Impacts of Climate Change and Sea Level Rise on the Mi'kmaq Communities of the Bras d'Or Lakes

Phase One Project Report

AANDC Climate Change Adaptation Program

March 2015

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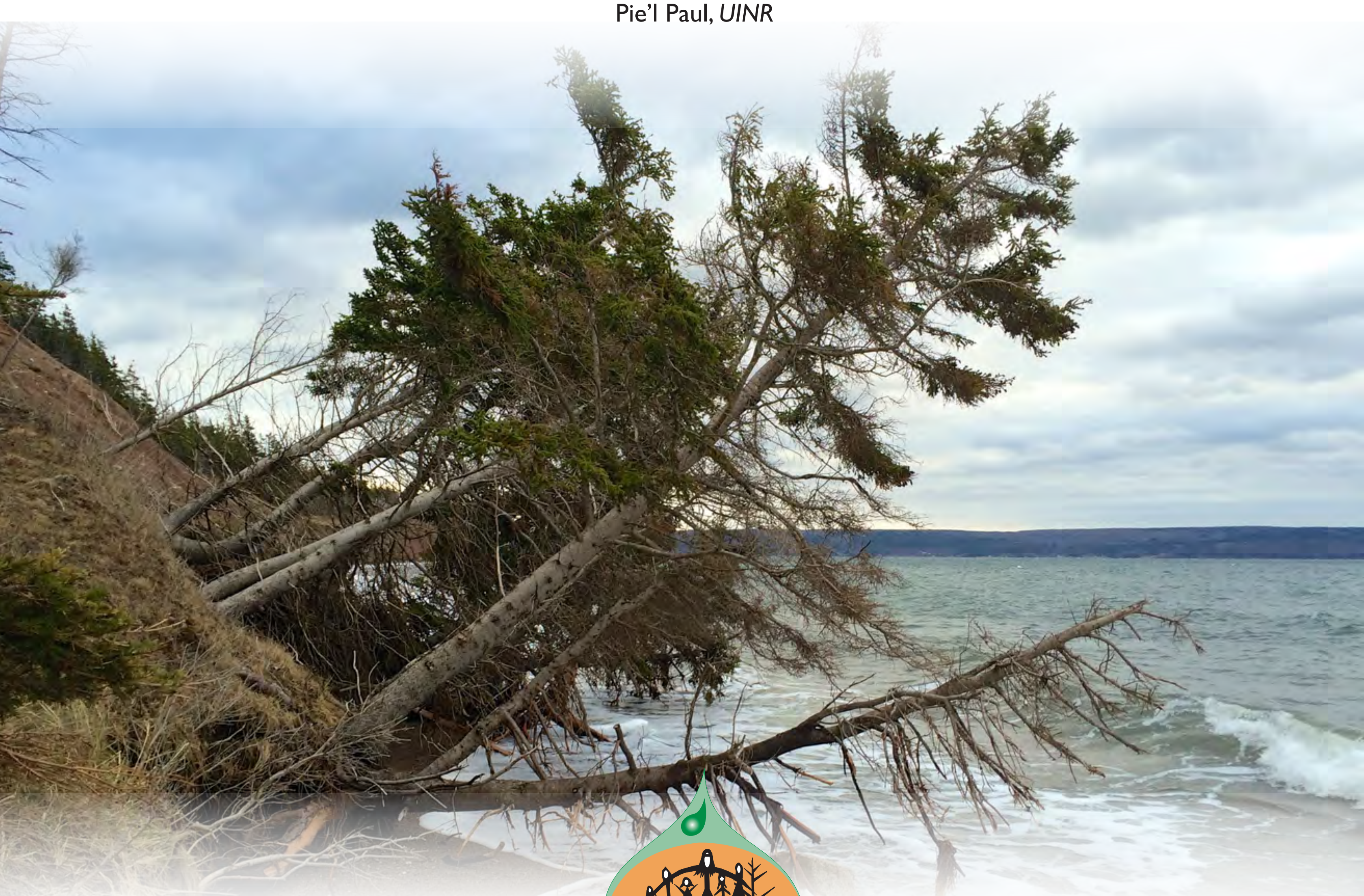

Unama'ki Institute of Natural Resources

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1 Background

The Unama'ki Institute of Natural Resources (UINR) is an organization that represents the five Mi'kmaq communities of Unama'ki (Cape Breton Island, Nova Scotia) on natural resource issues. UINR contributes to an understanding and protection of the Bras d'Or Lakes' ecosystem through research, monitoring, education, management, and by integrating Mi'kmaq and conventional ways of understanding, known as Two-Eyed Seeing. Four of our five communities (Potlotek, Eskasoni, Wagmatcook and We'koqma'q) are located on the Bras d'Or Lakes. A sixth community, Malikewe'j, which is owned jointly by the five communities, is also located on the Bras d'Or Lakes.

Coastal communities are susceptible to erosion that results from the increased storm surges and lack of ice coverage due to climate change. First Nation communities are particularly affected by these threats due to their limited infrastructure funding and land base. The intent of this project is to provide the Unama'ki communities with a powerful tool for the community development and adaptation planning needed to face the pending challenges that will arise due to Climate Change. The LiDAR mapping component of this project will identify the vulnerable sections of coastlines thus allowing the impacted communities to practically view flood zones and to plan adaptation strategies. The information generated from this tool will inform their community plans and decision making processes including land use development, future infrastructure needs and protection of cultural and historic significant areas.

Over the course of the project communities will be engaged in discussions on the cause and effects of climate change, vulnerabilities of their communities and some options on moving forward for mitigation and adaptation. Traditional knowledge will also be gathered on the impacts climate change has had on the communities. Meetings will be held with each Chief and Council to present the results of our research and inform them of the potential threats that are posed both to their own communities and the shared community of Malakowej'k.

This will empower the communities to adapt to the identified changes and challenges. Capacity will also be developed in the communities through the inclusion of band administration staff including public works, housing and lands officers and AFS guardians throughout the project.

2 Links to Climate Change

Before getting into the main aspects of this study, it is important to briefly set the general and broader context in which the coasts of the Bras d'Or Lakes have been evolving during the Holocene (since the melting of the last glaciers, some 12,000 years ago).

Since the last deglaciation, most of the coasts of Atlantic Canada have been submitted to a submergence by the sea. For example, sea level in Halifax has increased an average of 20 cm/century over the last 3000 years, and since tide gauges have been in operation (~75-100 years), the measured increase in sea level averages 30 cm/century (SHAW *et al.,* 2006). Closer to home, in North Sydney, SHAW *et al.* (2006) reported an average increase of 36.7 cm/century measured by tide gauges. It should be noted that in our region, these rates include an eustatic component (rise of the global sea level) and a tectonic component (crustal subsidence or land sinking after the last ice age), hence the term *relative* sea-level rise. Using high-precision Global Positioning System (GPS) monitoring, the sinking of the land mass at Baddeck has recently been evaluated to be **21 cm/century** (JAMES *et al.,* 2014).

Evidence of the response of the coast to the recent (geological) and present (historical) relative sea-level rise can be found throughout Eastern Canada. Marsh vegetation outcrops in the intertidal zone attest to the landward migration of sand spits and tombolos. Historical retreat of cliffs and bluffs are well documented from maps and aerial photographs. Submergence of salt marshes has been highlighted in southeastern New Brunswick based on the 1944 to 2001 aerial photograph series (O'CARROLL *et al.,* 2006). In Malikewe'j, a drowned forest (dead *in situ* tree stumps) has been observed in a salt marsh, a testimony to a rising relative sea level (ADI Limited, 2010). On the other hand, sandy coasts also showed sectors of accretion and growth of spits, as should be expected from such highly dynamic systems. Nevertheless, the general picture in Eastern Canada as well as the Bras d'Or Lakes suggests that retreat is a common response of most of the coasts to the on-going submergence.

Predictions of climate change that are directly relevant to the coastal environments of the Bras d'Or Lakes include an acceleration of sea-level rise, a shortening of the duration of the sea ice cover season, and an increase in the number and/or intensity of storms at mid-latitudes.

An acceleration of sea-level rise

According to the International Panel on Climate Change (IPCC), global sea level has risen 17 cm during the 20th century and it is expected to rise another 63 cm (45 to 82 cm) by 2100 (IPCC, 2013 – RCP8.5). DAIGLE (2015) projects a relative sea-level rise of **86 cm** to 2100 for the 5 Mi'kmaq communities along the Bras d'Or Lakes, based on the RCP8.5 and on the data compiled by JAMES *et al*. (2014) for the Baddeck monitoring station. This figure integrates the projected global sea-level rise, the regional crustal subsidence and other factors, the combination of these representing the total projected *relative* sea-level rise.

The direct anticipated effects of an acceleration of sea-level rise can include a landward migration of sand spits, tombolos and beaches, an increased erosion and retreat of cliffs and bluffs, and possibly a submergence of salt marshes (if the vertical accretion rates cannot keep up with the rate of rise in sea level). There could also be accretion of beaches, dunes and sand spits if the sediment input to these systems is positive. However, the common response to rising sea levels is what is currently being observed along many parts of Atlantic Canada: a retreat of the coast.

A shortening of the duration of the sea ice cover season

The Gulf of St. Lawrence and the Bras d'Or Lakes are not directly comparable water bodies, but since sea ice cover formation and duration are both related to winter air and sea surface temperatures, research carried out on sea ice cover in the Gulf of St. Lawrence can prudently be extended to the Bras d'Or Lakes, for illustration purposes.

In their 2006 study, DAIGLE *et al.* concluded that it was not possible to recognize a significant trend relative to sea ice cover in the Gulf of St. Lawrence since 1969 with the current available data. Weak trends towards a shorter duration of the seasonal sea ice cover have been identified but could not be used to model future conditions. However, a new study by Québec researchers at ISMER-UQAR confirm that the sea ice cover in the Gulf of St. Lawrence has decreased by 0.27% annually since 1969 and that this decrease in sea ice cover has accelerated to 1.53% annually over the last 15 years. These trends are projected to continue in future, with modelling indicating that sea ice will be almost completely absent in most areas of the Gulf of St. Lawrence by 2100 (SENNEVILLE *et al.,* 2013).

Since ice cover impedes wave formation, the shortening of the ice season increases the total energy of storm waves developing in an ice-free water body, and by ricochet, can lead to increased erosion of the coasts. Even if the Bras d'Or Lakes' sea ice cover season is longer than the Gulf of St. Lawrence's, the warming climate should also reduce the length of the ice season.

An increase of the number and/or intensity of storms at middle latitudes
This prediction is generally listed with the two previous ones but it is also much less robust. It is known that Eastern Canada is part of a zone that is considered to be amongst the stormiest areas in the northwestern hemisphere (SAVARD *et al*., 2013). However, there are no climate models to date capable of unequivocally showing a future trend related to storm frequency (either an increase or a decrease); the intensity of storms could however increase (DAIGLE, 2015). Given the expected sea-level rise, a storm event should reach higher water levels in the future. This means that the extreme conditions of today would occur more frequently (shorter return periods). Given the possible shortening of the sea ice cover season, winter storms waves that were previously abated by the presence of sea ice will be expected to be able to reach the coast. Coastal Mapping and Erosion Assessment *(Impacts of CC and SLR on the Mi'kmaq communities of the Bras d'Or Lakes Project)*

All of these predicted changes would result in an intensification of coastal dynamics. On a regional scale, this should translate into higher rates of retreat of cliffs and bluffs, landward migration and/or submersion of salt marshes, and landward migration of sandy coasts. Of course, the landward migration of low-lying coastal habitats is only possible in the absence of obstacles preventing its migration, such as higher grounds or human infrastructure (roads, protection structures, etc.). The latter situation would lead to what has been called ***coastal squeeze*** (DOODY, 2004; 2013; PONTEE, 2013), i.e. the loss of coastal habitats and the protection they afford as retreat is blocked and *in situ* erosion and/or submersion might proceed. Possible progradation (advance of the coast) at places is to be expected as eroded material has to settle somewhere else. Whatever scenario is considered, the expected impacts of climate change warrant a sound coastal zone planning which takes into account the dynamic nature of the coast.

3 Project Outcomes

The project outcomes are hereby summarized in this section according to the Objectives outlined in the Project Proposal

3.1 Objective 1: LiDAR elevation and photographic data for each community

3.1.1 Methodology:

Leading Edge Geomatics (LEG) was hired to capture and post-process LiDAR and aerial imagery for the Mi'kmaq communities of Potlotek, Eskasoni, Wagmatcook, We'koqma'q and Malikewe'j.

The LiDAR-derived digital elevation model (DEM) of the terrain was used to generate elevation contours specific to both the present-day sea levels (baseline 2010) and the future sea levels for time frames 2030, 2050 and 2100. Climate change related sea-level rise scenarios for 2030, 2050 and 2100 are described in Objective 3. Specific elevation contours were associated with storm-surge influenced flooding scenarios described in Objective 2. The water level contours were overlaid over the aerial photos to clearly identify the ecosystem and built infrastructure at risk from flooding.

3.2 Objective 2: Storm-surge flooding statistics and Traditional Ecological Knowledge (TEK) on storm-surge flooding for the Bras d'Or Lakes with emphasis on each community.

3.2.1 Methodology:

Storm-surge flooding statistics were previously prepared for the Sydney, NS region (Richards, W., Daigle, R., 2011) in "Scenarios and Guidance for Adaptation to Climate Change and Sea-Level Rise – NS and PEI Municipalities". Since the Bras d'Or Lakes are an "inland" water body connected to the North Atlantic by two narrow channels, the statistics for Sydney (based on the North Sydney tide gauge database) presented in the above-mentioned report were intended to be adapted through a combination of TEK about the behaviour of storms in the Bras d'Or Lakes and comparisons of water level measurements from the North Sydney tide gauge with local community measurements during recent storms and upcoming storms during project. A complementary approach as described in the next three sections of the report proved to be successful in the documentation of storm surge flooding scenarios for the Bras d'Or Lakes.

3.2.1.1 Volunteer Observing Method

A team of volunteers (the Guardians) was selected from each community to document high water marks during storm surge events thereby recording a value that could then be compared to the water levels officially recorded by the Canadian Hydrographic Service-operated North Sydney tide gauge. These high water marks were then referenced on the LiDAR digital elevation model. This method employed some easily readable rulers placed either against available wharves (Potlotek, Eskasoni and Wagmatcook) or planted directly in shallow water with the zero-line located at Mean Sea Level (Malikewe'j and We'koqma'q), this level being near zero geodetic (i.e. zero CGVD28), the reference level used in the LiDAR DEM. An example of such an application can be seen in Figure 1.

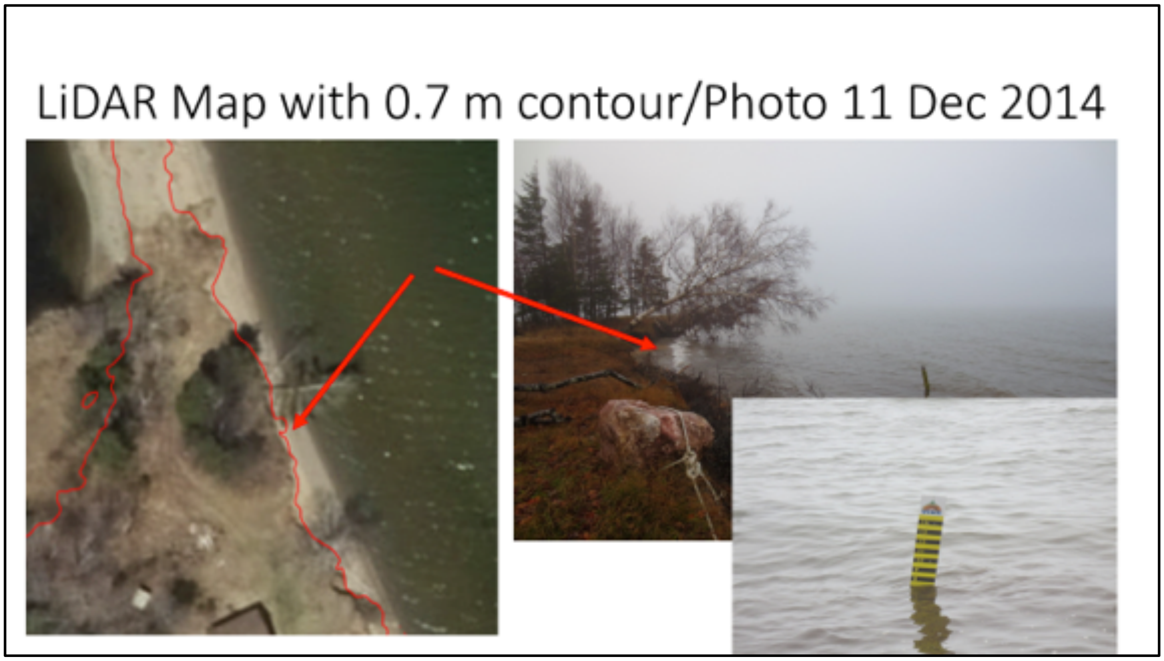

Figure 1 Image at left shows the LiDAR derived 0.7 m contour in red draped over aerial photograph. Photos at right show the water extent adjacent to leaning tree with inset photo showing 0.7 m level on water elevation ruler during storm-surge event on 11 December 2014. (Photo credit: Keith Christmas)

3.2.1.2 TEK Method

TEK on climate change events was collected to complement the scientific research on storm surge modeling. UINR engaged Mi'kmaq Elders from the five Unama'ki communities on their knowledge of storm surge frequency, duration and effects, seasonal changes and changes in natural patterns in nature. UINR has developed a protocol for the collection and use of TEK with our Unama'ki Elders. The preferred methodology of engaging Elders is through a workshop format. This provides a forum for Elders to engage with one another on specific issues in a way that encourages participation and provides opportunity for clarification and validation of their knowledge. In this way it is a collective knowledge that we are obtaining. Elders were selected with the assistance of UINR's Elder Advisor who has an extensive network in the communities and an awareness of whom within the communities holds knowledge most relevant to the issue we are discussing. The meetings were held in Mi'kmaq and facilitated by one of the Elders. The information was recorded and will be presented back to the Elders at a second meeting in phase two of the project to ensure that the information was captured and interpreted correctly. We will also take this opportunity to share the results of the study with the Elders so they may see how their knowledge has contributed to the research. The information will be used to inform the research on storm surge events and be included in the phase two final report.

The inclusion of TEK consultation also resulted in the discovery of valuable photos of Chapel Island (Potlotek) taken at the height of an intense winter storm on 21 December 2010. This well-documented storm caused extensive damage to coastal infrastructure (numerous road washouts, in particular) throughout Atlantic Canada. A comparison of the flood extents shown on the available photos from Chapel Island and the LiDAR DEM revealed a flooding level of 0.9 m above CGVD28 (see Figures 2 and 3).

Figure 2 Photos showing extent of flooding on 21 Dec 2010 at Chapel Island (photo Credit: Quentin Doucette)

Figure 3 LiDAR aerial photo with 0.9 m CGVD28 red contour depicting 21 Dec 2010 flooding limits

3.2.1.3 Automated Observing Method

Subsequent to the beginning of the project, in October 2014, the project team became aware of a new source of water level data in the form of regularly recorded water level data available at 20-minute intervals. This data is part of an on-going Bras d'Or Lakes monitoring program by the Science Branch Maritimes

Region of Fisheries and Oceans Canada, henceforth referred to as the Bedford Institute of Oceanography (BIO) database. Three sites (Dundee, Baddeck and East Bay) were installed in 2009 and the remaining sites were installed in 2012, with each site reporting on a seasonal basis (winter and summer). As expected, the highest storm surge events have been noted during the winter season.

Amongst other parametres, detailed 20-minute interval water level data is being collected at coastal locations identified in Figure 4 along with an additional site in Sydney Harbour. In particular, the locations of Dundee, St Peter's and East Bay were found to be representative of water levels at Malikewe'j, Potlotek and Eskasoni while Whycocomah and Baddeck were representative of water levels at We'koqma'q and Wagmatcook.

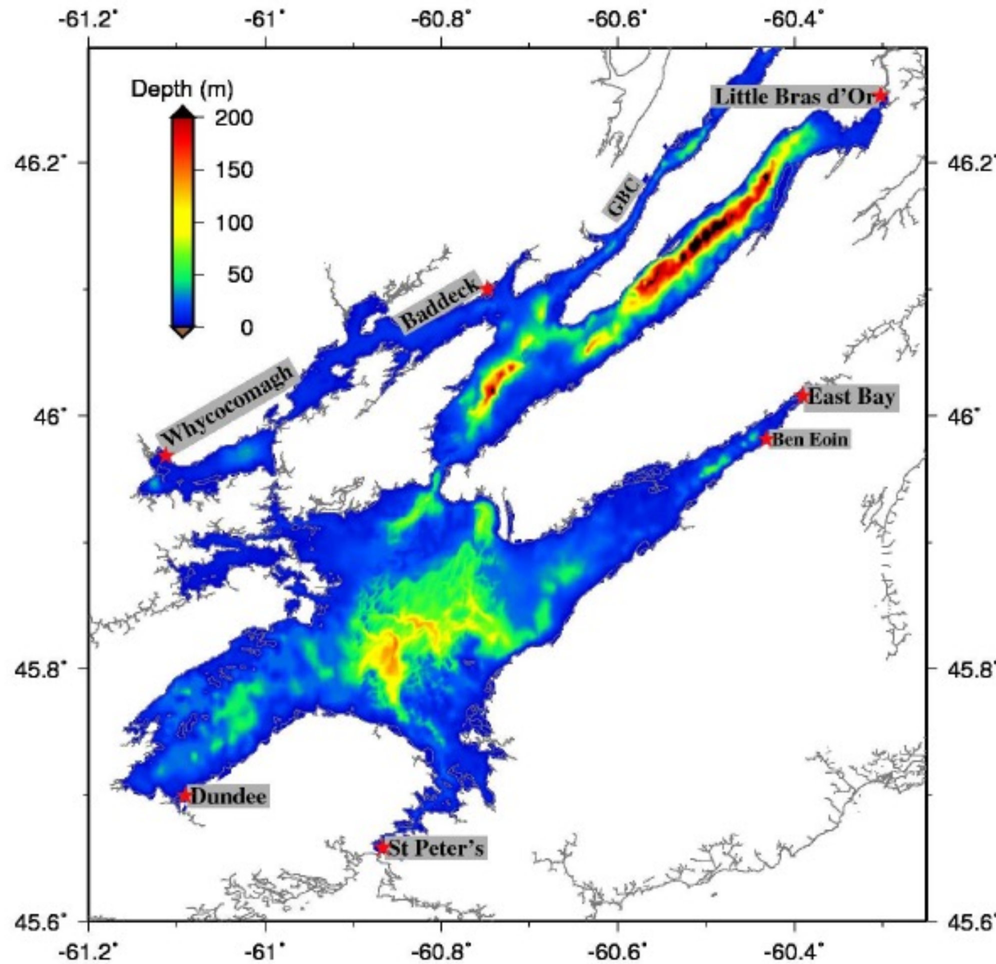

Figure 4 Map showing locations of Fisheries and Oceans Canada monitoring sites. (Map source: Drozdowski et al., 2014)

The entire water level database was made available to the project team in the form of Excel spreadsheets that facilitated the detection of important storm surge events that would have taken place since 2009 thereby allowing a comparison with the Fisheries and Oceans Canada North Sydney tide gauge database.

