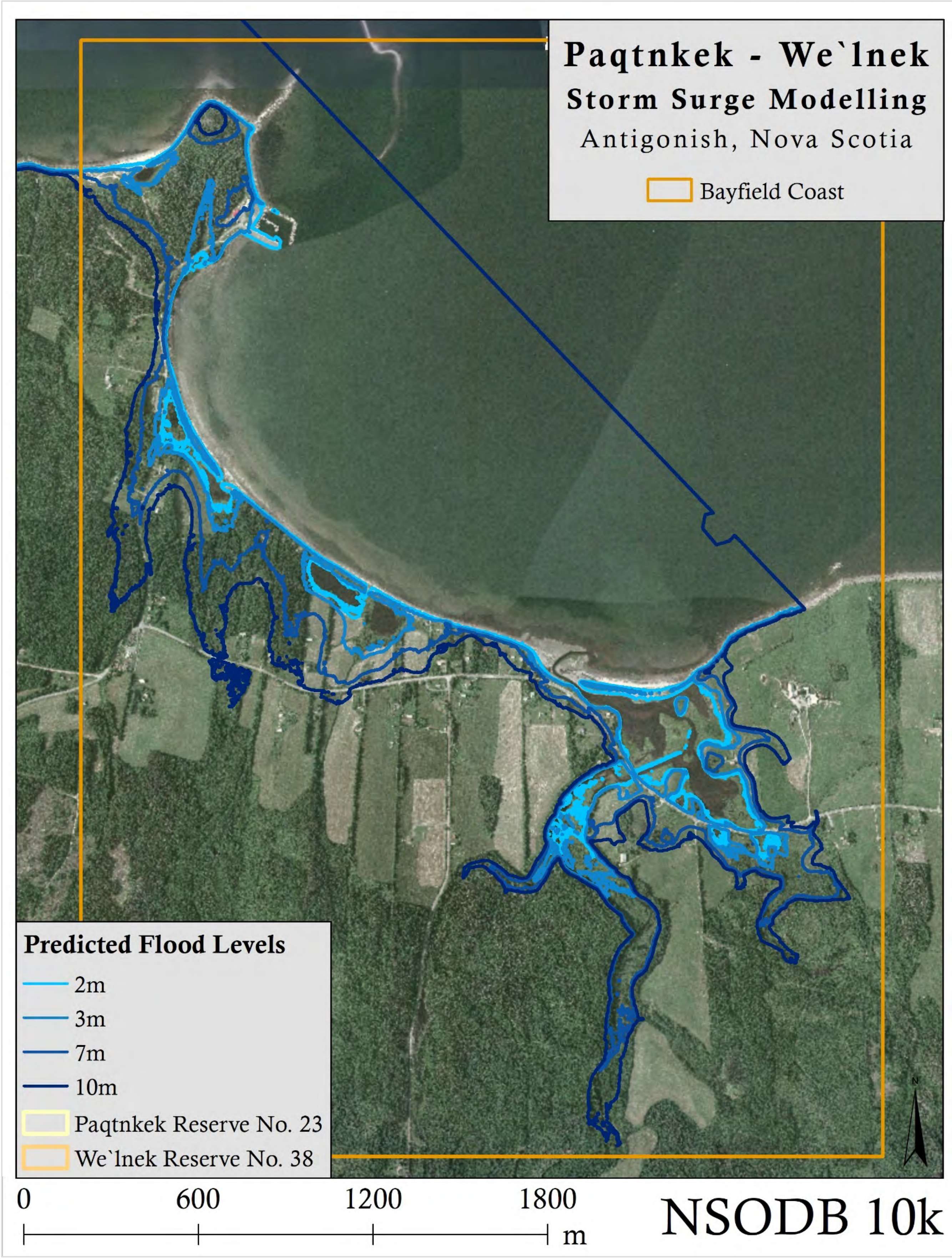

Figure 4.13: An overview of the Bayfield Coast, showing the extent of flooding for each major flooding scenario detailed in Table 3.3.