3.2.2 Results

The inclusion of TEK was instrumental in capturing the significance of the 21 Dec 2010 storm surge event which was also captured by the BIO database as a 0.8 m storm surge at the Dundee site. The Volunteer Observing Method was successful in identifying an apparent 0.7 m storm surge event at Malikewe'j on 11 December 2014. This event will be verified against the BIO database when the data becomes available in May 2015.

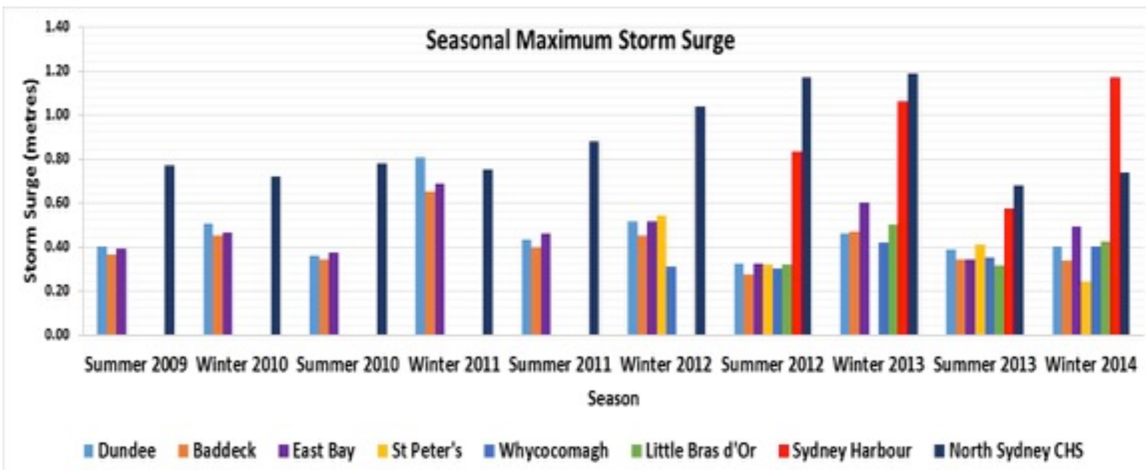

Figure 5 Graph displaying maximum storm surge values from BIO database for each available site and season. The Canadian Hydrographic Service (CHS) North Sydney data is also displayed

It becomes readily apparent from the results of the seasonal maximum storm surge values from the various sites displayed in Figure 5 that values from within the Bras d'Or Lakes are nearly 50% lower than the values from Sydney Harbour and North Sydney CHS. The main reason for this discrepancy is that the narrow Big Bras d'Or Channel (main exchange of tidal waters between the Lakes and the North Atlantic) significantly reduces the exchange of water both at high tide times and during storm-surge events. According to Drozdowski et al., (2014) the tide entering through the Big Bras d'Or Channel attenuates rapidly to about 10% of its original range by the time it reaches the interior of the Lakes. Consequently, it was decided to use the BIO data to provide a first estimate of storm surge events for the Mi'kmaq Communities of the Bras D'Or Lakes. The storm surge levels will be further adjusted pending the availability of a Coastal Hazard Assessment approach being proposed for Year 2 of this project.

3.2.3 Surge Trends

The BIO database was thoroughly analyzed to sort out dates when elevated storm surge values were recorded. The resulting dates were then verified against archived weather maps in order to identify the typical weather set-ups responsible for the storm surge events. It was this method that was utilized to generate the results in Figure 5. This process revealed that the predominant weather set-up for maximum storm surge events involved the typical nor'easter storm system which typically generates northeast to east winds in the speed range of 50 to 100 km/h for periods exceeding 24 hours. In the case of the extraordinary storm of Dec 21 to 24 2010, the period of east to northeast winds lasted a full 72 hours.

The weather set-ups described above will push water towards the west ends of both Big Bras d'Or and Little Bras d'Or Lakes after which a seiche effect (a standing wave equivalent to water sloshing back and forth in a bathtub) will cycle the water back towards the opposite end, thereby generating similar storm surge levels throughout the lakes. Drozdowski et al., (2014) have calculated seiche periods of 1.2 hours for Little Bras d'Or and 2 hours for Big Bras d'Or.

A nor'easter is a deep low pressure area that forms off the coast of New England and intensifies rapidly as it tracks south of Nova Scotia. It gets its name from the direction the wind is coming in from, i.e. the northeast. Nor'easters are usually accompanied with very heavy rain or snow and strong winds that can cause coastal flooding along easterly facing coastlines when the storm passage coincides with a high tide cycle.

3.2.3.1 Storm Surge Scenarios

As can be seen in Figure 5, there are three monitoring sites (Dundee, East Bay and Baddeck) with records going back to 2009 for a total of five years, thereby representing both Little and Big Bras d'Or Lakes. The maximum seasonal storm surge recorded values for these sites are displayed in Table 1.

Table 1 Maximum seasonal storm surge for Dundee, Baddeck and East Bay

Maximum Seasonal Surge			
	Dundee	**Baddeck**	**East Bay**
Summer 2009	0.4	0.4	0.4
Winter 2010	0.5	0.5	0.5
Summer 2010	0.4	0.3	0.4
Winter 2011	0.8	0.7	0.7
Summer 2011	0.4	0.4	0.5
Winter 2012	0.5	0.5	0.5
Summer 2012	0.3	0.3	0.3
Winter 2013	0.5	0.5	0.6
Summer 2013	0.4	0.3	0.3
Winter 2014	0.4	0.3	0.5
Site Average	**0.5**	**0.4**	**0.5**

It can be deducted from the results in Table 1 that on average an annual 0.5 m storm surge can be expected in Big Bras d'Or (for Potlotek, Malikewe'j and Eskasoni) and an annual 0.4 m storm surge can be expected in Little Bras d'Or (for We'koqma'q and Wagmatcook). During the Winter season of of 2011 (Dec 2010) a storm surge of 0.8 m was recorded in Big Bras d'Or with a slightly reduced value of 0.7 m for Little Bras d'Or. Due to the short record period of 5 years, it is not possible to determine the return period of the Winter 2011 event at this time.

Storm surge return values for the five Mi'kmaq Communities of the Bras d'Or Lakes were hence generated from the results in Table 1 as follows:

- For Potlotek, Malikewe'j and Eskasoni
  - Annual Average storm surge of 0.5 m
  - Maximum storm surge of 0.8 m with undetermined return period
- For We'koqma'q and Wagmatcook
  - Annual Average storm surge of 0.4 m
  - Maximum storm surge of 0.7 m with undetermined return period

3.3 Objective 3: Flooding scenarios for each community

3.3.1 Methodology

Flooding scenarios have been developed for each of years 2010 (baseline), 2030, 2050 and 2100. The scenarios include the sum of; the baseline tide level (the Higher High Water at Larger Tides level), the respective Regional Sea Level Rise component at each year indicated above, and the respective storm-surge component from Section 3.2.2.2. These scenarios were then presented as elevation lines on the LiDAR digital elevation model (from Objective 1) for each community.

3.3.1.1 Baseline water level

The Higher High Water at Larger Tides (HHWLT) is commonly used in Canada as a baseline water level for flooding scenario estimates. It is calculated as the average of the maximum annual predicted astronomical tide over a 18.6 year cycle period, thus representing a baseline level that is not necessarily reached every single year, but can also be exceeded during several years of the 18.6 year cycle. The HHWLT value for the Bras d'Or Lakes (using Canadian Hydrographic Service Big Bras d'Or tide prediction site #620) has been calculated as 0.8 m above Chart Datum (the reference level used for navigation and tide predictions). For land survey applications a geodetic reference such as CGVD28 is used to display elevations in GIS applications. For the Bras d'Or Lakes the difference between Chart Datum and CGVD28 is 0.4 m (Canadian Hydrographic Service value at North Sydney), whereby the CGVD28 elevations are 0.4 m less than Chart Datum. The HHWLT value of 0.4 M CGVD28 was also verified against the LiDAR DEM for Chapel Island (data capture 8-11 June 2014 near full moon cycle). The 2010 HHWLT baseline level of 0.4 m CGVD28 has hence been used for the development of flooding scenarios.

3.3.1.2 Regional Sea-Level Rise for the Bras d'Or Lakes

The regional sea-level rise projections for the Bras d'Or Lakes were extracted from a recent report entitled "Relative Sea-level Projections in Canada and the Adjacent Mainland United States, (James et al., 2014)". This report has taken the Intergovernmental Panel on Climate Change Fifth Assessment Report global sea-level rise predictions and "downscaled" results to a regional level that includes relative contributions of global sea-level rise, detailed crustal subsidence estimates, impacts of ocean dynamics changes associated with a weakening Gulf Stream circulation and the impacts of ice sheet meltwater distribution (fingerprinting).

The relative sea-level rise projections for the communities of Eskasoni, Potlotek, Malikewe'j, We'koqma'q and Wagmatcook were taken directly from the Baddeck projections in the above-noted publication. The projections for years 2030, 2050 and 2100 are respectively 0.14 m, 0.31 m and 0.86 m.above the HHWLT baseline value for year 2010 of 0.4 m above CGVD28.

3.3.2 Results

The resulting flooding scenarios for the five Mi'kmaq Communities of the Bras d'Or Lakes based on the discussions in Sections 3.2.2, 3.3.1.1 and 3.3.1.2 are hereby detailed in Table 2.

Table 2 Flooding scenarios rounded off to the nearest 10th of a metre above CGVD28 for Eskasoni, Potlotek and Malikewe'j

	2010	2030	2050	2100
Sea-Level Rise beyond 2010 (m)		0.1	0.3	0.9
Average Storm Surge (0.5 m)	0.9	1.0	1.2	1.8
Maximum Storm Surge (0.8 m)	1.2	1.3	1.5	2.1

Table 3 Flooding scenarios rounded off to the nearest 10th of a metre above CGVD28 for We'koqma'q and Wagmatcook

	2010	2030	2050	2100
Sea-Level Rise beyond 2010 (m)		0.1	0.3	0.9
Average Storm Surge (0.4 m)	0.8	0.9	1.1	1.7
Maximum Storm Surge (0.7 m)	1.1	1.2	1.4	2.0

Examples of flooding scenario maps are displayed in Figures 6 to 10 whereby the HHWLT, Average Surge and Maximum Surge are displayed for Years 2010, 2030, 2050 and 2100 for Potlotek. Maps for remaining scenarios and Communities are on a DVD accompanying this report, as well as the flooding scenario contours in a format which can be displayed in ESRI/ArcGIS software.

Figure 6 Map displaying the progression of HHWLT with sea-level rise between 2010 and 2100 at Potlotek

Figure 7 Map displaying HHWLT and flooding scenarios for year 2010 at Potlotek

Figure 8 Map displaying HHWLT and flooding scenarios for year 2030 at Potlotek

Figure 9 Map displaying HHWLT and flooding scenarios for year 2050 at Potlotek

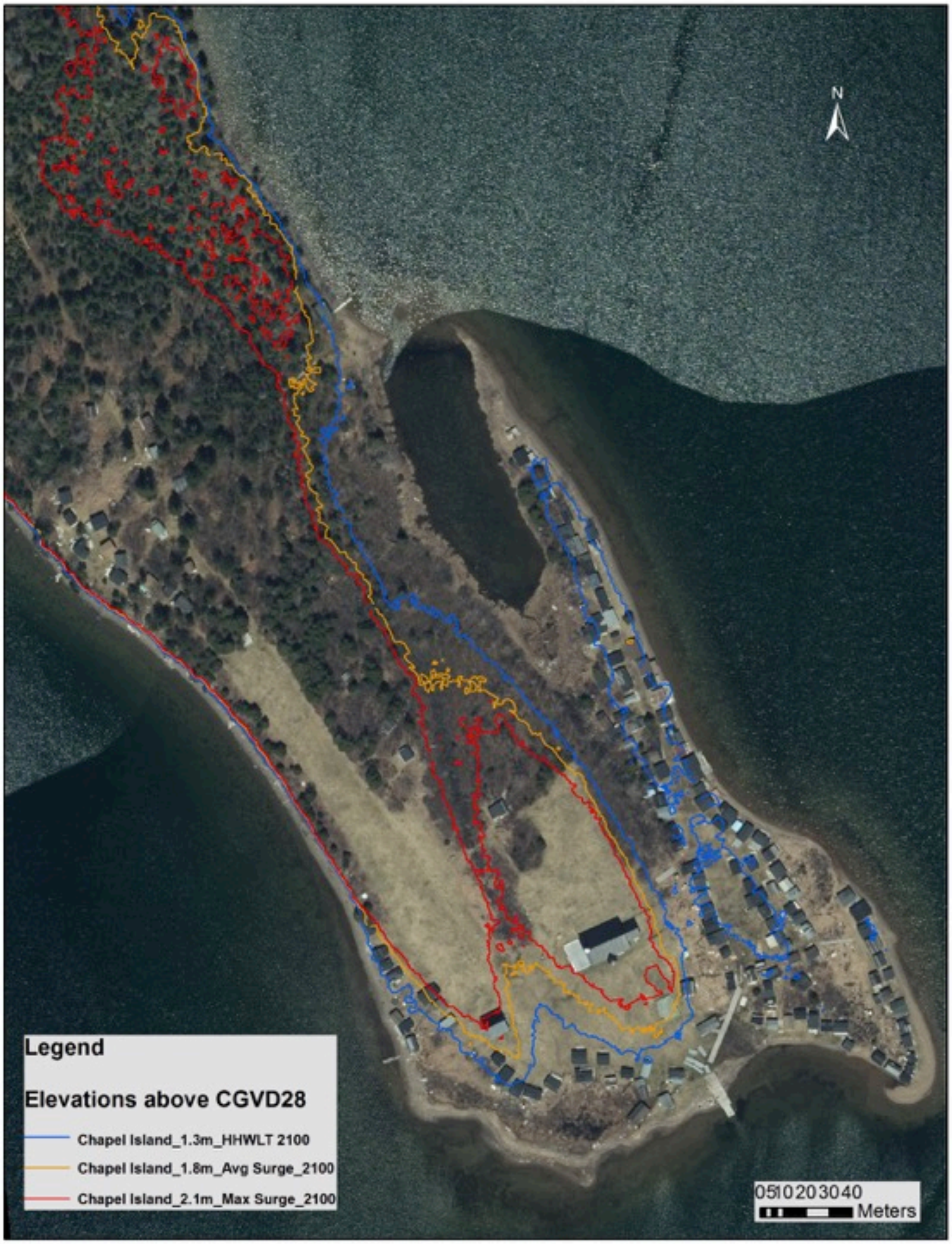

Figure 10 Map displaying HHWLT and flooding scenarios for year 2100 at Potlotek

3.4 Objective 4: 2014 coastal mapping for each community; Erosion assessment for two (2) sites: the Malikewe'j ancestral cemetery and the Chapel Island ceremonial grounds; and the Year 2100 shoreline projection scenario for the two sites.

3.4.1 2014 Coastal Mapping for Each Community[1]

The coast of the 5 Mi'kmaq communities was mapped using the orthophotos acquired by UINR in May 2014. The coastal mapping carried out here is inspired by the previous coastal mapping and classification work done by researchers at the Geological Survey of Canada (GSC), namely publications by TAYLOR and SHAW (2002) and by SHAW *et al.* (2006). Their work was initially based on the interpretation of an aerial video flown in 1996 (TAYLOR and FROBEL, 1998), where the coastal types were defined and transcribed onto 1:50 000 scale National Topographic Sheet maps (TAYLOR and SHAW, 2002) and later onto 1:10 000 scale maps (SHAW *et al.,* 2006). However, their coastal classification could not be entirely and directly transposed here. Given the large-scale mapping carried out in this project (Figure 11), an adaptation of the GSC's classification was needed; some coastal types were retained, while others were replaced with newly developed types.

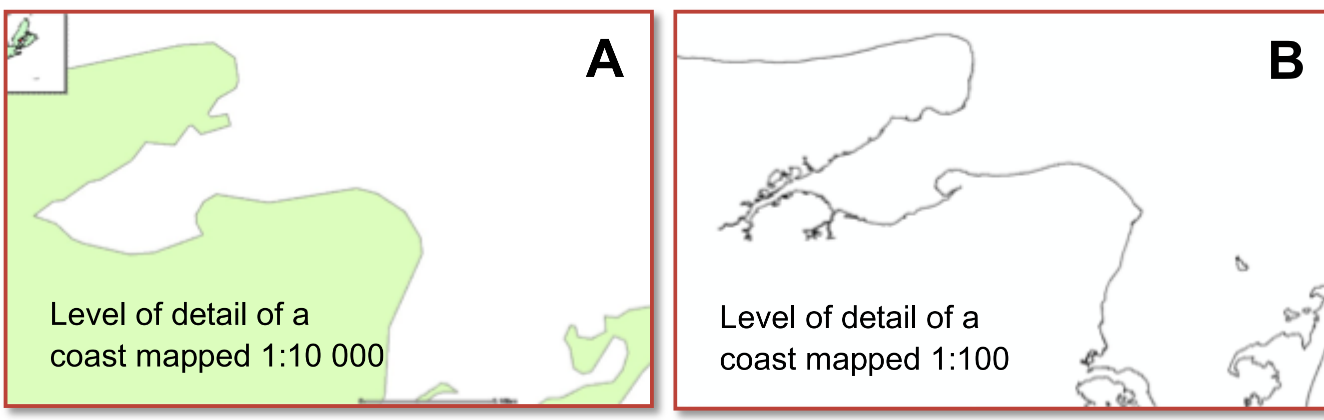

FIGURE 11. Parts of the coastal marshes of Boom Island (Malikewe'j) mapped at a 1:10 000 scale (A) and at a 1:100 scale (B). The overall aspects of the coast are comparable between the two map sets, however, some features have been overlooked at the 10 000 scale. The map in A is an extract taken from the Nova Scotia Department of Natural Resources GeoViewer website, which can be found here: http://gis4.natr.gov.ns.ca/website/nsgeomap/viewer.htm.

The large scale mapping carried out by *Géo Littoral Consultants* can be compared to a magnifying glass, an exercise highlighting the often overlooked details of the coast.

[1] Through out this Report, unless otherwise specified, the north is towards the top of each figure or illustration.

3.4.1.1 2014 coastal mapping methodology

In line with the coastal mapping carried out by the GSC in the late 1990's, early 2000's, *Géo Littoral Consultants* performed a mapping aimed at describing the landform features observed along the coasts of the 5 communities. The major features encountered were beaches, dunes, marshes, bluffs, deltas, peat bogs and human infrastructures. All mapping was done using *ArcGIS* (10.2).

Upon receiving the 2014 orthophotos, an initial examination of the coastal zone of all 5 communities was carried out in order to determine the criteria on how to best map the coastal features. A number of geomorphic and or topographic possibilities existed, such as the *scarp* (the top of bluffs, roc cliffs or dune cliffs), the *base* of the bluffs or rock cliffs, the *vegetation* limit of dunes and marshes and the *shoreline* (Figure 12). Based on the initial examination of the orthophotos and field observations (June 2014), *GLC* chose the most readily and reliably identifiable feature to map and describe the coast: the **instantaneous shoreline**. Given the very small tidal range in the Bras d'Or Lakes (~30 cm), the horizontal discrepancy based on the tide level relative to the timing of the 2014 orthophotos, should not affect significantly the identification nor the location of the coastal features to be mapped.

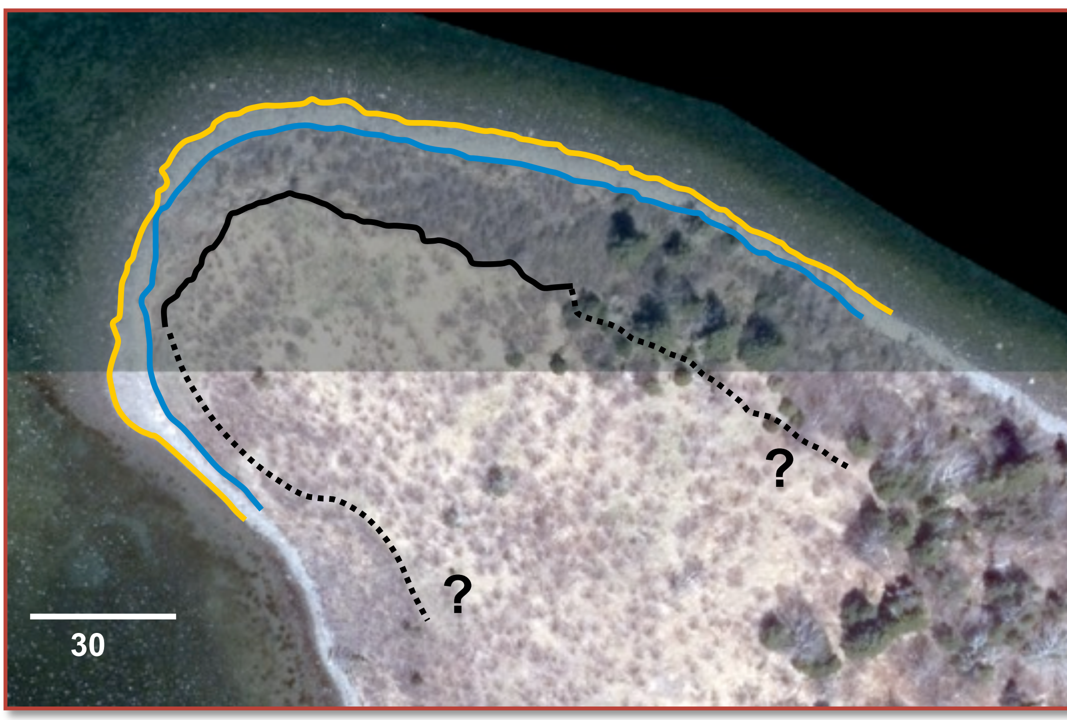

FIGURE 12. Landform features associated to bluffs that could be mapped: *scarp* or top of cliff (black), cliff *base* (blue), *shoreline* or contact between water and beach (yellow). The dashed black line highlights some difficulties in adequately identifying and positioning the scarp when the break in slope is gentle (rounded) or when the vegetation covers the scarp feature.

Nearly all mapping in this project was done at a **1:100 scale**. On occasions, smaller scales were used (1:150, 1:250 and 1:500), usually in problematic areas: where tree cover was too dense to see the coast; where trees were leaning over, hiding the shoreline; where the shoreline colour and texture rendered it difficult to clearly make out the coastal feature. The overall image quality of the 2014 orthophotos made feature identification and mapping fairly straightforward. On these orthophotos, the pixels represent 20 x 20 cm on the ground. Features of less than 2 pixels were not mapped.

Each vector or line mapped as part of this project contains information that was either generated automatically by *ArcGIS* or manually integrated during the mapping process - all this information is listed in the Attribute Tables of the shapefiles (Figure 13). For example, the information automatically populated by the software includes:

- *Object ID* (unique ID number for each object),
- *SHAPE* (type of shape – here, all objects are polylines),
- *SHAPE Length* (length in metres of each polyline or vector).

The information that was manually added to each vector includes:

- ***Feature_Code* (a shorthand legend or code describing the coastal feature)**,
- *Photo* (the name of the orthophoto *.tif* file in the background),
- *Notes* (additional information added to further explain the mapping).

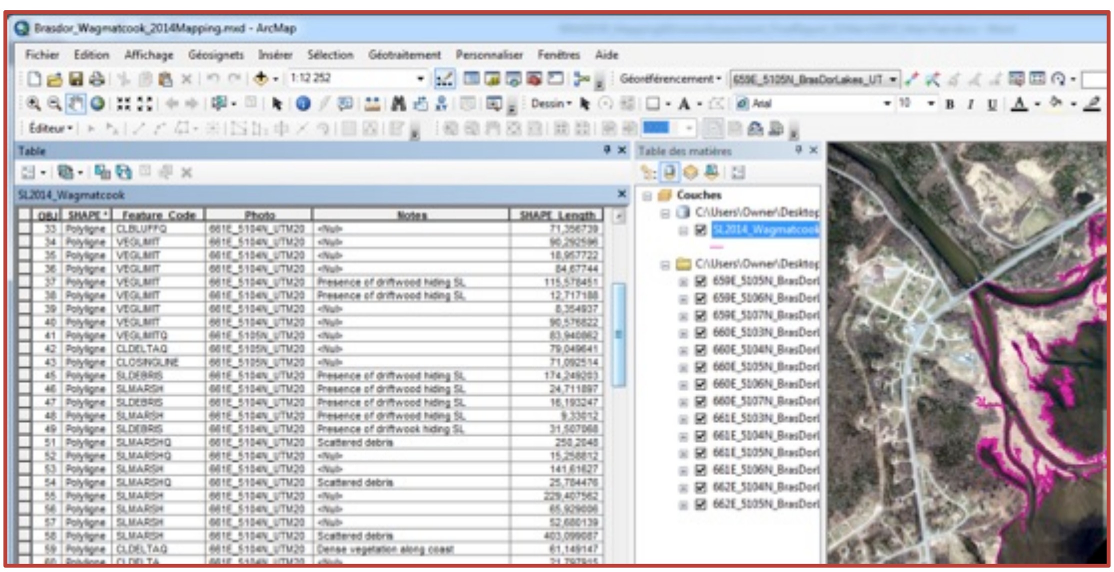

FIGURE13. Example of the Attribute Table contents of the 2014 coastal mapping of Wagmatcook.

A total of 26 unique Features Codes were assigned to vectors describing the coasts of the 5 communities – these Feature Codes, their description and their interpretation can be found in APPENDIX A. The following 6 figures (Figures 14a to14f) illustrate the main coastal features mapped using the 2014 orthophotos.

FIGURE 14a. Example of a beach shoreline backed by a dune mapped as: *SLBEACHDUNE* (red lines). The wet/dry sand boundary was used to delineate the shoreline.

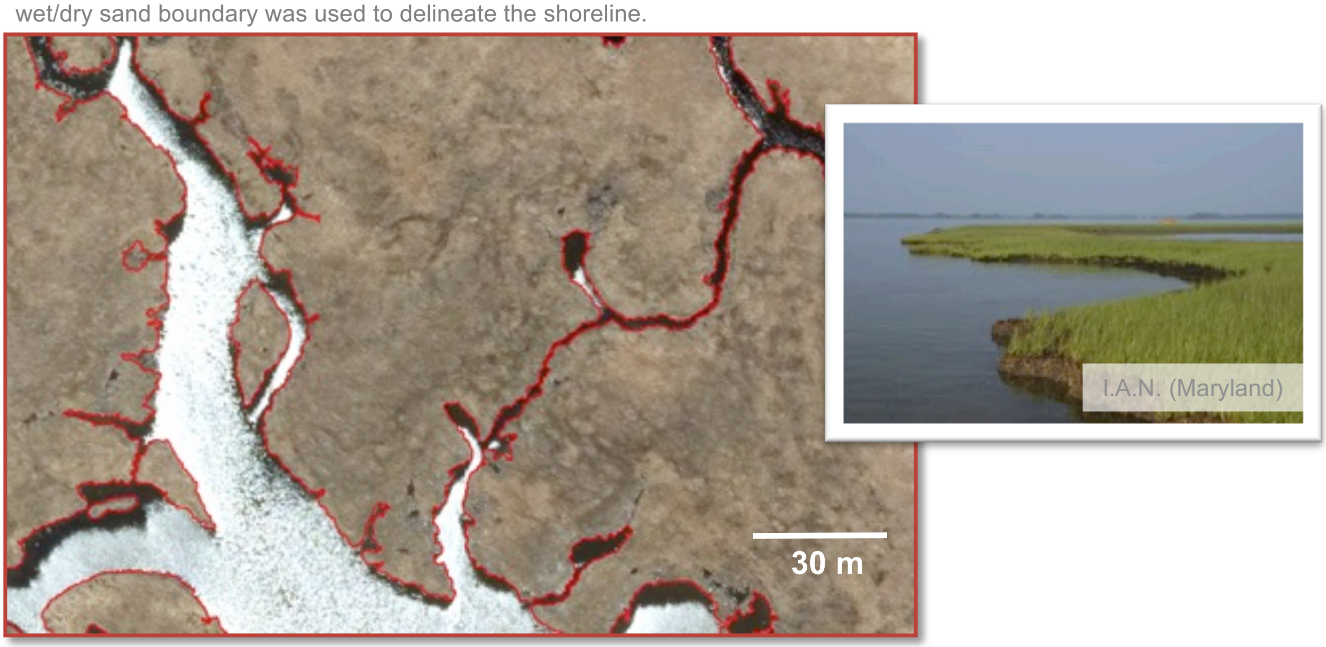

FIGURE 14b. Example of a coastal marsh shoreline mapped as: *SLMARSH* (red lines). The edge of the marsh vegetation was used to delineate the shoreline. This Feature Code was assigned to all marsh features influenced by the tides, such as the marsh edge, tidal creeks and semi-opened pans (or ponds connected to the lake).

FIGURE 14c. Example of a bluff shoreline mapped as: *SLBEACHBLUFF* (red lines). The wet/dry sand boundary at the base of the bluff was used to delineate the shoreline. The dark blue solid lines represent the location of the scarp (top of the bluff); the dark blue dashed lines represent approximations of the location of the scarp. *Given the difficulties in locating the scarp along all the bluffs along the coasts of the communities, this feature was not mapped.*

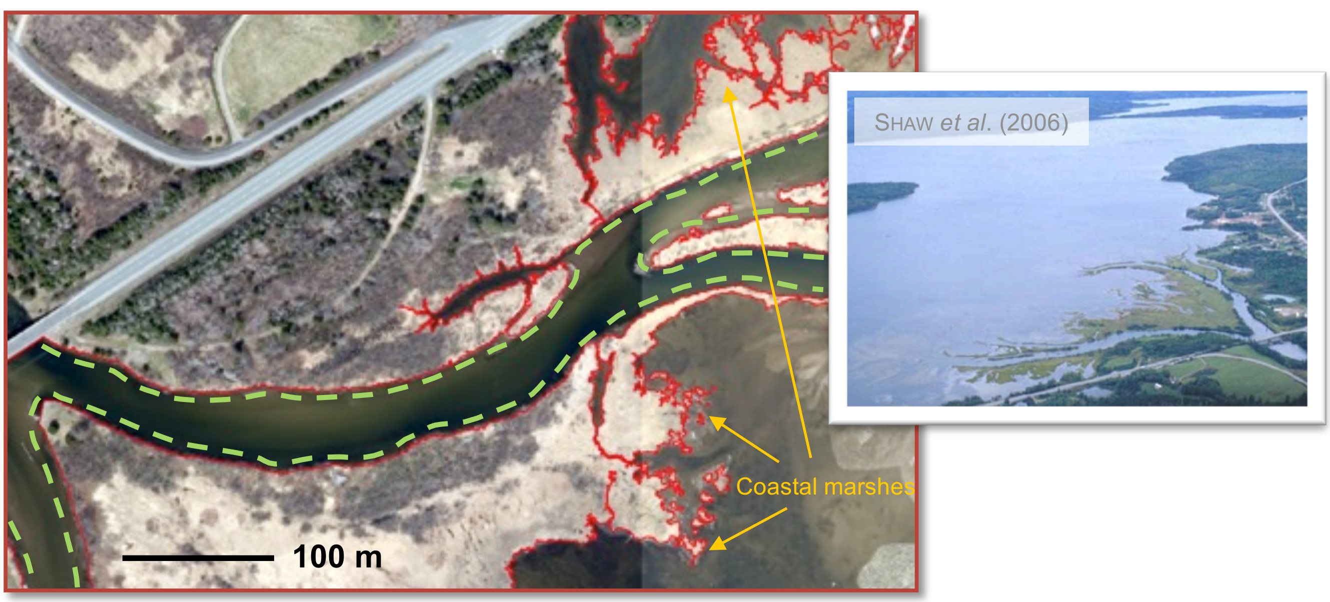

FIGURE 14d. Example of a delta shoreline mapped as: *SLDELTA* (red lines along the dashed green lines). Associated jointly to riverine processes transporting sediment to the coast and marine processes reworking these sediments, the delta portion of the shoreline Feature Code was restricted to active deltas or riverine channels (along the dashed green lines). The lee side of the deltas was mapped according to the dominant coastal feature: in the case shown here (yellow arrows) it is a *SLMARSH.*

FIGURE 14e. Example of an infrastructure coastline mapped as: *CLRIPRAP* (red lines). The Feature Codes associated to the different infrastructures begin with the letters "CL", meaning *coastline* (as opposed to "SL", for *shoreline*). Even though it exists, the shoreline fronting human infrastructures at the coast is often difficult to identify; the coastline is preferred.

FIGURE 14f. Example of stretch of coast where neither the shoreline nor the coastline are discernable, because of the dense tree cover. This type of situation was mapped as: *VEGLIMIT* (arrow pointing at red line). These coastal segments were mapped at a 1:500 scale and the edge of the treeline was used for the delineation.

3.4.1.2 2014 coastal mapping results

The 2014 coastal mapping for each community is completed. *Shapefiles* are included in the DVD that accompanies this report (see APPENDIX B). These vector files can be used directly in *ArcGIS*, as well as by many other GIS programs - minimal pre-transformation can be required (sometimes a simple "drag-and-drop" is sufficient to load these files). For readers who do not have access to a GIS program, five (5) georeferenced PDFs were produced corresponding to each community, and containing most of the mapping information of the shapefiles. However, these georeferenced PDFs cannot be modified and queries are limited. The georeferenced PDFs are included in the DVD that accompanies this report (see APPENDIX C).

A compilation of the coastal mapping data associated to the 5 communities is synthesized in Table 3. The communities' coasts total just under 217 km in length. Coastal marshes make up more than half of the coasts (111.2 km or 51%), while bluffs and dunes represent 15% and 13% (32.4 and 27.8 km), respectively. Densely vegetated coasts (feature code *VEGLIMIT* - corresponding to the edge of the treeline, where the shoreline and coastline were not detectible) totals 29.6 km or 14% of the coasts. When combining the 5 communities together, overall human infrastructure at the coast represents 2% of the total length (5.2 km). Of this total, riprap protection structures are present along 2.7 km of coast, and is by far the most common type of human intervention at the coast (52%) – this could be an indication of punctual or localised erosion issues. An interesting situation that comes up for Malikewe'j is that despite having relatively few people living there on a permanent basis, human infrastructure at the coast is the second highest of the 5 communities behind Eskasoni: 1.5 km of infrastructure at the coast on a total of 5.2 km (~30%).

Considering the coastal communities on an individual basis, Malikewe'j has the longest coast at 79.5 km, where coastal marshes represent 68% of the mapped features (53.9 km). In fact, coastal marshes are the dominant natural feature in each community (30-68% of the coasts) except at Potlotek, where bluffs are the prominent feature and make up 46% of the coasts (9.3 km). While dunes represent 13% of the coasts of the combined communities, half are found in Eskasoni (14.4 km); Malikewe'j has 6.7 km of dunes and Potlotek 4.6 km. Other noteworthy information that stands out as a result of this mapping exercise is that Wagmatcook and Waycobah each have delta features (associated to the Middle and the Skye Rivers, respectively); peat bogs appear directly at the coast in Malikewe'j (another probable indication of coastal erosion); bedrock shorelines only amount to 66 metres; and Potlotek has the least human interventions at the coast, the near totality of the 210 m of infrastructure consisting of wharves (and not protection structures like the other communities).

The fact that bedrock shorelines were only observed in Malikewe'j and over a length of 66 metres (field work could validate/adjust this number) highlights the fact that the coasts of the 5 communities are made up of unconsolidated material. Generally, this type of lithology is interpreted as being highly sensitive to erosion as well as to sea-level rise (GORNITZ, 1990; SHAW *et al.*, 1998, 2006; O'CARROLL, 2008).

TABLE 3. Length (metres) and corresponding percentage (%) of the different coastal features mapped from the 2014 orthophotos for each community. Figures in bold and maroon indicate the highest value for a natural feature and for an infrastructure, within each community.

Coastal Feature	Eskasoni		Wagmatcook		Waycobah		Potlotek		Malagawatch		5 communities	
	L (m)	%	L (m)	%	L (m)	%	L (m)	%	L (m)	%	L (m)	%
TOTAL Bluffs:	11 821	19	567	2	4 115	14	**9 251**	**46**	6 660	8	**32 414**	**15**
BLUFF (CL)	*948*	*2*	*182*	*1*	*64*	*0*	-	-	*912*	*1*	*2 106*	*1*
BLUFFBASE (CL)	*1 292*	*2*	-	-	-	-	-	-	-	-	*1 292*	*1*
BEACHBLUFF (SL)	*9 581*	*16*	*385*	*1*	*4 051*	*14*	*9 251*	*46*	*5 748*	*7*	*29 016*	*13*
TOTAL Dunes:	14 433	23	118	0	1 909	6	4 591	23	6 749	8	**27 801**	**13**
DUNE (CL)	*387*	*1*	-	-	*123*	*0*	*200*	*1*	*162*	*0*	*873*	*0*
BEACHDUNE (SL)	*14 046*	*23*	*118*	*0*	*1 786*	*6*	*4 391*	*22*	*6 587*	*8*	*26 928*	*12*
MARSH (SL)	**18 692**	**30**	**16 784**	**64**	**18 349**	**62**	3 465	17	**53 915**	**68**	**111 205**	**51**
VEGLIMIT (treeline)	14 319	23	1 134	4	1 802	6	2 749	14	9 592	12	29 596	14
DELTA (CL)	-	-	6 785	26	2 523	9	-	-	-	-	9 308	4
PEATBOG (SL)	-	-	-	-	-	-	-	-	744	1	744	0
BEDROCK (SL)	-	-	-	-	-	-	-	-	66	0	66	0
FLOODDELTA (SL)	-	-	-	-	-	-	-	-	73	0	73	0
BEAVERDAM (SL)	-	-	-	-	-	-	-	-	27	0	27	0
DEBRIS (SL)	-	-	297	1	-	-	-	-	152	0	449	0
TOTAL Infrastructure:	2 256	4	338	1	844	3	210	1	1 534	2	**5 182**	**2**
WHARF (CL)	*142*	*0*	*25*	*0*	*80*	*0*	***197***	***1***	*32*	*0*	*476*	*0*
RIPRAP (CL)	***1 147***	***2***	***232***	***1***	***563***	***2***	*5*	*0*	***732***	***1***	*2 678*	*1*
TIRES (CL)	*18*	*0*	-	-	-	-	-	-	-	-	*18*	*0*
WALL (CL)	-	-	*32*	*0*	*50*	*0*	-	-	-	-	*81*	*0*
SLIP (SL)	*10*	*0*	*6*	*0*	-	-	-	-	-	-	*16*	*0*
JETTY (CL)	*136*	*0*	-	-	-	-	-	-	-	-	*136*	*0*
GROYNE (CL)	*101*	*0*	-	-	-	-	*8*	*0*	-	-	*110*	*0*
LEVEE (SL)	-	-	-	-	-	-	-	-	*680*	*1*	*680*	*0*
BACKFILL (CL)	*702*	*1*	*44*	*0*	*124*	*0*	-	-	*83*	*0*	*953*	*0*
ROAD (CL)	-	-	-	-	*27*	*0*	-	-	*7*	*0*	*34*	*0*
TOTAL:	**61 522**		**26 023**		**29 542**		**20 267**		**79 511**		**216 864**	
CLOSINGLINE *	42		84		25		4		6			

Entries in italics are also tallied within their main category.

*the CLOSINGLINE feature code was used to artificially close-off streams, where the tidal influence was deemed non-existant. This artificial vector is not reflected in the total length of the coast.

3.4.1.3 Potential uses of the 2014 coastal mapping

The 2014 coastal mapping applied here represents a detailed description of the communities' coastal zone – it was performed at a fine scale. The corresponding shapefiles could be used for the management of the communities' coasts. Additional information can be added to these maps at any time. For example:

- The LiDAR data acquired for the 5 communities could be combined to the mapping data in order to determine the slope of the nearshore and backshore features. The steepness of the bluff slope can be more or less favorable to mass movement of sediment downslope (i.e. erosion).
- Through a field work campaign, a coastal geomorphologist could expand the description of the coast, by further detailing the dominant sediment types for beaches (mainly sand, sand/gravel, peat outcrops, etc.), the lithology of the backshore, the presence or absence of vegetation along the cliff slope, include field photographs, etc. - information that could be integrated to the shapefile's database.
- The 2014 mapping could also be used to gather additional information on the coastal habitats, as part of a subsequent mapping project (Figure 15). Since the main delineating vectors are now positioned, a future mapping phase could target the coastal habitats by identifying and mapping their boundaries, and using the current vectors to generate the polygons corresponding to the specific habitats. This type of mapping could produce important and useful information from a management point of view (important traditional flora/fauna) as well as from a biological perspective (species at risk, etc.), and could also serve in assessing the evolution of the communities' coastal habitats over the recent past (by mapping the coastal habitats on older aerial photographs, i.e. the 1940's) in order to detect trends.