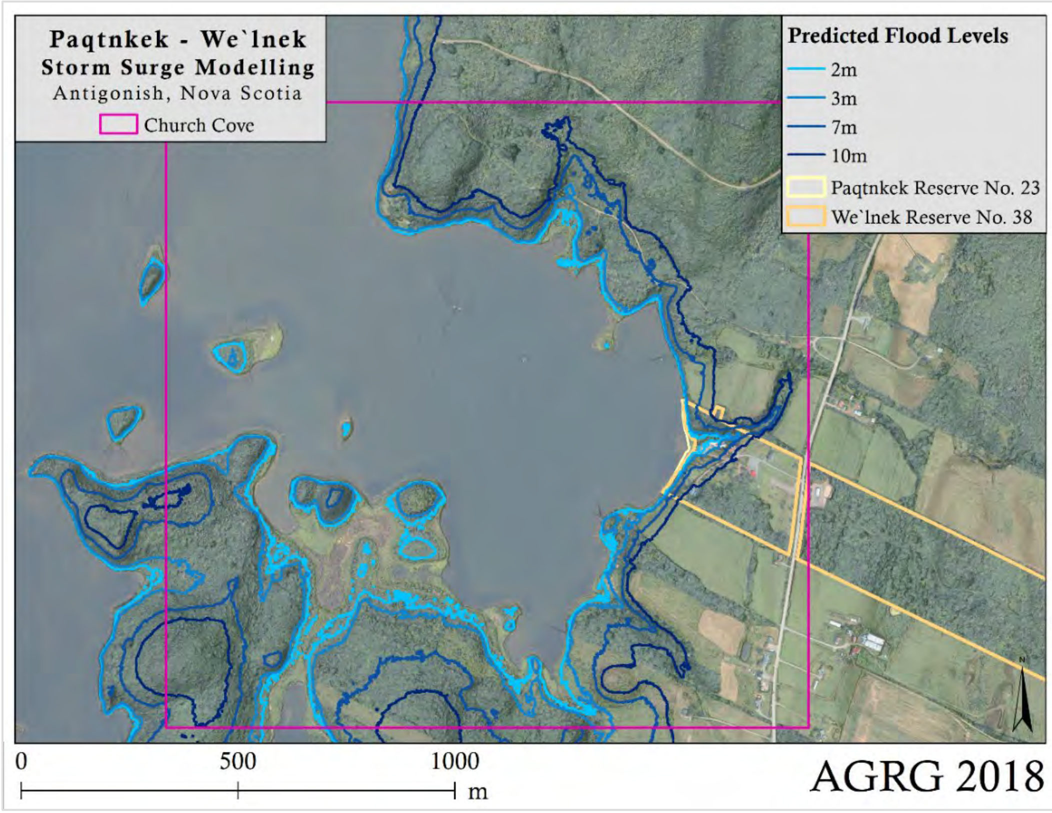

Figure 4.14: An overview of the Church Cove study area within Pomquet Harbour, showing the extent of flooding for each major flooding scenario outlined in Table 3.3.