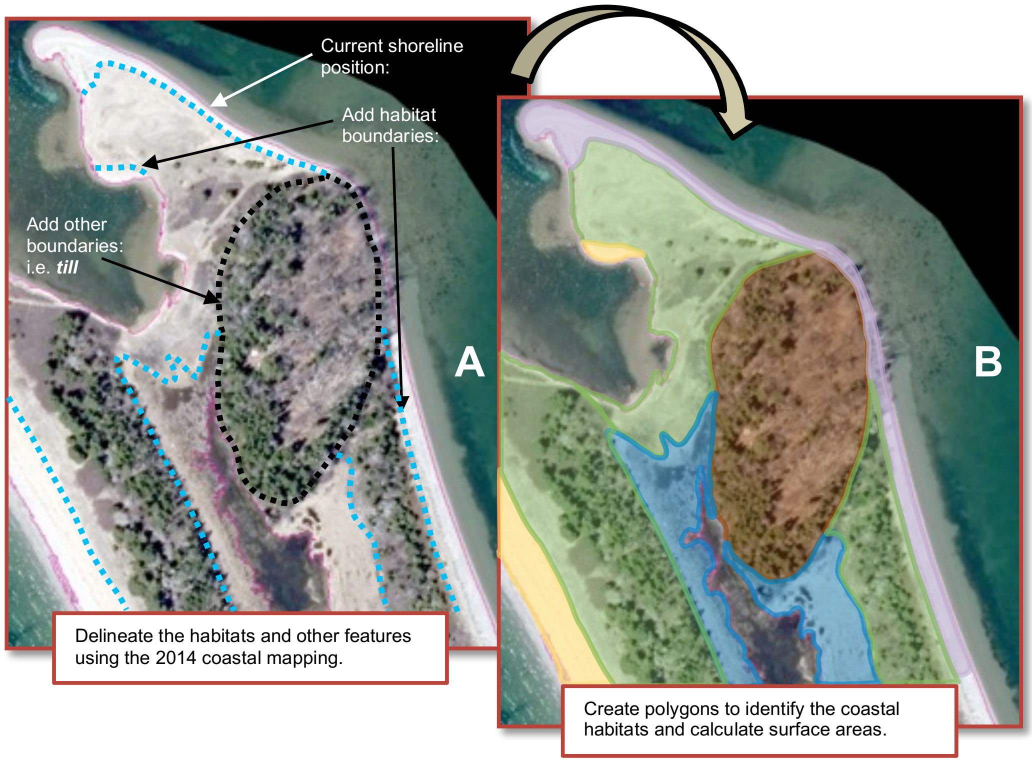

FIGURE 15. Example of the use of the current 2014 coastal mapping to produce coastal habitat maps. In "A", the existing vectors of the 2014 mapping are supplemented and joined with habitat boundary vectors to generate groups or polygons. In "B", the habitat polygons are generated and coloured according to each coastal habitat: beaches (yellow), dunes (green), marshes (blue), upland or outcrop (brown). *NOTE: this is a schematic illustration; the "red" lines of the 2014 mapping would not show up in the habitat mapping.*

3.4.2 Erosion Assessment of Malikewe'j and Potlotek Study Sites

Erosion is a chronic problem affecting many coasts of the world. In some areas, beaches have narrowed and in others they have completely disappeared due to erosion (ROMINE *et al.*, 2009); in others, soft rock cliffs and especially bluffs are being eroded away, threatening infrastructure as the coastline retreats (BERNATCHEZ, 2006; GUTIERREZ *et al.*, 2007). While human occupation at the coast is increasing and expanding, and as sea level continues to rise, it is to be expected that community infrastructure will come under increasing threat from erosion (GUTIERREZ *et al.*, 2007; FLETCHER *et al.*, 2011). It is therefore essential to have access to accurate information about trends and rates of shoreline movement and its evolution, to change current practices and aim at coastal zone management and planning decisions that are in line with adaptation to climate change.

In order to assess the erosion at the Malikewe'j and Potlotek study sites, *Géo Littoral Consultants* opted to use a widespread and recognized methodology: the net shoreline movement method (THIELER *et al.*, 2009). This computer-assisted approach integrates the use of aerial photographs, geomorphological mapping of past shorelines, and placement of transects to measure the shorelines' position change over time and to inform about the coast's evolution. In order to understand a coast's evolution and coastal erosion in particular, different options exist, however aerial photographs have the advantage of showing important coastal features, such as the shoreline. For a given site, by positioning sequential time series of aerial photographs one on top of each other at their exact location, the movement of the shoreline through time can be observed and be measured quite precisely (Figure 16). The technical manipulations that are involved will be explained in detail below.

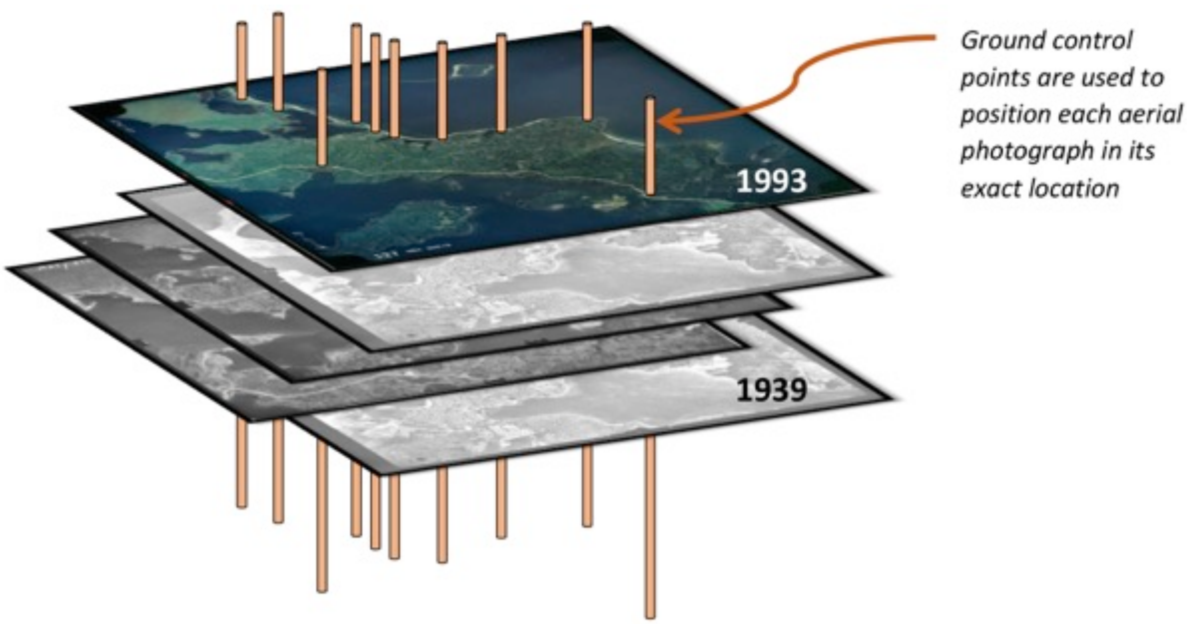

FIGURE 16. Schematic representation of the use of ground control points (GCPs) to adequately position individual aerial photographs in space. This process is required to assess erosion and to characterize the coast's recent evolution at Malikewe'j and Potlotek study sites. The shoreline appearing on each air photograph used in this study was mapped.

This erosion assessment method was adapted and refined by the United States Geological Survey (USGS) over the past 20 years; it is also currently being used by the New Brunswick Department of Natural Resources to assess erosion along its coasts (O'CARROLL *et al.,* 2006). A complete description of this method can be found in the following references: THIELER and DANFORTH (1994); MORTON and MILLER (2005); GUTIERREZ *et al*. (2007); THIELER *et al.* (2009); HAPKE *et al.* (2010); ROMINE *et al.* (2012).

3.4.2.1 Erosion assessment methodology

The use of aerial photographs in erosion assessments requires that the images be georeferenced, i.e. that the areas represented are located in their true position. In order to do so, each contact print (the paper copy of the aerial photograph) is first scanned to create a digital file (*.tif*) which is then imported into *ArcGIS* for processing. For this project, all aerial photographs were scanned at a high resolution (1800 dpi – *dots per inch*). Listed below are the aerial photographs that were georeferenced and used to assess erosion at the Malikewe'j and Potlotek sites[2]:

Malikewe'j (9 photos)	Potlotek (1 photo)
1939 A6649-27	1939 A6548-26
1953 A13715-89 and A13725-71	
1966 A19394-169	
1969 30219-127	
1975 75220-54	
1984 84310-41	
1993 93325-81 and 170	

3.4.2.1.1 **Ground control point identification and Image processing**

The most crucial aspect in the image georeferencing process is the ground control point (GCP) identification phase. The quality, quantity, distribution and accuracy of the GCPs used will directly impact the quality of the georeferencing process, and ultimately the location precision of the georeferenced image produced.

GCPs are landscape features (natural or human), such as isolated trees, indentations along the banks of streams or small ponds, field lines, ditches, corners of buildings or houses, road intersections, etc., that can be identified on both the non-georeferenced image (for example, the 1993 aerial photograph) and the georeferenced image (in the case of this contract, the UINR 2014 orthophotos were used as the georeferenced file) (Figure 17).

[2] The 2008 Provincial orthophotos and the 2014 orthophotos were also used to map shoreline features, but these images are already georeferenced products; they do not require additional spatial positioning to be loaded in a GIS program.

In order to properly georeference an aerial photograph, a minimum of ten (10) GCPs should be identified, whenever possible (a common practice). At the end of the georeferencing process, the residual error of each GCP (the position given by *ArcGIS* of the non-georeferenced GCPs VS the position of the same georeferenced GCPs as mapped on the georeferenced file) should not exceed 5 metres. For this study, a total of 105 GCPs were used to georeference the ten (10) aerial photographs (9 for Malikewe'j and 1 for Potlotek). The highest residual for a single individual GCP was 2.32 m and the lowest was 0.02 m; the total RMS error of georeferenced images ranged from 0.47 m to 1.93 m (see APPENDIX D).

FIGURE 17. Ground control point identification: A- 1993 non-georeferenced air photograph; and B- 2014 georeferenced orthophoto. Red arrow points to a conifer, common to both the 1993 and 2014 images, and used as a ground control point. Please note that figures A and B are selected portions of their original images, used here as part of an example.

3.4.2.1.2 Calculation of the margin of error (ME)[3]

Measurements made on any spatial document (hard copy or digital file) contain a margin of error. For this study, the ME associated to the measurement of shoreline displacement between different time periods integrates all possible sources of error (or inaccuracies), ranging from the production of the georeferenced images to the work of the cartographer.

Essentially, this calculation takes into account the following four (4) parameters:

- the resolution of the scanned aerial image (the ground pixel value): **P**
- the resolution of the 2014 orthophotos (the ground pixel value): **G**
- the total RMS error of the georeferenced images: **R**
- general quality of photographs and interpretation (potential error in mapping): **Q**

$$ME = P + G + R + Q$$

For example, the margin of error for the historical[4] period (1939-2014) at the Malikewe'j study site corresponds to:

1939

P(0.35 m) +**G**(0.2 m) + **R**(1.38 m) + **Q**(2.0 m + 0.5 m) = ±4.43 m

To obtain the annual range, the ME is divided by the number of years of the time period (75 years in this example): **ME** = ±4.43 m / 75 years = **±0.06 m/yr**

All shoreline displacement values (positive in case of accretion; negative in case of erosion) greater than the margin of error are considered to be **conclusive**; all

---

[3] The margin of error presented here integrates all sources of inaccuracies and represents an upper limit. *GLC* considers that the displacement values (in m or in m/yr) presented here are conclusive when they are greater than the margin of error. When the values are within the margin of error, independently of the actual movement of the coast, the method cannot conclusively detect small changes of the position of the shoreline.

[4] The term «historical» is meant to correspond to the longest time period for which adequate aerial photograph coverage exists. This terminology is widely accepted in the scientific community and can also include other types of cartographic documents, such as old topographic or bathymetric maps, provided that their reliability is confirmed. In certain cases, the historical period can extend beyond 100 years.

shoreline displacement values lower than the margin of error are considered **non-conclusive**. The exact formulation of the margin of error is detailed at the bottom of each shoreline displacement table presented in APPENDIX E.

3.4.2.1.3 Mapping and Data extraction

Once georeferenced, the shoreline on each aerial photograph was mapped at a 1:100 scale, as part of the multi-year methodology. Transects were then drawn perpendicular to the 2014 shoreline at every 25 m and used to measure the shoreline displacement. For example, the distance between the 1939 and 2014 shorelines was measured at the intersection of both shorelines along each transect (Figure 18). Each measured distance was then divided by 75 to obtain the annual rate of displacement, expressed in metres/year. The results for the 1939-2014 period were compiled in *Excel* spreadsheets; the *.xls* files for each study site are available on the accompanying DVD (see APPENDIX E).

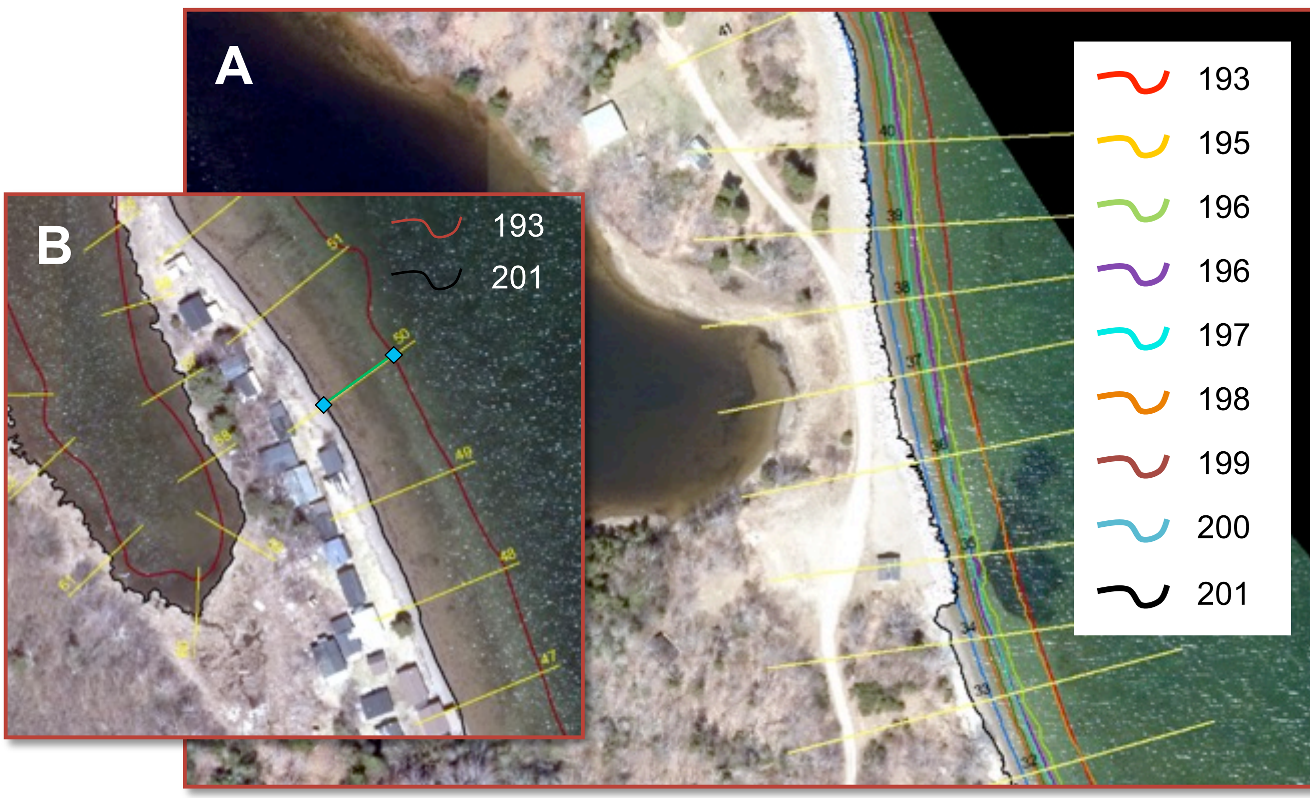

FIGURE 18. Example of the mapped shorelines and transect placement (25 m interval) in part of the Malikewe'j study site (A). Sub-set "B" part of the Potlotek study site shows how the shoreline displacement measurements were taken: the length of the green line represents the total retreat distance of the shoreline from 1939 to 2014.

3.4.2.2 Results for the Malikewe'j study site

The evolution of the coast at Malikewe'j was assessed along a ~2.5 km-long study site that is centered on the ancestral burial grounds (the Cemetary Road access and the Malikewe'j Presqu'isle). It was sub-divided into 4 sectors based on geomorphology, as interpreted from aerial photographs (Figure 19):

- **Sector A** – Small Malikewe'j Lagoons: beach and dune with bluff
- **Sector B** – Cemetary Road (*B1*) and Presqu'isle (*B2*): low bluffs
- **Sector C** – Indian Pond Barrier Beach: low gravel/sand barrier beach
- **Sector D** – Noel Point Sand Spit: low, multi-ridged sand spit

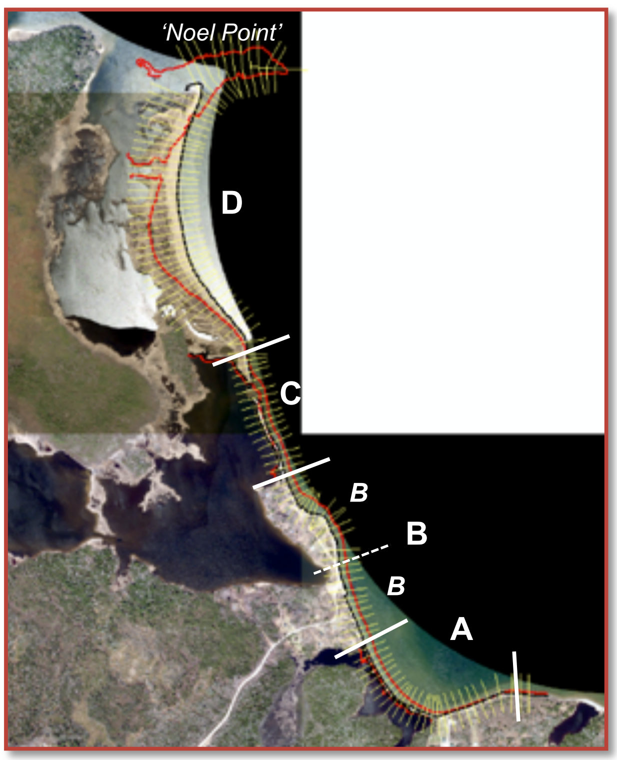

FIGURE 19. The Malikewe'j study site is approximately 2.5 km long, from the small Malikewe'j lagoons sector A) in the south to "Noel Point" (sector D) in the north. Sector B, sub-divided into *B1* and *B2*, is the main focus of the Malikewe'j study site. *The thin yellow lines correspond to the 132 transects for the study site.*

3.4.2.2.1 Historical shoreline evolution at Malikewe'j: the 1939-2014 period

The historical shoreline evolution at the Malikewe'j study site shows two distinct and opposite trends: erosion and accretion. Table 4 summarizes the shoreline displacement for each Sector (see also the *Excel* file in APPENDIX E for the measured distance and the calculated rate along each transect).

Sectors A, B and C show an erosional trend over the 1939-2014 period, while Sector D shows and accretional trend. Sectors A and C both have comparable average historical erosion rates of -0.18 and -0.19 m/yr (±0.06 m/yr) respectively, while the average rate of erosion in Sector B is 1.83X greater than the adjacent sectors A and C: -0.33 ±0.06 m/yr. This notable difference could be explained by the coastal types making up each Sector. The shoreline along Sectors A and C corresponds to ***barrier beaches*** and ***beaches*** backed by ***dunes***. These coastal types are known to be highly dynamic features, able to retreat during storms and re-establish themselves partially or sometimes fully during the following calmer period. These fluctuating shoreline positions are evident in Sector C (Figure 20). Also, beach and dune coasts can exhibit advance if an increase in sediment is introduced in the system (i.e. the migration of a sand wave or lobe along the coast, or rapid erosion of updrift bluffs, for example). The shoreline along Sector B is backed almost entirely by low ***bluffs***. This coastal feature, on the other hand, will not be able to recover from an erosion episode: when erosion provokes the bluff's cliff face to retreat, the new landward position of the bluff is often stable until the next erosion episode affects the coast.

TABLE 4. Average historical (1939-2014) shoreline displacement rates by sector, Malikewe'j erosion assessment study site.

Sector	Length (m)	# Transects	Average (m)	Error (m)	Rate (m/yr)	Error (m/yr)
Sector A	515	27	-13.48	±4.43	**-0.18**	±0.06
Sector B	560	26	-24.71	±4.43	**-0.33**	±0.06
Sector C	405	17	-14.11	±4.43	**-0.19**	±0.06
Sector D	1 055	62	+40.74	±4.43	**+0.54**	±0.06
	2 535	132				

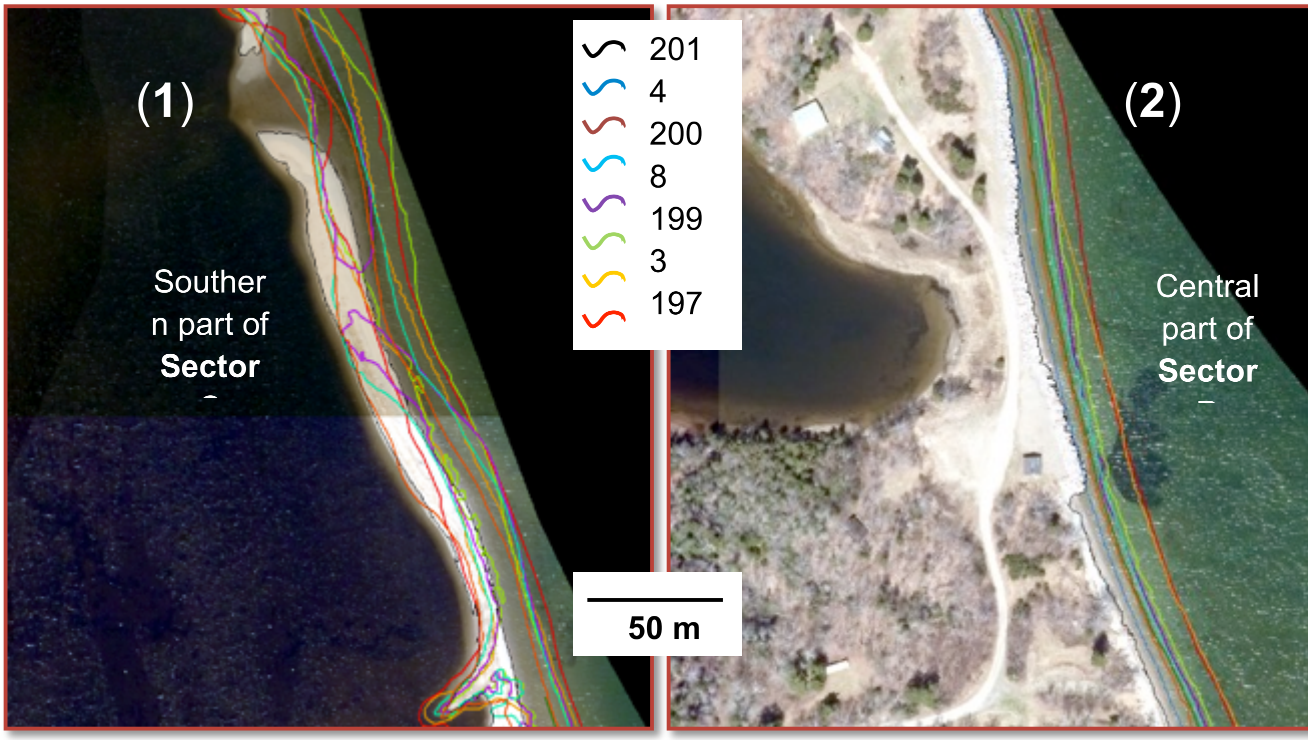

FIGURE 20. (1) Example of fluctuating shoreline positions associated to sandy environments (Sector C, Malikewe'j). The overall evolutionary trend here is erosion, but it is made up of alternating phases of erosion and accretion. (2) Example of a regular retreating pattern of shoreline positions associated to bluffs, Sector B (Malikewe'j). For the same time period as in Sector C, the shorelines in Sector B have progressively moved landward in a quasi-unidirectional fashion.