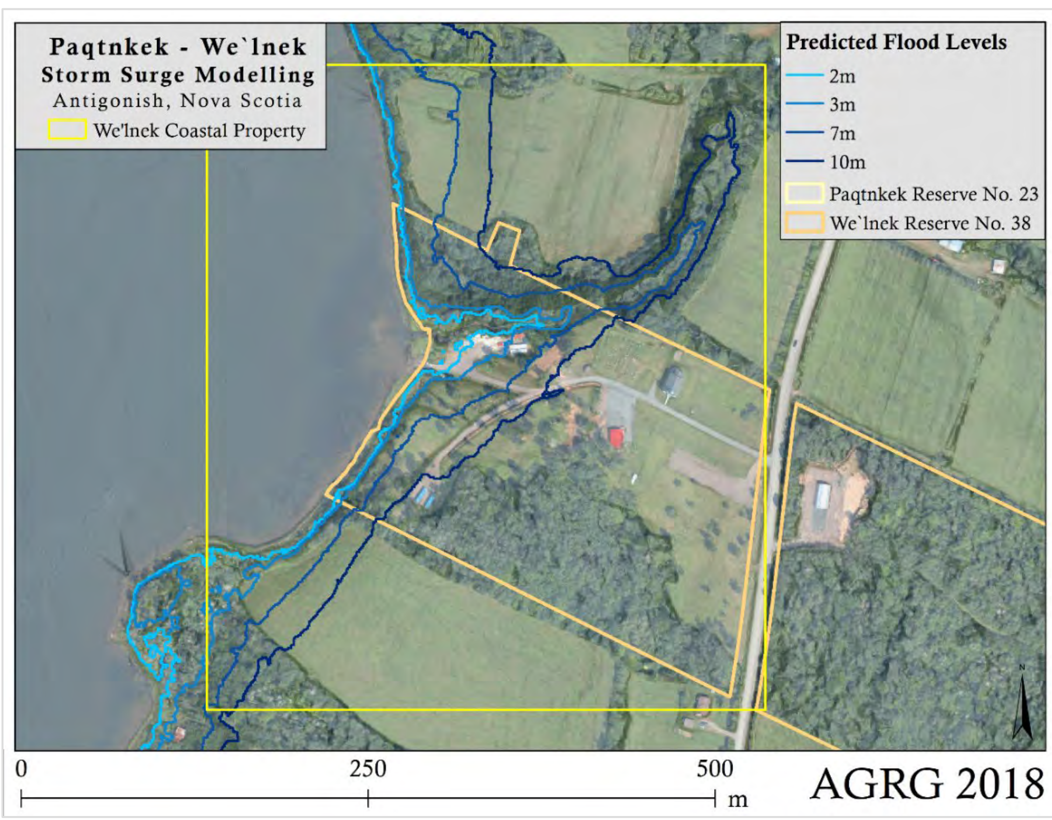

Figure 4.15: An overview of the coastal We'lnek Reserve property, showing the extent of flooding for each major flooding scenario outlined in Table 3.3.

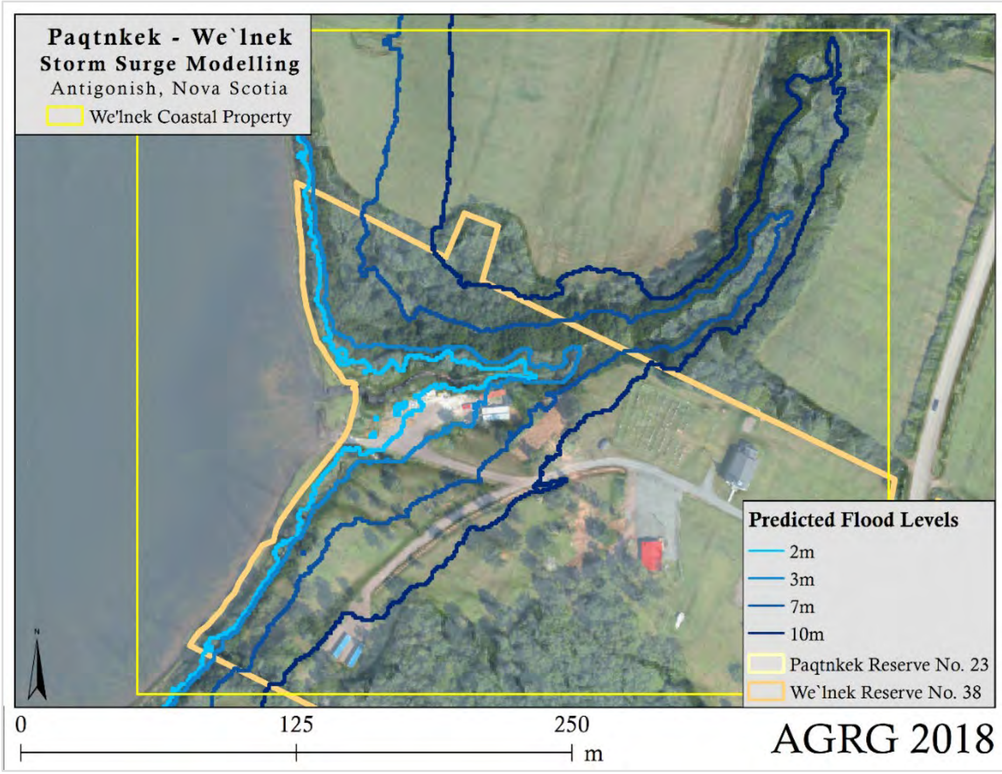

Figure 4.16: The extent of flooding for each major flooding scenario detailed in Table 3.3 zoomed to the coastal region of the We'lnek Reserve property.

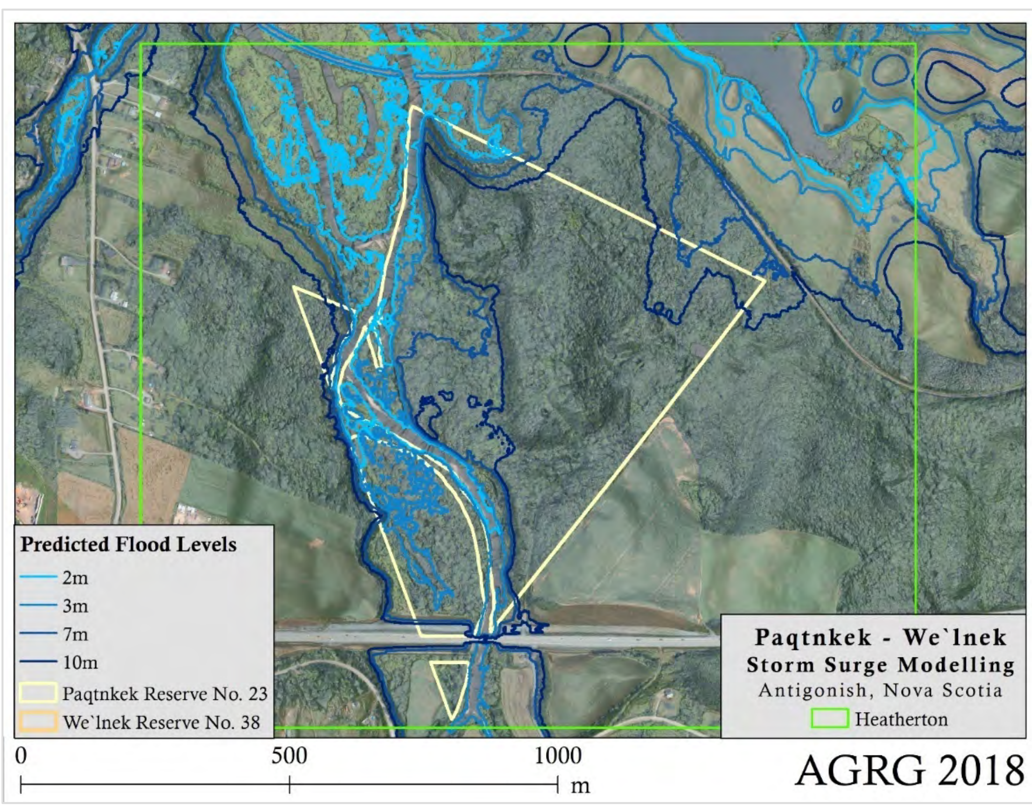

Figure 4.17: An overview of the most southern Paqtnkek Reserve property, near Heatherton showing the extent of flooding for each major flooding scenario detailed in Table 3.3.

4.3 Adaptation Solutions

4.3.1 Community meeting

A community meeting was held on February 20th, 2019 at the Paqtnkek Community Centre. Throughout the meeting, both the Mi`kmaw Conservation Group (MCG) and AGRG were able to present their research and current results. MCG updated the group on their 20 m lidar flood modelling efforts and reported that they are still adjusting their scenario's parameters to discover which is the most realistic and meaningful result. AGRG presented the erosion and storm surge analysis as reported here. During the meeting community members were encouraged to contribute any knowledge of the We'lnek coastal property and Afton River study area for historical significance or areas of noticeable changes in regard to climate change. Those who attended the community meeting also had the opportunity to use a virtual reality headset to view the coastal We'lnek property and entire lidar study area and manually raise/lower water levels, gaining a more hands-on and visual understanding of the research findings (Figure 4.18) The meeting was finished with a round-table discussion between researchers and locals to learn more about erosion mitigation suggestions and Traditional Ecological Knowledge.

Figure 4.18: NSCC-AGRG Research Associate Kate Collins helps Paqtnkek community members experience raising/lowering water levels of the We'lnek coastal property.

4.3.2 Incorporation of TEK

Incorporating the traditional knowledge from the Paqtnkek community members will mainly be the responsibility of MAPS and will involve more interviewing to further record accounts of significant locations/changes. Ground truthing with a GPS of significant locations/changes will also be required. These areas could involve noticeable erosion/landslide locations, riverbed flow changes, changes in river depth and any areas of cultural importance.

4.3.3 Proposed solutions

Erosion mitigation solutions were discussed at the community meeting, including living shorelines as well as building a reef to create a barrier or break water, which may reduce erosion by limiting wave action against the shoreline within the cove. This could help protect the area around the brook, which will flood with rising sea levels. The wooded area around the brook has been reported to be culturally significant with burial sites and the sight of the area's original church.