By representing graphically the historical shoreline displacement rates for the entire study site at Malagawach (Figure 21), it seems reasonable to postulate that the average accretion trend observed in Sector D (~half a metre a year over the last 75 years) comes from sediments eroded away from Sectors A, B and C, and transported a northward by the longshore drift. A northward longshore drift was suggested by FINCK (2011).

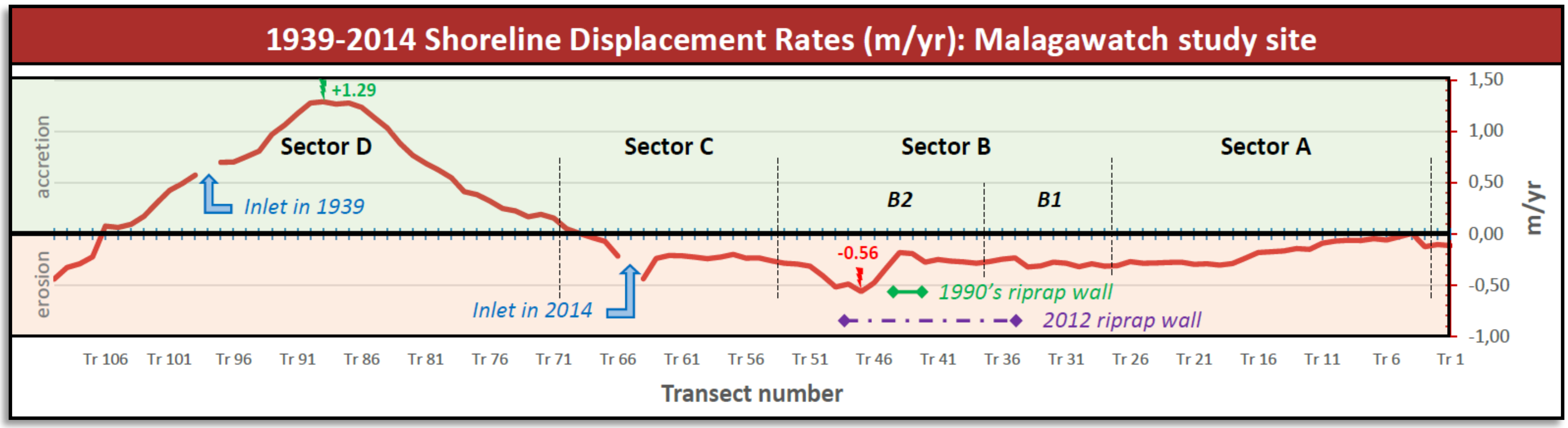

FIGURE 21. The historical displacement rates for Malikewe'j study site plotted along each transect (thick red line). The horizontal axis corresponds to the individual transects (Tr 1 to the right of the figure is the southern part of the study site, while Tr 106 to the left corresponds to the northern part of the study site). The vertical axis corresponds to the displacement rate in m/yr: rates above the 0.0 m line indicate accretion or progradation of the shoreline, rates below the 0.0 m line indicate erosion or retreat of the shoreline. The two interruptions in the plotted rates are owed to the presence of tidal inlets (where one of the two shoreline was absent, therefore no rate was extracted). The highest erosion rate occurred in Sector B along transect 47 (-0.56 ±0.06 m/yr) and the highest accretion rate occurred in Sector D along transect 89 (+1.29 ±0.06 m/yr). *Figure is not at scale*.

The most dramatic changes in the Malikewe'j study site in the past 130 years happened in Sector D.

An 1884 geological map produced by the Geological Survey of Canada shows that "Noel Point" was a prominent landscape feature and that the coastal feature we have called the Noel Point Sand Spit (Sector D) in this report did not exist (Figure 22). This map also shows the overall indented aspect of the coast, the presence of a large lagoon connected to the Lake in the central part of Sector D, and the presence of a wide inlet between Sectors C and D. In fact, there seems to be both northward- and southward-forming barriers in Sector C.

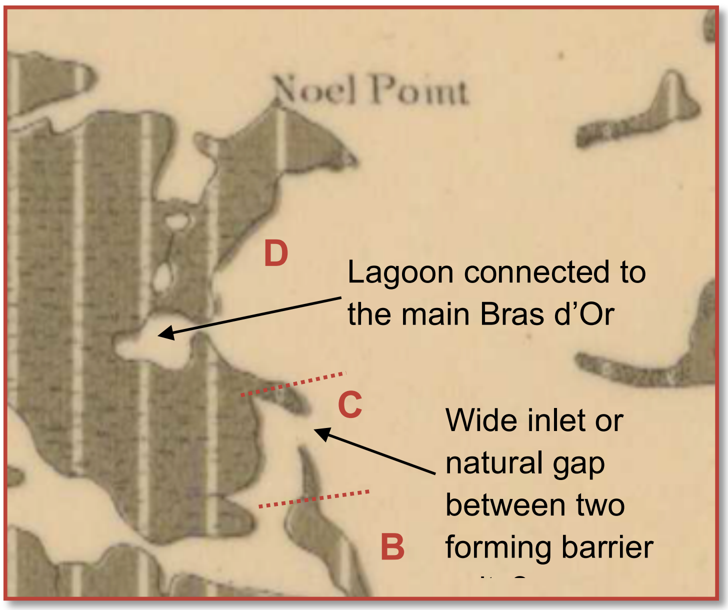

FIGURE 22. Extract of H. FLETCHER's 1884 geological map, showing "Noel Point" and part of the Malikewe'j study site.

From 1939 onwards, the air photo sequence documents well the erosion and disappearance of "Noel Point" in the northern part of the study site (the complete destruction happened somewhere after 1993) (Figure 23). "Noel Point" eroded quite rapidly: from 1939 to 1993, the shoreline moved westward ~190 m (an approximate rate of ***-3.5 m/yr***). In conjunction with this evolution, tidal inlets opened and closed in the main sand spit throughout the period, and the central part of the spit accreted (built eastward: the shoreline moved towards the lake) significantly: + 96.75 m of progradation, a rate of ***+1.29 ±0.06 m/yr*** (at transect 89).

The concave or "bowl-shaped" aspect of the coast in 1939 was progressively infilled and its overall shape today is more linear. The origin of this sustained influx of sediment to the central portion of the sand spit is unknown. It could originate from a variety of sources, including from the northward longshore drift coming from the south, from waves moving sediment onto the foreshore in the vicinity of the sand spit, from the destruction of "Noel Point", or from a combination of all these sources. It is interpreted here that a portion of the sediments could have come from the erosion of "Noel Point", implying a **southward longshore drift** in this part of the Sector. In his 2010 site assessment, FINCK (2011) does note the erosion of the northern-most end of the spit ("Noel Point") for the period 1953-2008 as well as the apparent seaward advance of the central part of the spit – however, no link is made between the two morphological changes.

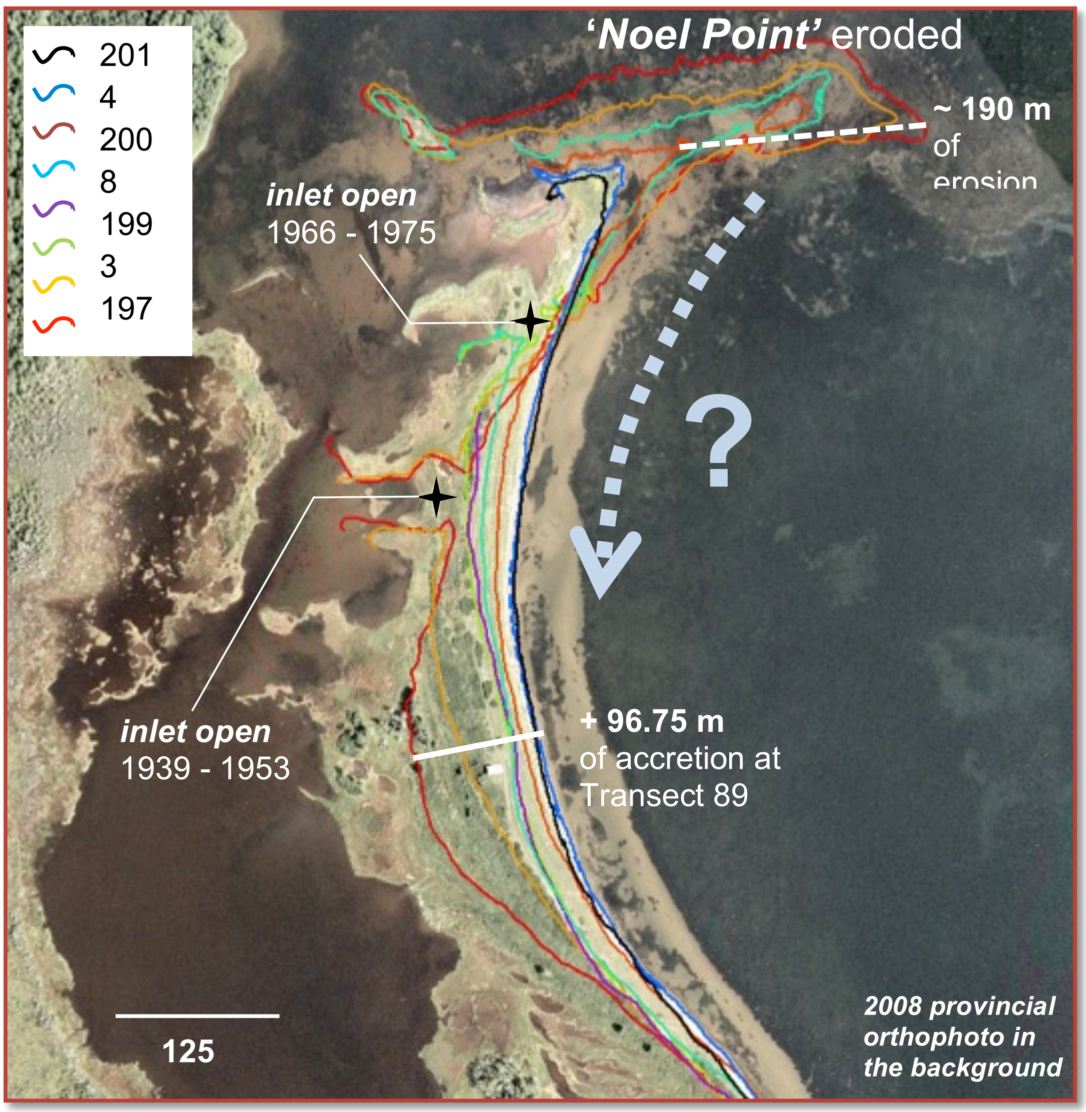

FIGURE 23. Major geomorphological changes occurred in Sector D during the period 1939-2014: complete erosion of "Noel Point"; opening and closure of tidal inlets; significant accretion and infilling of the concave part of the sand spit. The erosion of "Noel Point" could have provided the sediments for the infilling of inlets and the progradation of the sand spit – this implies a southward direction of the longshore drift, at least in the vicinity of Sector D.

The broad reach of the Malikewe'j study site (~2.5 km) was required in order to properly set the context for a closer look at the graveyard site (Sector B) and analyse its recent evolution.

3.4.2.2.2 Focus on Sector B: What intermediate and short-term periods can reveal

Géo Littoral Consultants understands the particular interest the Malikewe'j graveyard site represents to the Mi'kmaq communities of the Bras d'Or Lakes, therefore an in-depth analysis of Sector B was performed. Since the mid-1990's, 9 studies, assessments and site visits pertaining to shoreline erosion at the graveyard site or in the greater area of Malikewe'j have taken place (ADI Limited, 2010). Although these initiatives all confirmed the site is eroding, none of these initiatives actually ***quantified the erosion*** (historical or recent). At what rate is the shoreline eroding at the graveyard site? Is the erosion at the site of greater magnitude than in adjacent sectors to the north and south? Has the rate of erosion always been the same, or has it increased in the recent decades, and if so why? The answer to these questions are important for management decisions concerning this unique site; the present erosion assessment aims at understanding this site's recent evolution.

Table 5 compiles the average shoreline displacement rates for Sector B based on the different time periods enabled by the aerial photography coverage used in this study. Of importance to note here is that the shorter the time period considered, higher are the possibilities that the margin of error will exceed the rate of displacement, rendering the rates non-conclusive. Despite these reservations, the evolution during shorter time periods can be assessed carefully and offers some precious insights that the study of the 1939 and 2014 shoreline positions alone might conceal.

As mentioned in sub-section 3.4.2.2.1, the shoreline in Sector B has been retreating landward at an average rate of -0.33 ±0.06 m/yr over the last 75 years. This erosion trend is also reflected within the short-term periods where conclusive rates are obtained (greater than the margin of error): the shoreline is consistently eroding from one time period to the next. The average shoreline erosion rates for Sector B vary from a low of -0.29 ±0.20 m/yr in 1993-2008 to a high of -1.06 ±0.24 m/yr in 2008-2014. The latter period is quite short (6 years), yet it includes a series of major storms that hit the coasts during each week in December 2010:

Impacts of four storms in December 2010 on the eastern Shore of Nova Scotia

Date Added: April 5, 2013

A series of intense low pressure systems struck the Atlantic Maritime Provinces during each week in December 2010. Record storm surges during December 21 and 27 most impacted the shores of Cape Breton Island and southern Gulf of St. Lawrence. Impacts along the coastal highlands of Cape Breton Island were compounded by high river discharge and slope instability caused by heavy rainfall during the December 14 and 21 events. Detailed observations and repetitive surveys of physical

Author: Taylor, R B; Frobel, D; Mercer, D; Fogarty, C; MacAuley, P

Date Published: April 5, 2013

More Information

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(TAYLOR *et al.* 2013)

TABLE 5. Average shoreline displacement rates for different time periods, Sector B; *B1* and *B2* (Malikewe'j).

Air photo Period	Sector	Rate (m/yr)	Error (m/yr)	Greatest retreat (m/yr)
1939-1953	Sector B	-0,13	0,43	
	B1	0,01	0,43	-0,13 (Tr37)
	B2	-0,22	0,43	-0,44 (Tr39)
1953-1966	Sector B	-0,46	0,38	
	B1	-0,65	0,38	-0,79 (Tr29)
	B2	-0,34	0,38	-0,57 (Tr45)
1966-1969	Sector B	-0,42	1,59	
	B1	-0,70	1,59	-0,84 (Tr29)
	B2	-0,24	1,59	-0,96 (Tr49)
1969-1975	Sector B	-0,32	0,64	
	B1	-0,06	0,64	-0,35 (Tr37)
	B2	-0,48	0,64	-0,81 (Tr48)
1975-1984	Sector B	-0,47	0,39	
	B1	-0,24	0,39	-0,32 (Tr36)
	B2	-0,66	0,39	-1,51 (Tr46)
1984-1993	Sector B	-0,22	0,47	
	B1	-0,13	0,47	-0,17 (Tr31)
	B2	-0,30	0,47	-1,14 (Tr47)
1993-2008	Sector B	-0,29	0,20	
	B1	-0,26	0,20	-0,33 (Tr29)
	B2	-0,32	0,20	-0,57 (Tr48)
2008-2014	Sector B	-1,06	0,24	
	B1	-0,77	0,24	-0,97 (Tr34)
	B2	-1,47	0,24	-1,89 (Tr49)
1939-2014 (historical)	Sector B	**-0,33**	0,06	
	B1	**-0,30**	0,06	-0,32 (Tr34)
	B2	**-0,36**	0,06	-0,52 (Tr49)

Air photo Period	Sector	Rate (m/yr)	Error (m/yr)	Greatest retreat (m/yr)	
1939-1975	Sector B	-0,31	0,15		36 years
	B1	-0,30	0,15	-0,33 (Tr34)	
	B2	-0,31	0,15	-0,43 (Tr44)	
1975-2014	Sector B	-0,38	0,06		39 years
	B1	-0,31	0,06	-0,35 (Tr28)	
	B2	-0,49	0,06	-0,71 (Tr49)	

Greyed values are non-conclusive: within the margin of error.

Following the site visit in June 2014 and discussions with community members about the Malikewe'j graveyard site, where the history of shoreline protection measures at the site was outlined, *GLC* decided to sub-divide Sector (B) was in two parts (see Figure 19 above) in order to better understand the site's evolution:

- *B1* (Cemetary Road – southern part) = 235 m long (10 transects)
- *B2* (Presqu'isle – northern part) = 325 m long (16 transects)

When considered as distinct coastal segments, it is possible to see that sub-sectors *B1* and *B2* show a similar erosion trend, but the rate of erosion is of different magnitude. As shown in Table 5, the average historical (1939-2014) shoreline displacement rate in sub-sector *B1* is -0.30 ±0.06 m/yr, while it is higher in *B2* at -0.36 ±0.06 m/yr. This discrepancy is not unusual along adjacent coastal segments, where factors such as foreshore morphology, lithology at the coast or shoreline orientation can differ and explain such variability. However, based on the information available at hand, sub-sectors *B1* and *B2* are comparable in terms of lithology at the coast (the bluffs consist of unconsolidated glacial outwash – ADI Limited, 2010), shoreline orientation and exposure to energetic waves (SSE-NNW) and foreshore morphology (similar topography of the lake bed near the coast). The coast's average height is ~2 m for Sector B, however the elevation at the north end of sub-sector *B2* is very low: <1.2 m above the common high tide (FINCK, 2011) – this factor might account for some of the higher historical erosion rates of sub-sector *B2*.

In order to understand the difference between the historical erosion rates of sub-sectors *B1* and *B2*, the 75-year period (1939-2014) was divided in two intermediate periods (Table 5). During the first 36 years (1939-1975), the average erosion rates for *B1* and *B2* were similar: -0.30 ±0.06 m/yr (*B1*) and -0.31 ±0.06 m/yr (*B2*). However, during the last 39 years (1975-2014), the average erosion rate for sub-sector *B1* remained relatively the same as the previous period (-0.31 ±0.06 m/yr), while the rate for sub-sector *B2* increased significantly (-0.49 ±0.06 m/yr – **1.5X**[5] **more than the first 36 years**). By assessing the intermediate period we can see that the higher historical erosion rate observed in sub-sector *B2* has in fact been occurring over the last few decades (1975-2014), and not over the entire historical period. This dismisses the height of the coast as the sole factor explaining the higher erosion rates in *B2* than in *B1*.

By assessing short-term periods (~10 years), sub-sector *B2* still registers higher average erosion rates compared to sub-sector *B1*, since the 1970's. For example, the most recent time period measured (the 2008-2014 period) corresponds to the highest erosion rates of any short-term period for sub-sectors *B1* and *B2* (Tables 3 and 4). However, sub-sector *B2*'s average erosion rate is ~2X greater than *B1*'s (-1.47 VS -0.77 m/yr). The same situation occurs when periods of low erosion are assessed (calmer conditions). The 1993-2008 period (period just prior to 2008-2014) corresponds to the lowest erosion rates of any short-term period for sub-sectors *B1* and *B2* (Tables 5 and 6). However, again sub-sector *B2*'s average erosion rate is higher (~1.2X more) than the one of sub-sector *B1*'s (-0.32 VS -0.26 m/yr).

The analysis of intermediate as well as short-term periods shows that since the early 1970's, the average erosion rate of sub-sector *B2* is systematically higher than *B1*'s (Table 5). A look at the different mapped shorelines will confirm this,

[5] 1.5X is synonymous to 1.5 times.

but will also provide a visual explanation of what has been happening in *B2* since the 1970's.

TABLE 6. Average erosion rates for the historical period (1939-2014) and for the period of highest erosion rates (2008-2014), including the second highest and lowest erosion rates for Sector B; *B1* and *B2* (Malikewe'j).

Sector	1939-2014 75 years (m/yr)	2008-2014 6 years (m/yr)	Other intermediate periods	
			2nd highest rate	Lowest rate
B	-0.33	**-1.06**	-0.47 (1975-1984)	-0.29 (1993-2008)
B1	-0.30	**-0.77**	-0.65 (1953-1966)	-0.26 (1993-2008)
B2	-0.36	**-1.47**	-0.66 (1975-1984)	-0.32 (1993-2008)

Figure 24 shows all the shorelines mapped from the available aerial photographs and orthophotos, with the shorelines of 1939 to 1975 "bolded" (thicker lines) to highlight their overall regularity and convex shape moving from sub-sector *B1* to *B2*, along the Malikewe'j graveyard site. This regular shoreline aspect continues on from 1975 to 2014 in sub-sector *B1* as well as the southern half of sub-sector *B2*, but northward, past the shrine to Ste-Anne, the shoreline pattern changes: its previous convex shape has progressively evolved into a concave or "spoon" shape over the last ~35-40 years.