4.4 Coastal Threats Discussion

The projections of coastal change use historical imagery to make assumptions about the future based on the changes that occurred in the past, and do not account for the increased rate of sea level rise or how resulting accelerated coastal change inside or outside of Pomquet Harbour might influence local dynamics at the We`lnek land. The storm surge analysis is also limited by its methods, which do not incorporate moving water of any kind (e.g., waves, currents), and do not consider future erosional change to the shoreline.

5 Inland Threats

Year 2 of this project will focus on inland threats to the community due to flooding and erosion of the Afton River. Fieldwork was initiated in Year 1 so that modelling could begin at the start of Year 2 with a good dataset to work with.

5.1 Afton River Data Collection

A Hobo pressure sensor was installed in the Afton River at the Highway 4 bridge near Afton Road (Figure 3.2) on June 7, 2018 and retrieved on Nov. 30. 2018 (Table 5.1). River stage and flow were measured on four occasions (Table 5.1) using a Valeport Electromagnetic Flow Meter at the location of the pressure sensor. Cross sectional measurements of the riverbed were taken using RTK GPS at pressure sensor and upstream (Figure 3.2) and will be used for validation of the lidar. The majority of cross-sectional measurements are planned to occur in Year 2 of the project.

Date	Pressure sensor	Other fieldwork	Stage (m CGVD28)	Discharge (m^3/s)
June 7	Installed	Flow measurements	29.67	1.46
July 4		Flow measurements	29.52	0.28
July 27		Flow measurements		0.14
Oct 23		Flow measurements	29.69	0.82
Nov 30	Retrieved	Cross section measurements at bridge and upstream		
Oct 30 – present		Manual water level measurements by Project GIS technician Kara Pictou		

Table 5.1: Afton River fieldwork summary including river stage and flow.

Figure 5.1: Pressure sensor deployed in the Afton River (left); Project GIS technician Kara Pictou and AGRG Research Associate Sam Lewis taking cross section measurements on Oct 23 (right).

River cross section measurements were normalized by maximum depth per survey to assist with visualizing the depth of the river (Figure 5.2). The river was shallowest on July 27 and was deepest (~0.3 m deeper) on June 6. The riverbed represented here, shown from east to west bank, shows a sill at 1.5 m from the riverbank, and small changes in bathymetry between surveys reflect the rocky nature of the riverbed.

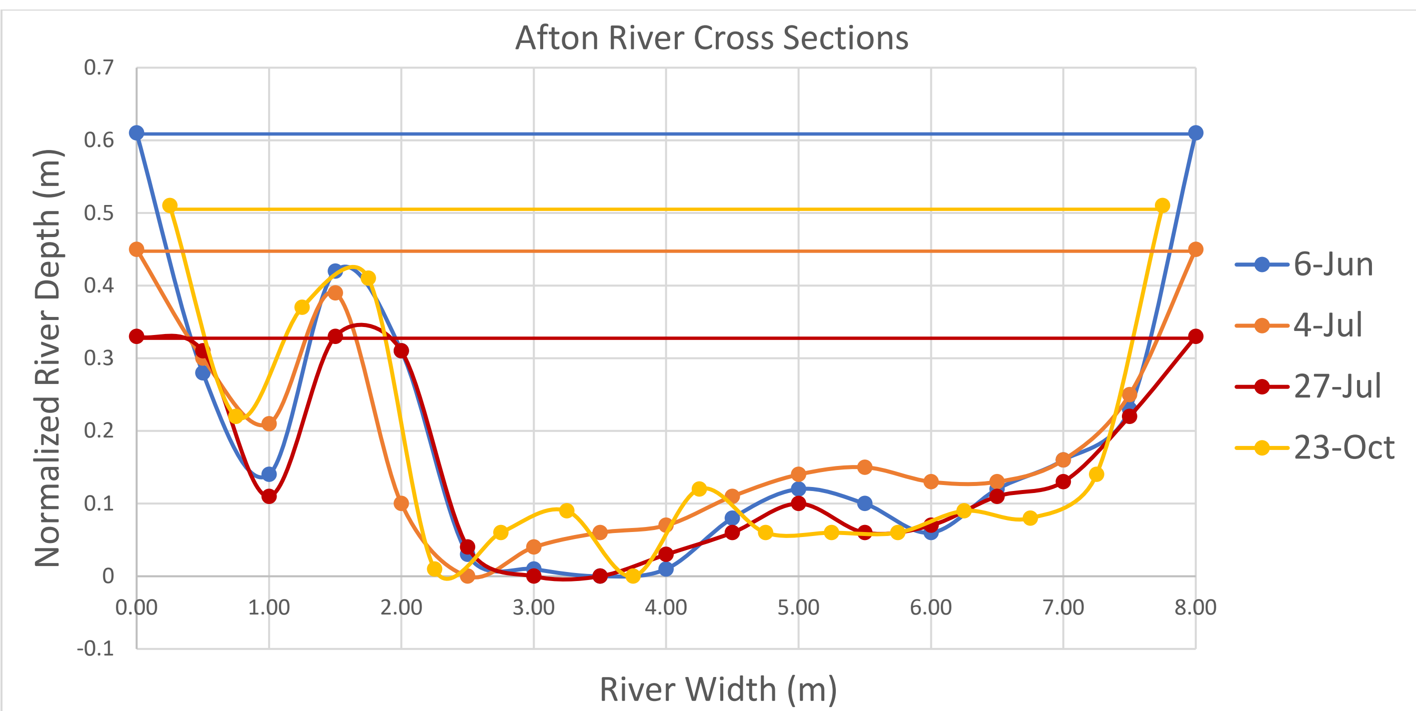

Figure 5.2: Normalized Afton River cross section measurements at the pressure sensor location, going from east bank to west bank. Depth measurements were normalized by maximum depth and show lowest river level on July 27 and highest river level on June 6. Small changes in bathymetry reflect the uneven riverbed.

The pressure sensor data were compensated for the effects of air pressure by subtracting ECCC Tracadie air pressure data from observed water pressure. The resulting pressure values were converted from kPa to m using a conversion factor of 0.101972 m/kPa (https://www.sensorsone.com/kpa-to-mh2o-conversion-table/). The resulting values represented the depth of water above the sensor. These values were converted to the elevation of the water surface in CGVD28 by adding the depth of water above the sensor to the elevation of the sensor as referenced to CGVD28. The water level measurements recorded by the GIS technician were converted to CGVD28 using the GPS elevation of the bridge. The hydrograph for the duration of the pressure sensor deployment (Figure 5.3) shows how the Afton River responds to rainfall (as measured at Tracadie). River level was moderately high in the spring at sensor deployment and increased by ~0.5 m following rain events of ~30 mm. Water level was lowest during the summer and highest during the fall, when frequent heavy rainfall events caused the river level to rise. A heavy rainfall event in the middle of the summer resulted in a smaller increase in water level, likely because of several factors related to the dryness of the land, and the level of the river. Closer inspection of the fall data (Figure 5.4) shows that the river level rose sharply following rainfall events and lowered within a few days. Each successive rainfall event raised the base water level slightly.