This change in the coast's overall shape coincides with the placement of rocks at the base of the bluff sometime in the 1970's in order to stabilize the shoreline in front of the graveyard site, where human remains and archeological artifacts were found exposed in the bluff face and on the beach (ADI Limited, 2010; FINCK, 2011; UINR representatives – personal communications, 8 June 2014). None of the aerial photographs used in this study document the construction of this protection measure: the 1969 and 1975 air photos are not adequately contrasted (high reflectance) to clearly identify the presence of a protection structure at the foot of the bluff (Figure 25). However, from 1984 onwards, a ~40 m-long linear feature is recognizable at the base of the bluff along the beach, and on the 1993 and 2008 images, this feature clearly appears to be a rock/rubble mound protection structure. According to reports and testimony by UINR representatives concerning the site's recent history, the only other documented protection measure undertaken at the site was the placement of a geotextile membrane or filter fabric over the eroding bluff face in 2008 (ADI Limited, 2010; FINCK, 2011). Therefore, the rocks at the base of the bluff observed on the 1984, 1993 and 2008 images have been sitting there since their placement sometime in the

1970's - the on-going lateral erosion eventually made the structure "stand out", becoming clearly visible on the post-1993 images. This increased lateral erosion at the downdrift extremity of a coastal protection structure (seawall or riprap) is known as "flanking erosion" or the ***edge effect*** (KRAUS, 1988; O'CONNELL, 2010; BERNATCHEZ and FRASER, 2012; ROMINE and FLETCHER, 2013).

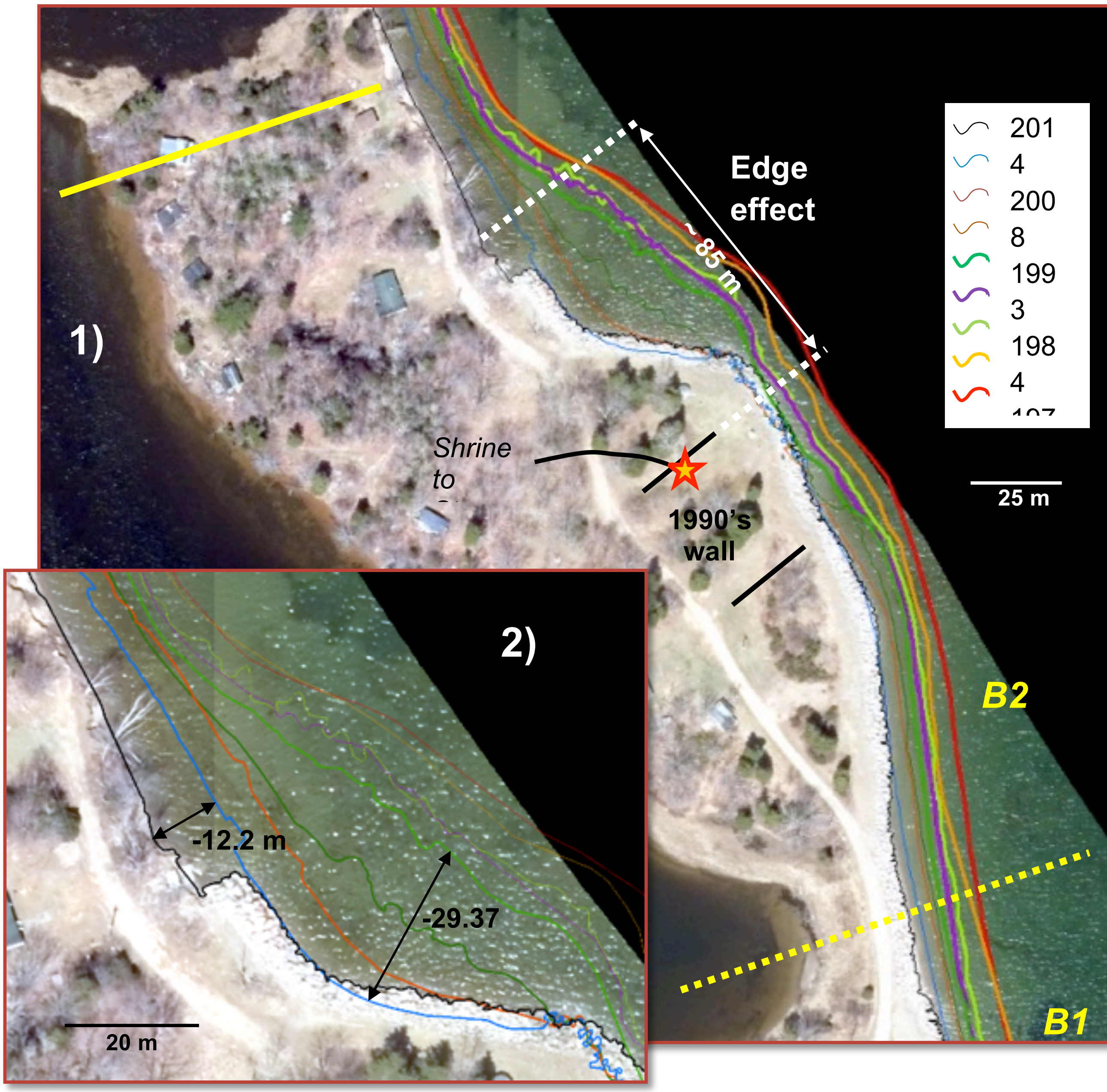

FIGURE 24. Multi-year shoreline mapping in sub-sector *B2*. In the main frame (1), the bolded shorelines of 1939 to 1975 show the overall convex shape or aspect of the coast along the Malikewe'j Presqu'isle. Since 1975, the shorelines in the area north of Ste-Anne's shrine changed toward a concave or "spoon shape" aspect (thinner lines of 1984 to 2014). In the sub-set (2), the maximum shoreline retreat since the 1970's is -29.37 m.

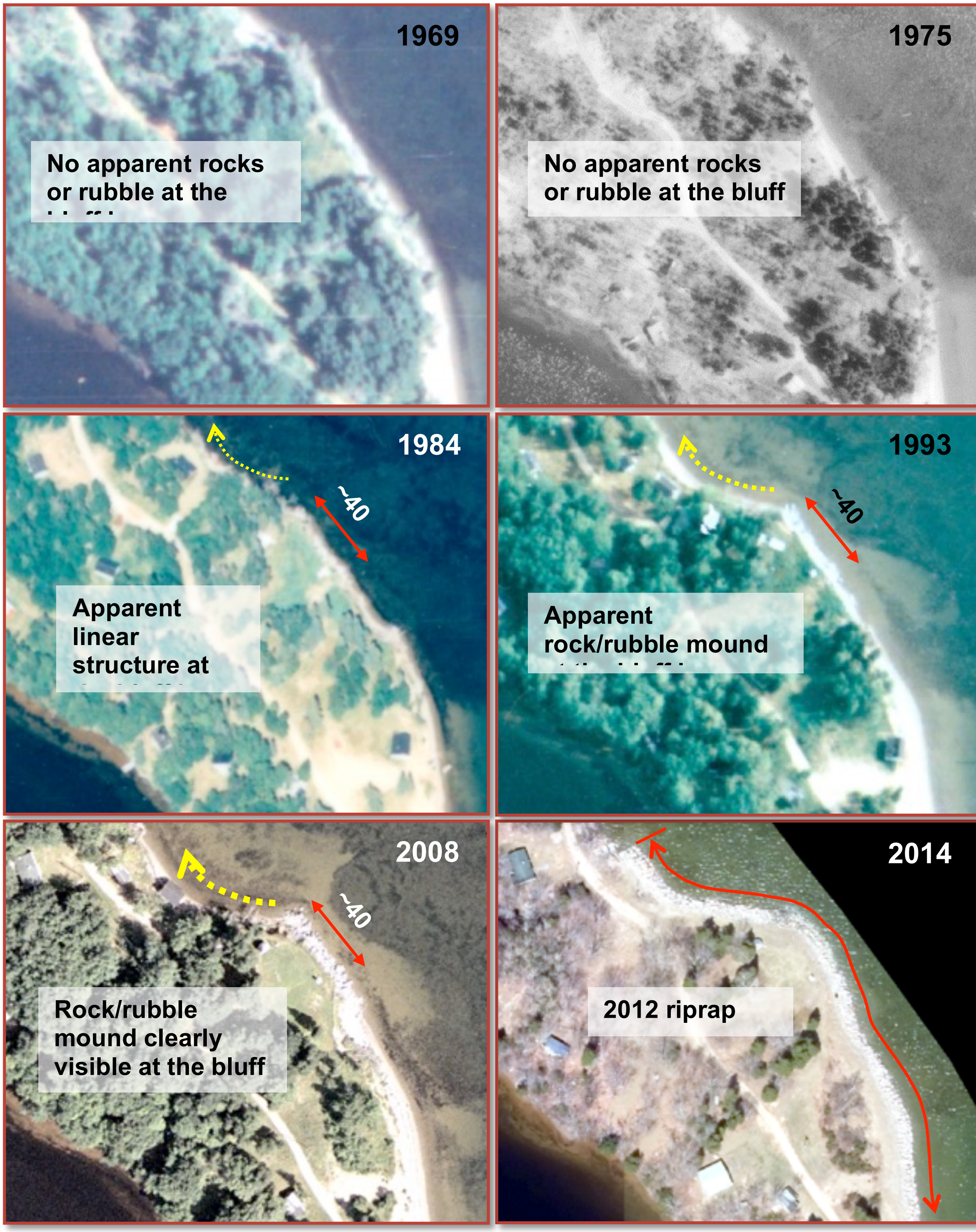

FIGURE 25. Set of available aerial coverage for the graveyard site since 1969 and centred on the rock mound of the1970's (*yellow dashed arrow represents the edge effect*).

The *edge effect* of the rocks placed at the foot of the bluff in the 1970's represents an approximate distance (range of influence) of 85 metres northward of the structure (Figure 24 "1"). Over this 85 m of coast, the maximum measured shoreline retreat at a single location was -29.37 m between 1975 and 2008 (a rate of **-0.89 m/yr**, ~3X greater than the "pre-wall" average for *B2*, i.e. the 1939-1975 period) (Figure 24 "2"). For the current riprap wall, the total distance of the *edge effect* is unknown because the shoreline is still adjusting to the presence of the structure built in 2012, and will probably be adjusting itself for a number of years. However, since 2008 (most recent aerial coverage before the construction of the riprap wall), the maximum measured shoreline retreat at a single location immediately north of the new wall is -12.2 m (a rate of **-2 m/yr**, ~6.7X greater than the "pre-wall" average for *B2*, i.e. the 1939-1975 period). This very high erosion rate is a clear illustration of the *edge effect* (wave refraction along the end of the wall and concentration in neighbouring shoreline), and is a common consequence of rigid coastal protection structures built in unconsolidated coasts (Figure 26).

FIGURE 26. Local example of the *edge effect* in an unconsolidated coast: increased lateral erosion at the downdrift end of a riprap protection structure, Québec North Shore (BERNATCHEZ and FRASER, 2012).

Undoubtedly, the presence of rocks at the base of the bluff has affected the evolution of the shoreline in the vicinity of the Malikewe'j graveyard site. As can be seen on Figure 27 (A and B), the shoreline retreat has ceased directly in front of the rock/rubble mound and riprap wall (rate of displacement ~0 m – a few centimetres, negligible). The 1970' rock/rubble mound and the 2012 riprap protection structure seem to have achieved their initial purpose to protect the graveyard site from further erosion (or shoreline retreat). However, both structures have also affected the nearby downdrift shores (to the north) by increasing lateral erosion via the *edge effect*. For the shorelines represented on both images of Figure 27 (A and B), the average erosion rates downdrift of the walls are approximately **2X greater** than the rates observed updrift of the walls, confirming the contribution of these structures to the increased average erosion rates of sub-sector *B2* over the last ~40 years. Finally, another effect of these two protection structures concerns the erosion of the beach fronting the structures, effect observed rather than measured. A beach shoreline (*SLBEACH* – see coastal mapping section 3.1 above) was mapped for each aerial photograph series used in this study up until the year 1984, where for the first time since 1939 no beach was detected in front of the Malikewe'j graveyard site (see Figure 25 and 28). This can be observed today, just 2 years after the construction of the current riprap wall: along the entire length of the protection structure there is no beach (water laps the base of the wall at high and low tides).

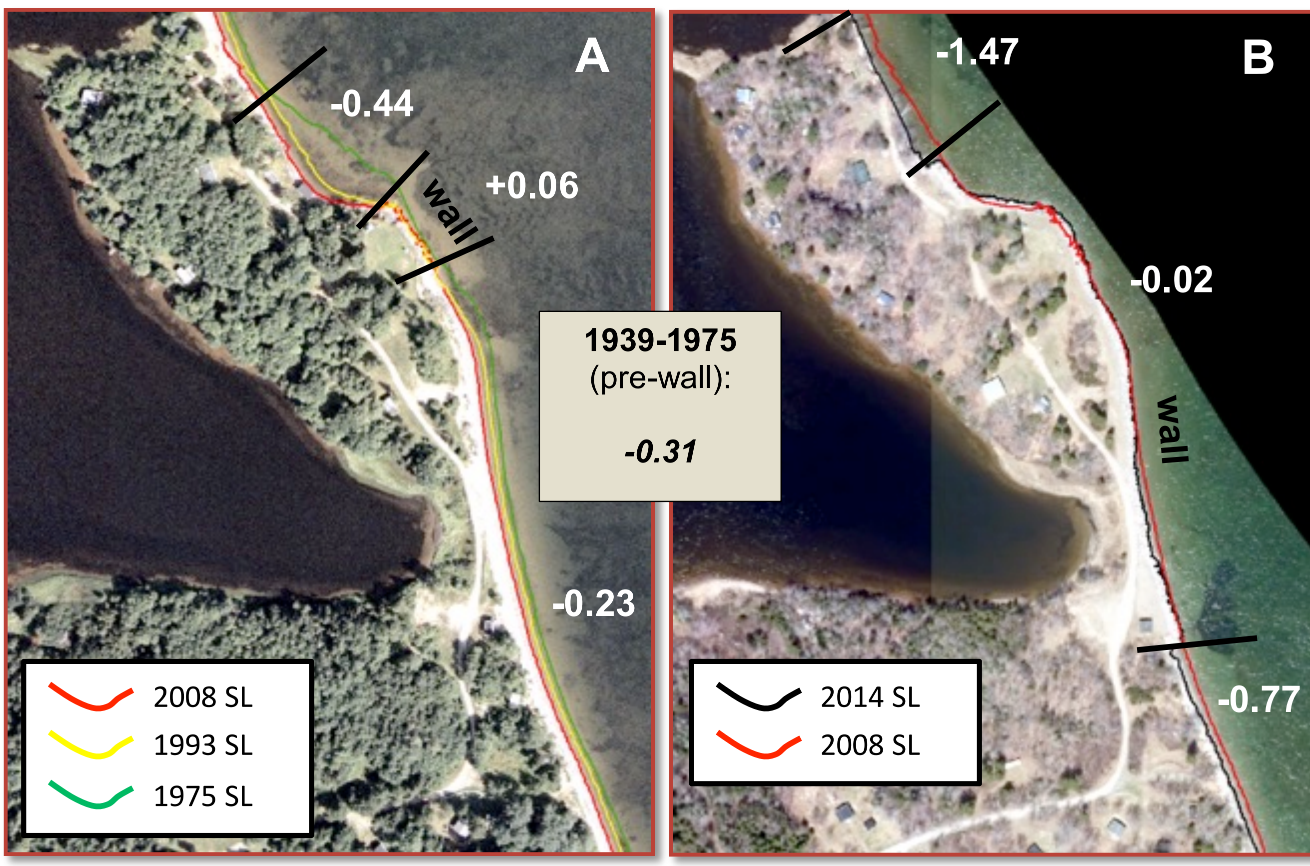

FIGURE 27. A) Effect of the 1970's rock/rubble mound on the erosion rates downdrift (north) of the structure (1993-2008 period); and B) Effect of the 2012 riprap wall on the erosion rates downdrift (north) of the structure (2008-2012 period). The 1939-1975 (pre-wall) average erosion rate for sub-sector *B2* is indicated for reference. *All rates are in m/yr*.

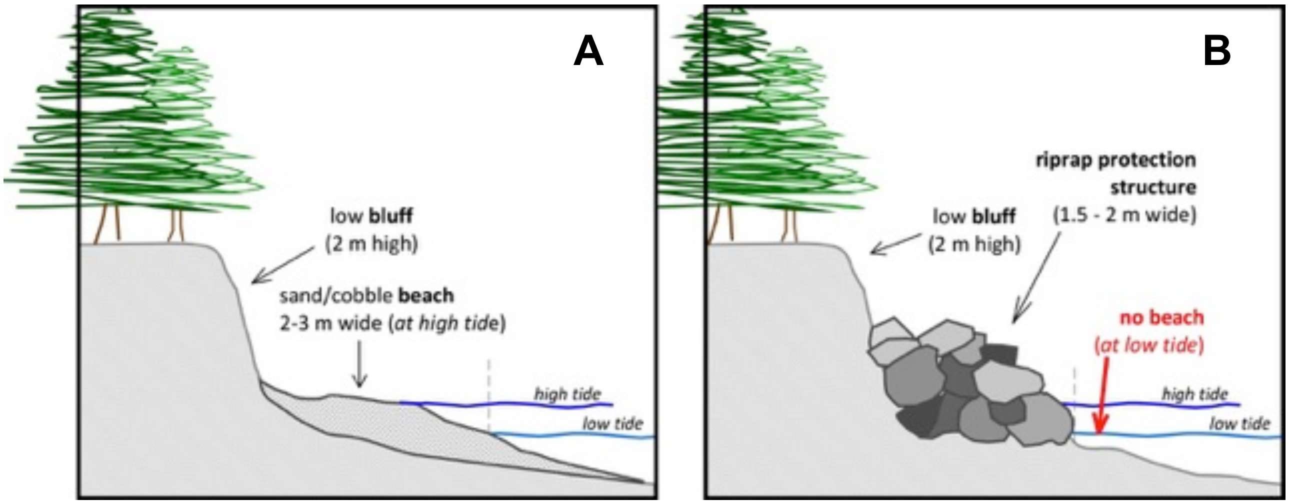

FIGURE 28. A) Typical beach width along the low bluffs near the Malikewe'j graveyard site prior to the placement of rock/rubble and/or riprap; and B) Typical effect of hard protection structure on fronting beaches: eventually, following erosion and scour at the base of the structure, the beach disappears even at low tide.

3.4.2.3 Results for the Potlotek study site

The historical (1939-2014) evolution of the shoreline at Potlotek was assessed along a ~1.6 km-long study site that is centered on the ceremonial grounds, in the southern part of Chapel Island. It was sub-divided into 4 sectors based on geomorphology, as interpreted from aerial photographs and a site visit in June 2014 (Figure 29):

- **Sector A** – St. Peters Inlet Shore: low bluffs with boulders
- **Sector B** – Southern and Eastern Sandy Shores: mostly sandy coast
- **Sector C** – Lagoon/Wetland Shore: coastal marshes
- **Sector D** – Chapel Island Cove Shore: low bluffs

Along each sector of the study site, erosion is the dominant historical (1939-2014) trend (Figure 30 and Table 7) (see also the *Excel* file in APPENDIX E for the measured distance and the calculated rate along each transect). Along the sheltered shores of Sector A, the average shoreline displacement rate in these low bluffs is considered non-conclusive (-0.06 ±0.07 m/yr); however the shoreline over the first 150 metres of this Sector (transects 2 to 7) did erode an average of -7 m since 1939, a conclusive rate of -0.09 ±0.07 m/yr. Sector B's shoreline eroded an average of -16.94 m over the last 75 years, the highest average shoreline displacement rate of the Potlotek study site: **-0.22 ±0.07 m/yr**. In fact, the more exposed eastern shores of Sector B (transects 38 to 53) are responsible for the higher portion of this erosion: -0.28 ±0.07 m/yr, while the southern shores eroded on average -0.16 ±0.07 m/yr. It comes as no surprise that the highest erosion rate of the study site was observed in Sector B (along transect 42) on the eastern shore of Chapel Island: **-0.33 ±0.07 m/yr**. The higher erosion of the sandy eastern shores might contribute some sediments to the southern shores of Sector B, slightly off-setting the erosion rates (southerly longshore drift?).

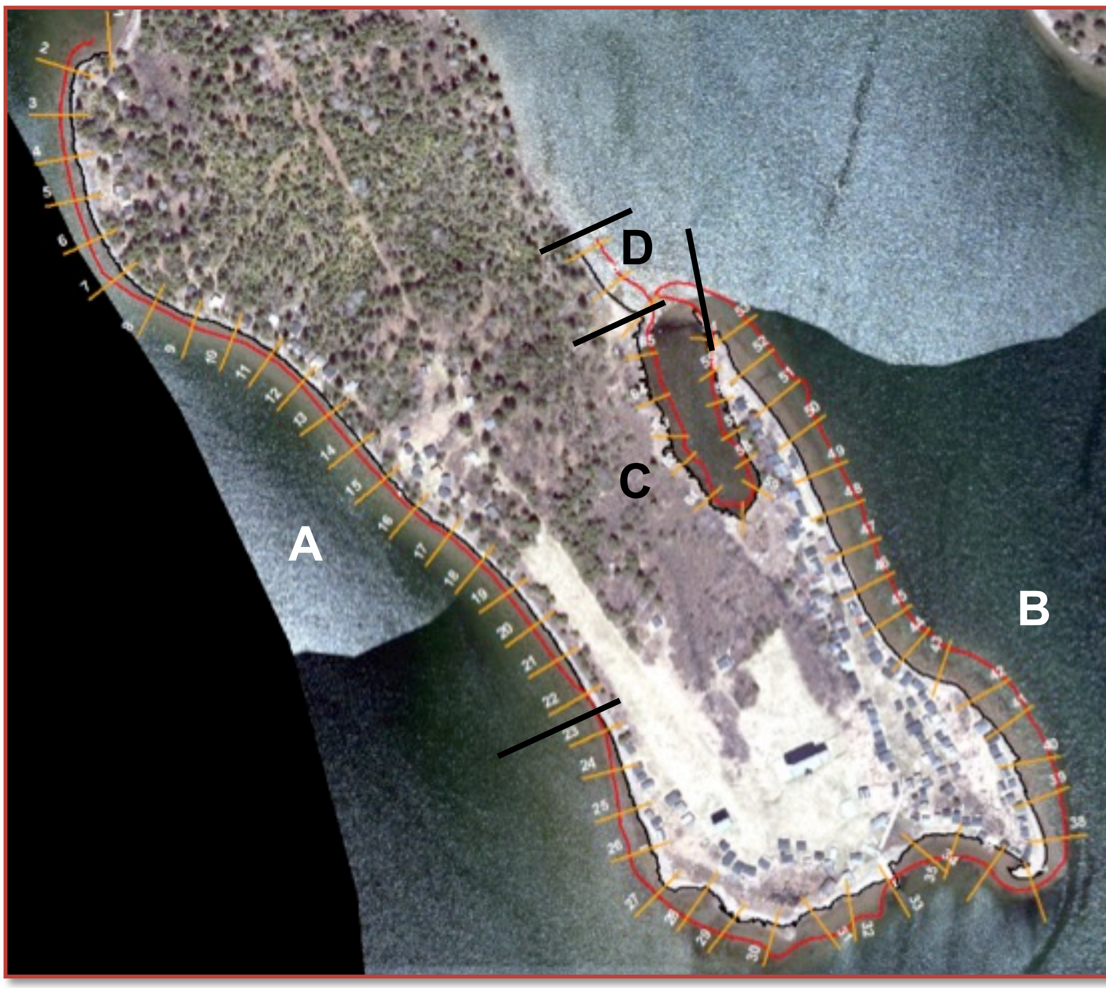

FIGURE 29. The Potlotek study site is approximately 1.6 km long, surrounding the southern tip of Chapel Island. ***The yellow lines in the figure correspond to the 68 transects (25 m interval) used to assess the historical erosion at the study site*.**

The coastal marshes along the very sheltered shores of Sector C eroded an average of -5.02 m during the 1939-2014 period, a distance slightly above the margin of error (±4.96 m), representing a conclusive rate of -0.07 ±0.07 m/yr. Finally, for the low bluffs of Sector D, the average historical shoreline displacement rate is -0.15 ±0.07 m/yr – please note that this figure is based on the measurement along 3 transects only.

TABLE 7. Average historical (1939-2014) shoreline displacement rates by sector, Potlotek erosion assessment study site.

Sector	Length (m)	# Transects	Average (m)	Error (m)	Rate (m/yr)	Error (m/yr)
Sector A	565	23	-4.77	±4.96	**-0.06**	±0.07
Sector B	740	30	-16.74	±4.96	**-0.22**	±0.07
Sector C	275	12	-5.02	±4.96	**-0.07**	±0.07
Sector D	50	3	-11.38	±4.96	**-0.15**	±0.07
	1 630	68				

Despite being in a more sheltered environment than the Malikewe'j study site that is exposed to fetches from the east and north-east, shoreline erosion and retreat is the dominant evolutionary trend in Potlotek. The coast that is experiencing the highest erosion rates (Sector B) is also the coast where most of the summer cottages and camps are located. Considering the overall low elevation of the southern part of the study site (most of Sector B and C), flooding issues might be a greater concern than erosion, on the short term. None-the-less, these two coastal hazards (flooding and erosion) should be considered jointly in future management decisions.

3.4.3 Scenarios for the Year 2100 Projected Shorelines

In order to plan for the sustainable management of the coastal zone of the Malikewe'j and Potlotek study sites that takes into consideration the erosion risk, *Géo Littoral Consultants* developed scenarios of the projected shoreline position for the year 2100.

The projected shoreline position scenarios are based on the historical displacement rates calculated for the period 1939-2014. These rates are considered conservative because they correspond to a period where sea-level rise was less important that what is predicted for the next 86 years (2014-2100) (DAIGLE, 2015). This choice was nevertheless made because the scenarios are based on an observed evolution; another alternative would have been to model the shoreline evolution based on different factors relating to the local topography of the coastal zone, the geology, the longshore drift, hydrodynamic conditions at the coast, etc. This second option requires many data sources and assumptions as well as mathematical relationships that require local validation; this is beyond *GLC*'s current capabilities. However, we believe that the conservative scenarios developed here will enable the communities to appraise the erosion risk to the year 21.

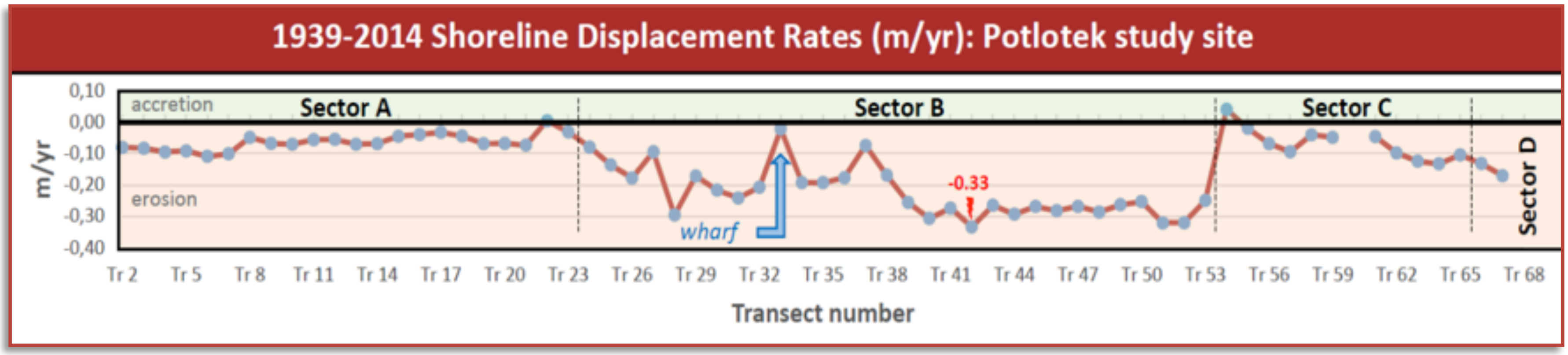

FIGURE 30. The historical displacement rates for Potlotek study site plotted along each transect (thick red line). The horizontal axis corresponds to the individual transects (Tr 1 to the left of the figure is the western part of the study site, while Tr 68 to the right corresponds to the eastern part of the study site). The vertical axis corresponds to the displacement rate in m/yr: rates above the 0.0 m line indicate accretion or progradation of the shoreline, rates below the 0.0 m line indicate erosion or retreat of the shoreline. The two interruption in the plotted rates in Sector C is owed to the presence of a tidal creek. The highest erosion rate occurred in Sector B along transect 42 (-0.33 ±0.07 m/yr) and the highest accretion rate occurred in Sector C along transect 54 (however it is below the margin of error: non-conclusive value). *Figure is not at scale*.

3.4.3.1 2100 shoreline projection methodology

To establish the scenarios, the 2014 shoreline was divided into segments of homogenous (similar) evolution based on the positions of the 1939 and 2014 shorelines as well as the historical displacement erosion rates (Figure 31). For the Malikewe'j study site, the coast was divided into 15 segments, and for the Potlotek study site, the coast was divided into 5 segments.

In order to avoid the irregularities and minor indentations of the 2014 shoreline, a new vector was generated and "smoothed". It is this shoreline that was projected landward (in the case of erosion) and lakeward (in the case of progradation or accretion), based on the average historical displacement rate of the transects contained in each segment. These segment rates were then multiplied by 86 (2014-2100 = 86 years) to obtain the total distance of projection.

Adjacent projected segments of differing distance values were joined together by arbitrary lines. It is important to remember that the scenarios (segments and joining lines) should not be interpreted as a definite position or even as a prediction of the future shoreline position.

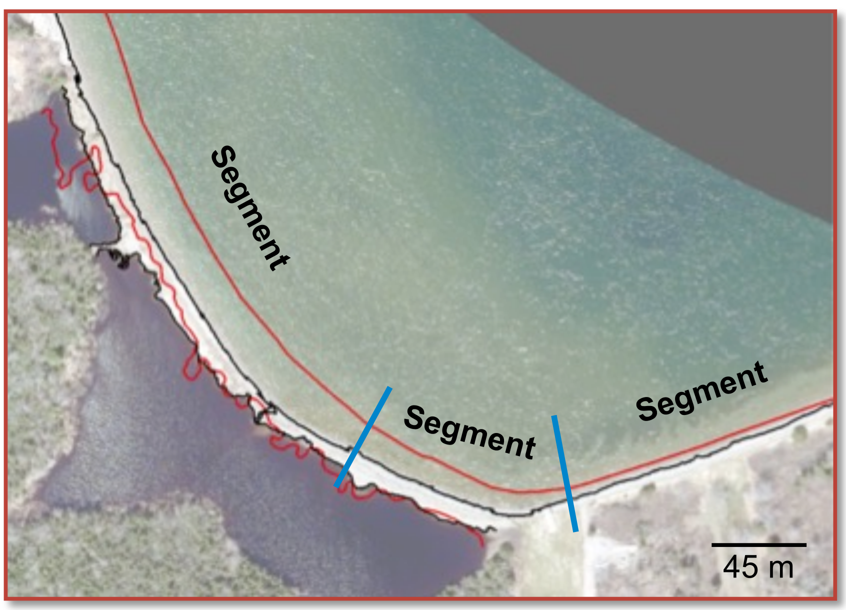

FIGURE 31. Example of the shoreline segmentation in Sector A, Malikewe'j study site.

3.4.3.2 Caveat and Disclaimer

These scenarios should be understood as being a rough approximation of the shoreline displacement to the year 2100, ***if its evolution continued at the same rate as the one observed before 2014.*** The year 2100 projected shoreline corresponds more so to a "zone" or a "strip", than to a line or a boundary. Nevertheless, the scenarios can help identify places near the coast where current or future developments could find themselves in an exposed situation. We must also keep in mind that the increase in sea level and the decrease in the length of the ice cover season predicted for the coming century should translate into an acceleration of coastal processes, such as erosion. The year 2100 projected shoreline position could be exceeded and it is therefore good practice to allow some leeway when buildings or infrastructure are or would be too close.

3.4.3.3 2100 shoreline projection results: Malikewe'j and Potlotek study sites

The scenarios for the year 2100 projected shoreline positions are complete for the Malikewe'j and Potlotek study sites (see APPENDIX F for large scale maps showing the year 2100 projected shoreline positions and APPENDIX G for the year 2100 vector shapefiles).

For the Malagawach study site, two scenarios were developed for the year 2100 projected shoreline position; the main difference in the two scenarios is related to the presence or absence of the riprap protection structure along the graveyard site (Figure 32). *Scenario A* was developed to show where the future shoreline could possibly be located if the riprap protection structure was not maintained or was abandoned, and the shoreline evolution resumed its historical erosion trend. *Scenario B* was developed to show how the shoreline in the vicinity of the graveyard site could be positioned in the presence of the riprap protection structure (this scenario supposes that the protection structure will be maintained over the next 86 years). Please note that in *scenario B*, the future shoreline position in the area north of the protection structure (downdrift of the riprap wall) is probably under-estimated due to the *edge effect* – a more landward position of the shoreline should be envisaged here (the values presented in Table 8 are for the *scenario B*).

For the Potlotek study site, the projected shoreline position scenario for the year 2100 shows that the western shores (Sector A) as well as the shores along the coastal marshes/lagoon area (Sector C) would retreat ~5.5 m over the next 86 years (Figure 33 and Table 8). The southern shores of Sector B (segment 2) are projected to retreat 14.6 m while the eastern shores are projected to retreat 23.7 m over the next 86 years.

FIGURE 32. Year 2100 projected shoreline position scenarios, Malikewe'j study site. *Scenario A* supposes that the riprap protection structure at the graveyard site will not be maintained over the next 86 years and that the shoreline evolution will resume (retreat). *Scenario B* is exactly the same as *scenario A* except along the graveyard site, where it supposes that the riprap protection structure will be maintained over the next 86 years. The yellow arrow indicates that the projected shoreline position is probably under-estimated downdrift of the protection structure due to the *edge effect.*

TABLE 8. Retreat distance applied to project the shoreline position for the yr 2100, Potlotek and Malikewe'j study sites.

	Segment (and approximate corresponding Sector)		Historical Rate (m/yr)	Retreat Distance (and Margin of Error), in metres Yr2100 (86 years)
Malikewe'j (scenario B)	Seg 4	(B1)	-0.29	**-25.10** (±5.08)
	Seg 5	*riprap wall*	*-0.31*	***0 (fixed)***
	Seg 6	(B2)	-0.36	**-31.39** (±5.08)
Potlotek	Seg 1	(A)	-0.06	**-5.52** (±5.69)
	Seg 2	(B)	-0.17	**-14.57** (±5.69)
	Seg 3	(B)	-0.28	**-23.73** (±5.69)
	Seg 4	(C)	-0.07	**-5.76** (±5.69)
	Seg 5	(D)	-0.15	**-13.04** (±5.69)

FIGURE 33. Year 2100 projected shoreline position scenario, Potlotek study site (see Figure 19 for Sector location).

3.5 Objective 5: Provide knowledge and tools for the integration of climate change adaptation into community plans

3.5.3 Community Engagement

A presentation on the modeling imagery of the coastline prepared for the coastal communities of Potlotek, including Chapel Island Mission, Wagmatcook, We'koqma'q, Eskasoni and Malakowej'k was presented to the UINR Board of Directors on February 25th in Wagmatcook. The UINR board is comprised of the five Unama'ki Chiefs. Similar presentations were also given to the Chief and Council of Potlotek and Membertou on February 24th and March 10th respectively. Due to time constraints and scheduling conflicts we were not able to meet with the Chief and Council of Eskasoni, Wagmatcook and We'koqma'q during this phase of the project.

Datasets containing Lidar and DEM data for each of the 5 Mi'kmaw communities within Unama'ki were incorporated within UINR's existing GIS web management system and made accessible on a community level/login basis. A training session on how to access and use the GIS tool was delivered to the community land managers and Aboriginal Fishery Strategy (AFS) guardians. These individuals will be given a secure access to the UINR GIS web management system specific to their community. They will also have access to a GIS tool which will allow them to view sea level changes within their community based upon a pre-set range of sea level elevations as well as other basic GIS functionality tools.

Adaptation strategies will be developed in year 2 (15-16) for the communal community of Malikewe'j and Chapel Island mission in conjunction with the seasonal residents, Elders and Grand Council through meetings and workshops. The resulting recommendations will be presented to UINR's Board of Directors and community Chief and Council members to inform their decision making processes. The recommendations for Malikewe'j will complement the existing Malikewe'j BMPs that were developed with the assistance of UINR.

4 Summary

The LiDAR-derived digital elevation model of the terrain was used to generate elevation contours specific to both the present-day sea levels (baseline 2010) and the future sea levels for time frames 2030, 2050 and 2100 for the Mi'kmaq communities of Potlotek, Eskasoni, Wagmatcook, We'koqma'q and Malikewe'j.

The relative sea-level rise projections for the Mi'kmaq communities were taken directly from recent up-to-date regional sea-level projection (James, et al., 2014). The projections for years 2030, 2050 and 2100 are respectively 0.14 m, 0.31 m and 0.86 m.above the Bras d'Or Lakes HHWLT baseline value for year 2010 of 0.4 m above CGVD28.

Through a combination of TEK information and the availability of a detailed water level database from Fisheries and Oceans Canada (Drozdowski et al., 2014) storm surge flooding statistics were developed for a nearly annual average storm surge of 0.5 m for Big Bras d'Or (0.4 m for Little Bras d'Or) and a maximum storm surge of an undetermined return-period of 0.8 m for Big Bras d'Or (0.8 m for Little Bras d'Or). The storm surge levels will be further adjusted pending the availability of a Coastal Hazard Assessment approach being proposed for Year 2 of this project.

Flooding scenarios have been developed for each of years 2010 (baseline), 2030, 2050 and 2100. The scenarios include the sum of; the baseline tide level (the Higher High Water at Larger Tides level), the respective Regional Sea Level Rise component at each year and the respective average and maximum storm-surge component. These scenarios were then presented as elevation lines on the LiDAR digital elevation model for each community.

An inspection of the flooding scenario maps reveals that Chapel Island and Malikewe'j will be the most impacted by rising sea levels. Specifically, the low lying areas of Chapel Island on the south side of the island in vicinity of many cabin locations will be experiencing storm-surge flooding several times per year by year 2030. At Malikewe'j the Big Harbour Island Road will experience overtopping from annual average storm surges by year 2030 and overtopping from HHWLT tides by year 2100.

TEK on climate change events was collected to complement the scientific research on storm surge modeling. Mi'kmaq Elders from the five Unama'ki communities shared their knowledge of storm surge frequency, duration and effects, seasonal changes and changes in natural patterns in nature. The information captured will be reviewed by the Elders for accuracy and will be included in the phase two final report.

A presentation on the modeling imagery of the coastline prepared for the communities of Potlotek, including Chapel Island Mission, Wagmatcook, We'koqma'q, Eskasoni and Malakowej'k was presented to the UINR Board of Directors and the Chief and Council of Potlotek and Membertou.

Datasets containing Lidar and DEM data for each of the 5 Mi'kmaw communities within Unama'ki were incorporated within UINR's existing GIS web management system and made accessible on a community level/login basis. A GIS tool which will allow for the viewing of sea level changes based upon a pre-set range of sea level elevations as well as other basic GIS functionality tools will also be accessible. A one day training session was provided to the communities on how to access and use the GIS tool.

Based on the 2014 orthophotos (acquired by UINR in May 2014), a coastal mapping was performed detailing the shores of each of the 5 Mi'kmaq communities of the Bras d'Or Lakes. The main coastal features mapped were beaches, dunes, coastal marshes, bluffs, peat bogs and human infrastructure. This large scale mapping exercise used the instantaneous shoreline as the proxy for the coastal feature description. A total of 217 km of shoreline was mapped along the 5 communities:

- 61.5 km Eskasoni dominant coastal feature: marshes
- 26 km Wagmatcook dominant coastal feature: marshes
- 29.5 km Waycobah dominant coastal feature: marshes
- 20.3 km Potlotek dominant coastal feature: bluffs
- 79.5 km Malikewe'j dominant coastal feature: marshes

Marshes are the most common coastal feature forming the shoreline (~111 km, 51%). Human infrastructure at the coast is of the same order of magnitude as what was inventoried elsewhere along the Bras d'Or Lakes in 2006 by the Geological Survey of Canada (3%): for the 5 communities, it totals 5.2 km or 2% of the shoreline, with riprap protection structures representing 52% of all infrastructure.

The erosion assessment of the Malikewe'j and Potlotek study sites was carried out using a GIS. The analysis was based on the use of historical aerial photographs to locate past shorelines: the landward or lakeward movement of these shorelines relative to one another was measured along the coasts of the two study sites. This assessment generated over 430 shoreline displacement rates of variable time periods, from 1939 to 2014. The historical (1939-2014) evolution of the shoreline at Malikewe'j is dominated by erosion in the southern portion of the site (-0.18 to -0.33 m/yr), while the northern portion is generally accreting (+0.54 m/yr), except for the place known as "Noel Point", which has completely eroded away since 1939. The rocks placed at the foot of the bluff at the graveyard site in the 1970's have halted the shoreline from receding, but they have also had the perverse effect of increasing the erosion of the coast downdrift, sometimes by as much as twice the rate observed updrift. This phenomenon known as the edge effect led to increased scour to the north of the rocks and to a net change in the shoreline's overall pattern or aspect. In Potlotek, the near totality of the area studied over the historical period showed an erosion trend. The shoreline along the eastern coast of Chapel Island is eroding at -0.28 m/yr, while the shoreline along the south is eroding at -0.16 m/yr.

Using the historical shoreline displacement data, scenarios were prepared projecting the shoreline position in yr 2100. For Potlotek, the projected shoreline position in yr 2100 is located landward of many of the current cabins and cottages in the southern tip of Chapel Island. For Malikewe'j, in the general area near the graveyard site, cottages and cabins as well as parts of the road leading to the shrine to Ste-Anne will become exposed to erosion risks.

5 Acknowledgements

The availability of Bras d'Or Lakes water level data supplied by the Coastal Ecosystem Sciences Division, Maritimes Region, of Fisheries and Oceans Canada (Adam Drozdowski) has been critical in determining the extent of storm surge flooding events affecting five Mi'kmaq Communities in the context of climate change adaptation planning.

Our community Elders who generously gave their time and knowledge to help us better understand the impact of Climate Change in Unama'ki.

We also wish to acknowledge the contribution of two coastal geomorphologist: Dr. Serge JOLICOEUR (Université de Moncton) for his input in the interpretation of the erosion results and for his comments and suggestions on a previous draft of the report, and Bob TAYLOR (formerly of the GSC) for his insight in the recent evolution of the Malikewe'j sand spit.