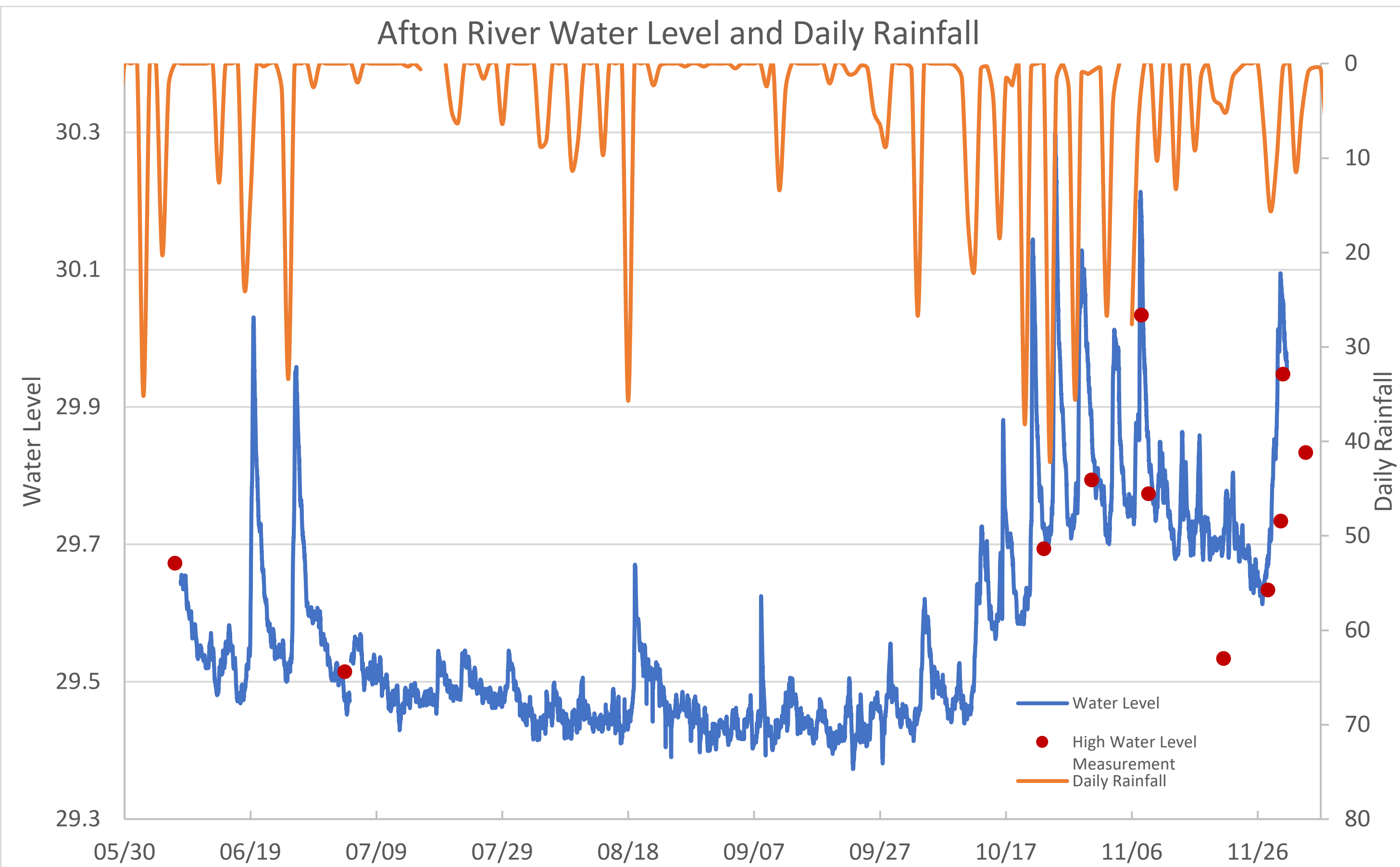

Figure 5.3: Afton River hydrograph for the duration of the pressure sensor install (June – Nov 2018) showing rainfall measured at the Tracadie ECCC weather station.

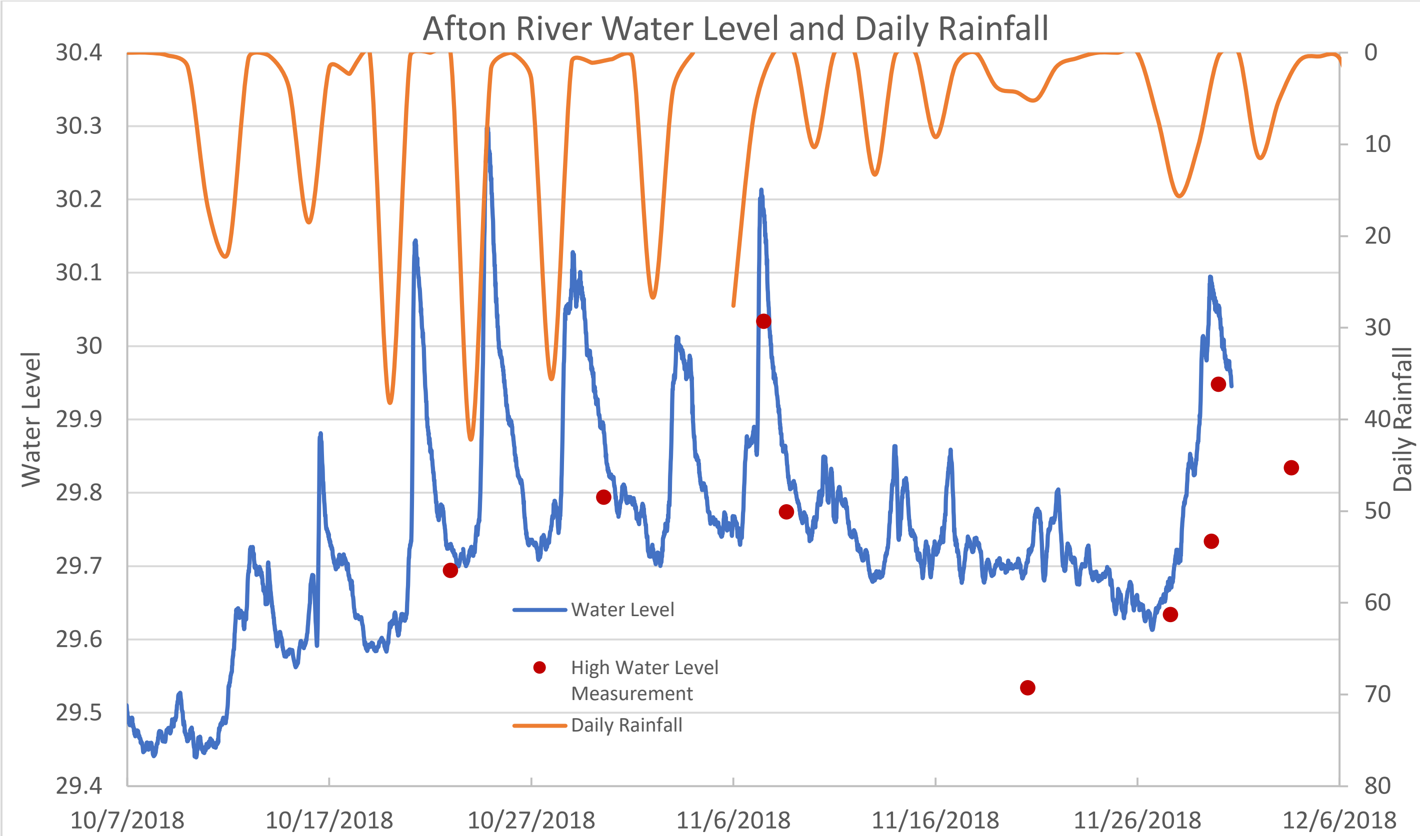

Figure 5.4: Afton River hydrograph during the fall when many high rainfall events resulted in high water levels.

5.2 Future Work

Year 2 of the project will use the lidar data products from Year 1 to develop a 1D river model of the Afton River. To support this, Year 2 fieldwork will require additional flow and discharge measurements for the Afton River to be collected, as well as additional detailed river cross sections in any areas that the bathymetric lidar did not penetrate to the river bottom. The river model will establish relationships between heavy rainfall and high water in the Afton River and identify areas susceptible to flooding. All community infrastructure susceptible to flooding will be identified. A riverbank erosion vulnerability assessment will be conducted using historic imagery for the Afton River from 1936 to present. The vulnerability assessment will determine the rate of erosion along the Afton River where it flows through Paqtnkek and identify the past and present location of the river. The resulting erosion rates will be compared with the results of the 1D river model to determine areas of greatest susceptibility to erosion in the future, and threatened infrastructure will be identified. Land use and impervious surface maps will be constructed for the entire study area and a land use change analysis will be completed to compare major current land uses (urban, forested, agriculture) with land use maps produced by Agriculture and Agri-Food Canada in 2012. These results will be presented to the community during the final engagement meeting, and possible adaptation solutions will be discussed.

6 Summary

Deliverables for Year 1 of the project are complete:

- MAPS and AGRG worked together to employ local community members to help with river modelling fieldwork, including measuring river structures and high water levels using high resolution GPS.
- A lidar survey was conducted of the Paqtnkek Mi'kmaq Nation. The lidar data were processed from discrete unclassified points to finished lidar products such as a digital elevation model. AGRG and Paqtnkek worked together to collect ground truth data for validation of the lidar and to support the 1D model.
- A coastal erosion analysis was conducted and erosion was predicted by decade to 2120. The lidar data was used to do a GIS analysis of the inundation extent of floodwater at the coast using the latest sea-level rise estimates.
- Project results were presented to the community at year-end. Following the presentation, meeting participants had a discussion facilitated by MAPS on possible adaptation solutions for the threatened church. A year-end report was prepared.

AGRG will begin coordination of Year 2 activities with MAPS and PMN as soon as possible.

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