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APPENDIX A – 2014 Coastal Mapping: Description of Feature Codes Used

Feature Code*	Description
CLACCESS	Coastline - road access leading to the coast (usually the width of a vehicle)
CLBACKFILL (Q)	Coastline - infill material in contact with the lake (gentle slope or micro-cliff in backfill material)
CLBLUFF (Q)	Coastline - scarp or top of the bluff
CLBLUFFBASE (Q)	Coastline - base of the bluff slope
CLDELTA (Q)	Coastline - edge of the sediment deposit, mapped for channels currently evacuating freshwater
CLDUNE	Coastline - edge of dune vegetation on backbeach or top of the dune cliff (scarp)
CLGROYNE	Coastline - external limit (lake side) of a small structure, perpendicular to the shore
CLJETTY	Coastline - external limit (lake side) of a structure extending into the lake, maintain navigation channel
CLRIPRAP (Q)	Coastline - external limit (lake side) of a stone wall structure to protect the coast
CLROAD	Coastline - edge of a road that runs parallel to the coast
CLSLIP	Coastline - best approximation of the high water mark on a boat slip platform structure
CLTIRES	Coastline - external limit (lake side) of a tire wall structure to protect the coast
CLWALL	Coastline - external limit (lake side) of a wall structure (concrete or wood) to protect the coast
CLWHARF	Coastline - external limit (lake side) of the structure making up the wharf
SLBEACHBLUFF (Q)	Shoreline - lakeward limit of a beach (sediment type undefined) backed by a bluff
SLBEACHDUNE (Q)	Shoreline - lakeward limit of a beach (sediment type undefined) backed by a dune
SLBEACHMARSH	Shoreline - lakeward limit of a beach (sediment type undefined) backed by a marsh
SLBEAVERDAM	Shoreline - edge of beaver dam in small lagoon (one occurrence, in Malikewe'j)
SLBEDROCK	Shoreline - lakeward limit of bedrock outcrop at the base of a cliff (one occurrence, in Malikewe'j)
SLDEBRIS	Shoreline - lakeward limit of driftwood and fallen trees hiding completly the natural shoreline
SLFLOODDELTA	Shoreline - edge of a sand bank in a lagoon inlet
SLLEVEE	Shoreline - edge of a levee constructed in lagoon to access the main lake
SLMARSH (Q)	Shoreline - lakeward limit of a salt marsh (includes also all marsh features affected by the tides)
SLPEATBOG	Shoreline - lakeward limit of a peat bog
VEGLIMIT (Q)	Edge of the treeline where neither the coastline nor the shoreline can be identified
CLOSINGLINE	Manually mapped line to artificially close-off streams (where tides are no longer felt)

A Feature Code followed by the letter "Q" in parentheses indicates that this type of vector was mapped, but not with sufficient precision or accuracy. The letter "Q" has been added to Feature Codes when shadows cast by trees partially interrupted the identification of the coastal feature or when the picture quality rendered the interpretation difficult.

APPENDIX B – 2014 Coastal Mapping: Shapefiles produced

The shapefiles are copied to the accompanying DVD. For each coastal community map, 6 file extensions are generated: .dbf; .prj; .sbn; .sbx; .shp; .shx

Eskasoni_SL2014 Wagmatcook_SL2014

Malikewe'j_SL2014 Waycobah_SL2014

Potlotek_SL2014

APPENDIX C – 2014 Coastal Mapping: Georeferenced PDFs

The georeferenced PDFs are copied to the accompanying DVD.

Appendix C_2014Mapping_Eskasoni.pdf

Appendix C_2014Mapping_Malikewe'j.pdf

Appendix C_2014Mapping_Potlotek.pdf

Appendix C_2014Mapping_Wagmatcook.pdf

Appendix C_2014Mapping_Waycobah.pdf

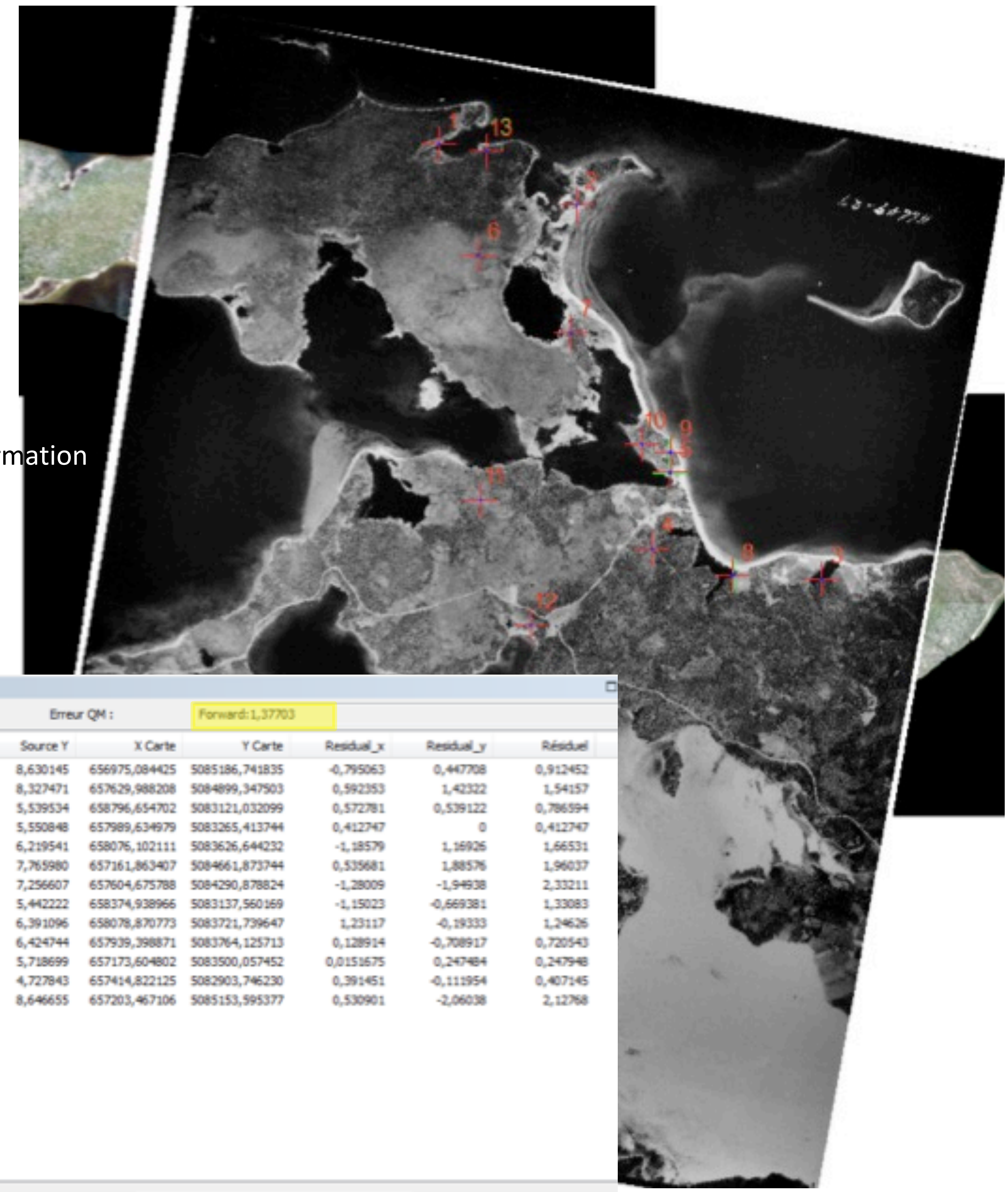
APPENDIX D – Erosion Assessment: GCP Location and RMS Error

Ground Control Point (GCP) location and Root Mean Square (RMS) error

Georeferencing process of historical aerial photographs

Malikewe'j study site (9 historical aerial photos)

1939 A6649-27



13 GCP used

Projective Transformation

RMS error: 1.38 m

Lier

Erreur QM : Forward:1,37703

Lier	Source X	Source Y	X Carte	Y Carte	Residual_x	Residual_y	Résiduel
1	2,384192	8,630145	656975,084425	5085186,741835	-0,795063	0,447708	0,912452
2	3,632279	8,327471	657629,988208	5084899,347503	0,592353	1,42322	1,54157
3	6,269688	5,539534	658796,654702	5083121,032099	0,572781	0,539122	0,786594
4	4,765261	5,550848	657989,634979	5083265,413744	0,412747	0	0,412747
5	4,815085	6,219541	658076,102111	5083626,644232	-1,18579	1,16926	1,66531
6	2,865824	7,765980	657161,863407	5084661,873744	0,535681	1,88576	1,96037
7	3,768434	7,256607	657604,675788	5084290,878824	-1,28009	-1,94938	2,33211
8	5,503505	5,442222	658374,938966	5083137,560169	-1,15023	-0,669381	1,33083
9	4,786531	6,391096	658078,870773	5083721,739647	1,23117	-0,19333	1,24626
10	4,524428	6,424744	657939,398871	5083764,125713	0,128914	-0,708917	0,720543
11	3,225575	5,718699	657173,604802	5083500,057452	0,0151675	0,247484	0,247948
12	3,835773	4,727843	657414,822125	5082903,746230	0,391451	-0,111954	0,407145
13	2,797002	8,646655	657203,467106	5085153,595377	0,530901	-2,06038	2,12768

☑ Ajustement aauto   Transformation : Transformation projective

☐ Degrés Minutes Secondes   Forward Residual Unit : Unknown

1953 A13715-89

8 GCP used

Projective Transformation

RMS error: 0.47 m

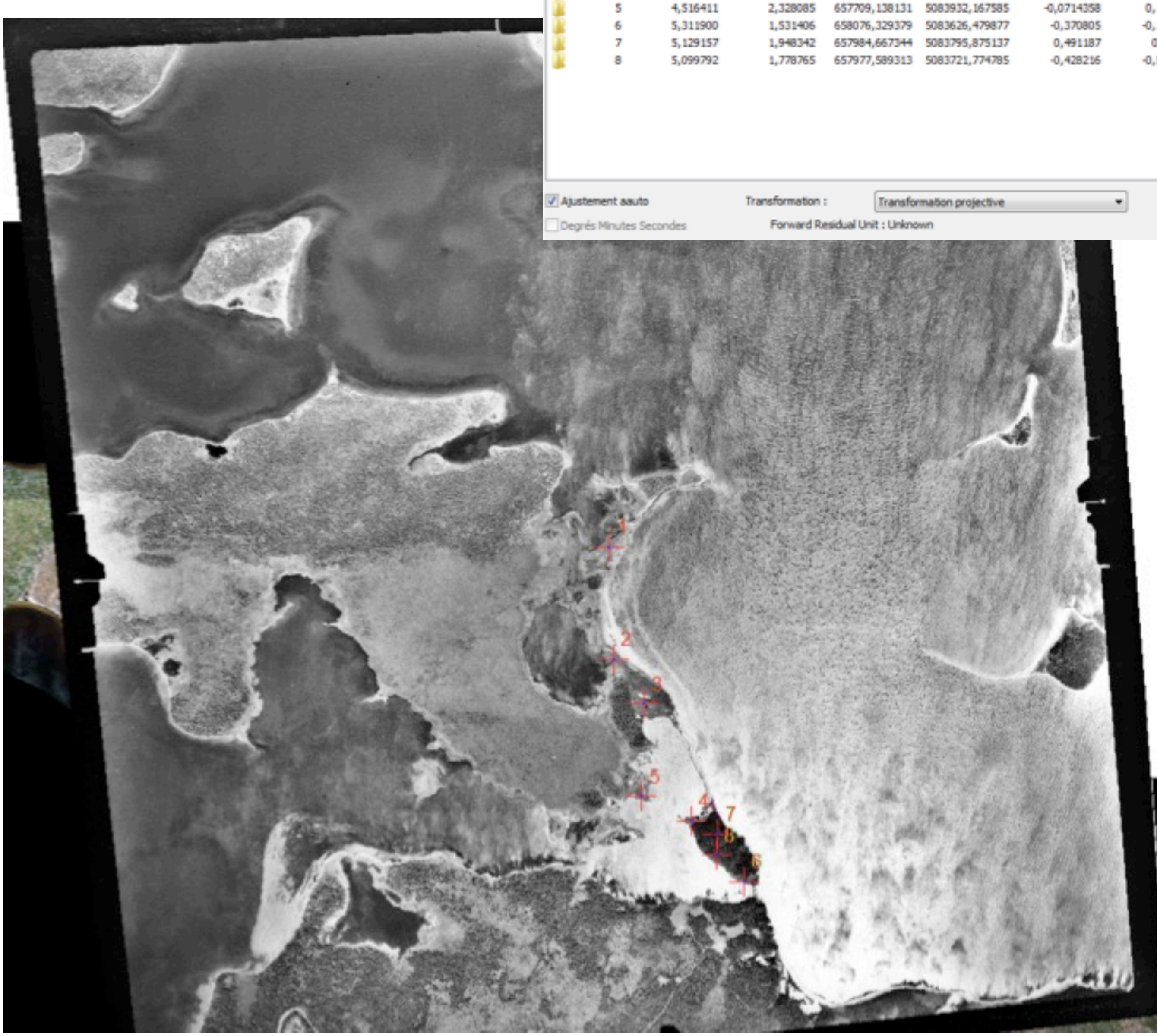
Lier

Erreur QM : Forward:0,467148

Lier	Source X	Source Y	X Carte	Y Carte	Residual_x	Residual_y	Résiduel
1	4,433527	4,430722	657593,033918	5084830,102607	-0,0213389	0	0,0213389
2	4,387018	3,500746	657608,617555	5084428,195663	-0,233127	-0,180488	0,294829
3	4,601688	3,105692	657716,280886	5084266,964409	0,129901	0	0,129901
4	4,911685	2,083580	657887,432854	5083843,846620	0,503834	0,0691725	0,508561
5	4,516411	2,328085	657709,138131	5083932,167585	-0,0714358	0,151039	0,16708
6	5,311900	1,531406	658076,329379	5083626,479877	-0,370805	-0,167644	0,406941
7	5,129157	1,948342	657984,667344	5083795,875137	0,491187	0,67136	0,831859
8	5,099792	1,778765	657977,589313	5083721,774785	-0,428216	-0,560405	0,705282

Ajustement aauto   Transformation : Transformation projective

Degrés Minutes Secondes   Forward Residual Unit : Unknown

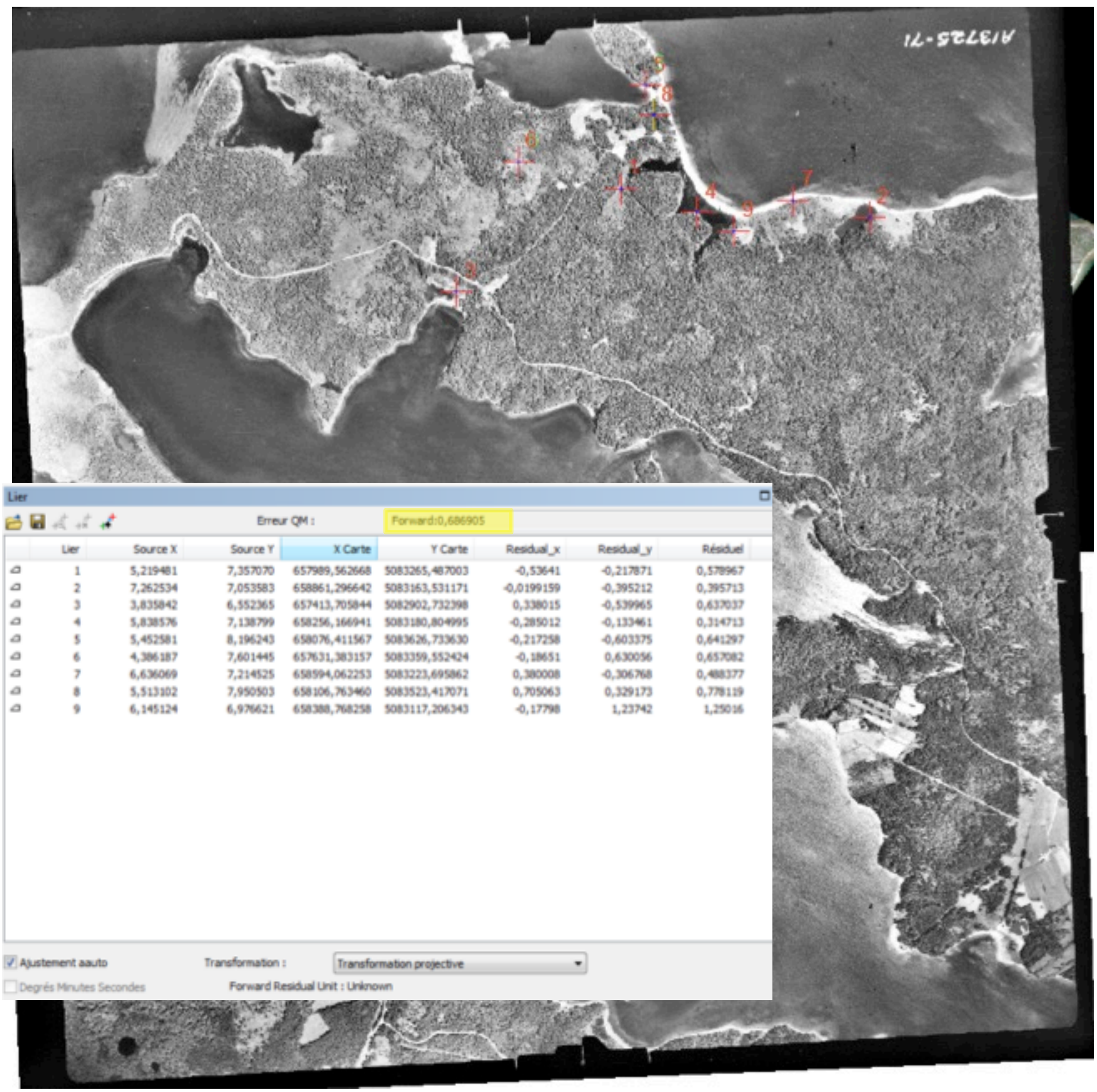


1953 A13725-71

9 GCP used

Projective Transformation

RMS error: 0.69 m



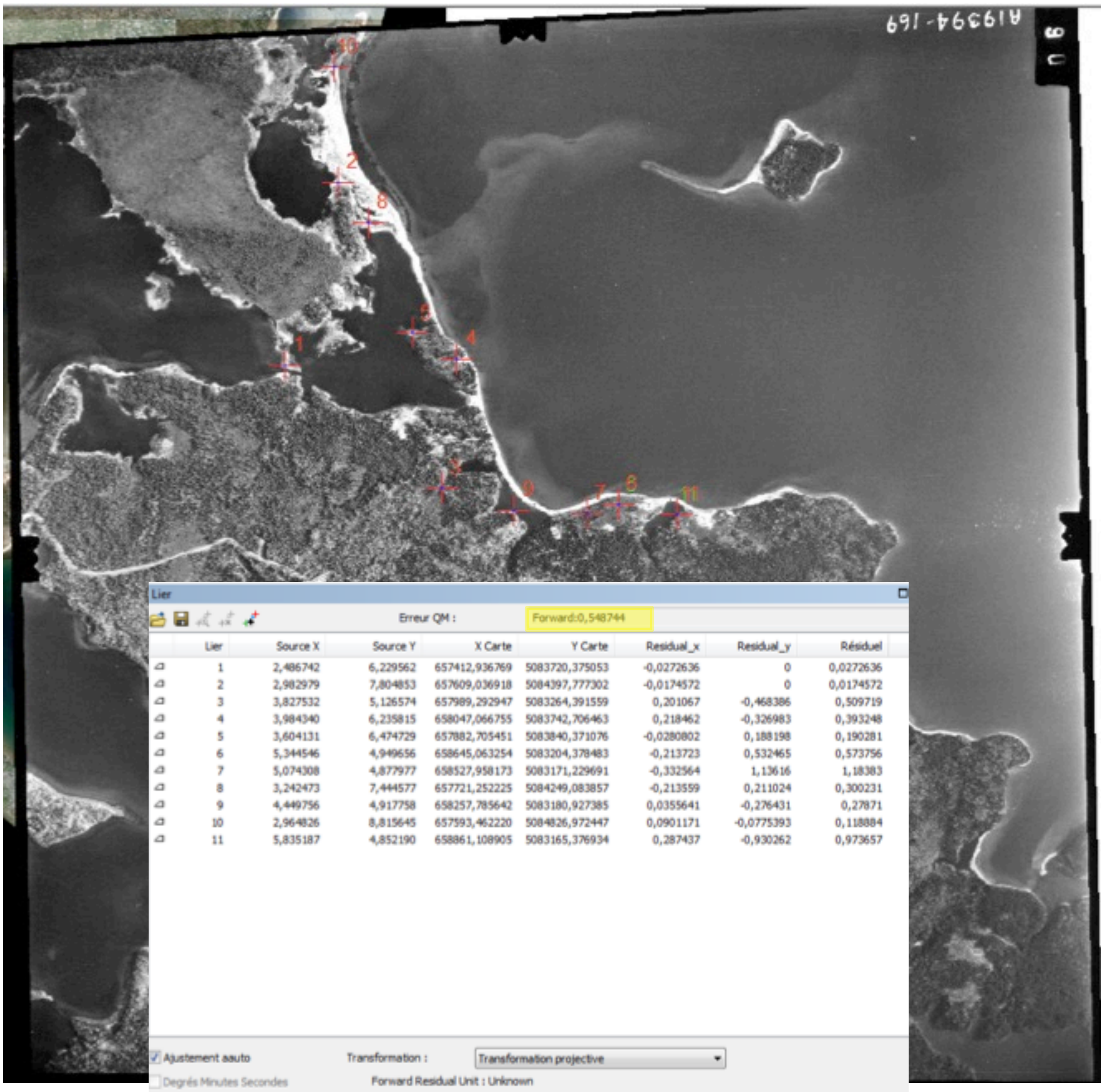
Lier	Source X	Source Y	X Carte	Y Carte	Residual_x	Residual_y	Résiduel
1	5,219481	7,357070	657989,562668	5083265,487003	-0,53641	-0,217871	0,578967
2	7,262534	7,053583	658861,296642	5083163,531171	-0,0199159	-0,395212	0,395713
3	3,835842	6,552365	657413,705844	5082902,732398	0,338015	-0,539965	0,637037
4	5,838576	7,138799	658256,166941	5083180,804995	-0,285012	-0,133461	0,314713
5	5,452581	8,196243	658076,411567	5083626,733630	-0,217258	-0,603375	0,641297
6	4,386187	7,601445	657631,383157	5083359,552424	-0,18651	0,630056	0,657082
7	6,636069	7,214525	658594,062253	5083223,695862	0,380008	-0,306768	0,488377
8	5,513102	7,950503	658106,763460	5083523,417071	0,705063	0,329173	0,778119
9	6,145124	6,976621	658388,768258	5083117,206343	-0,17798	1,23742	1,25016

1966 A19394-169

11 GCP used

Projective Transformation

RMS error: 0.55 m



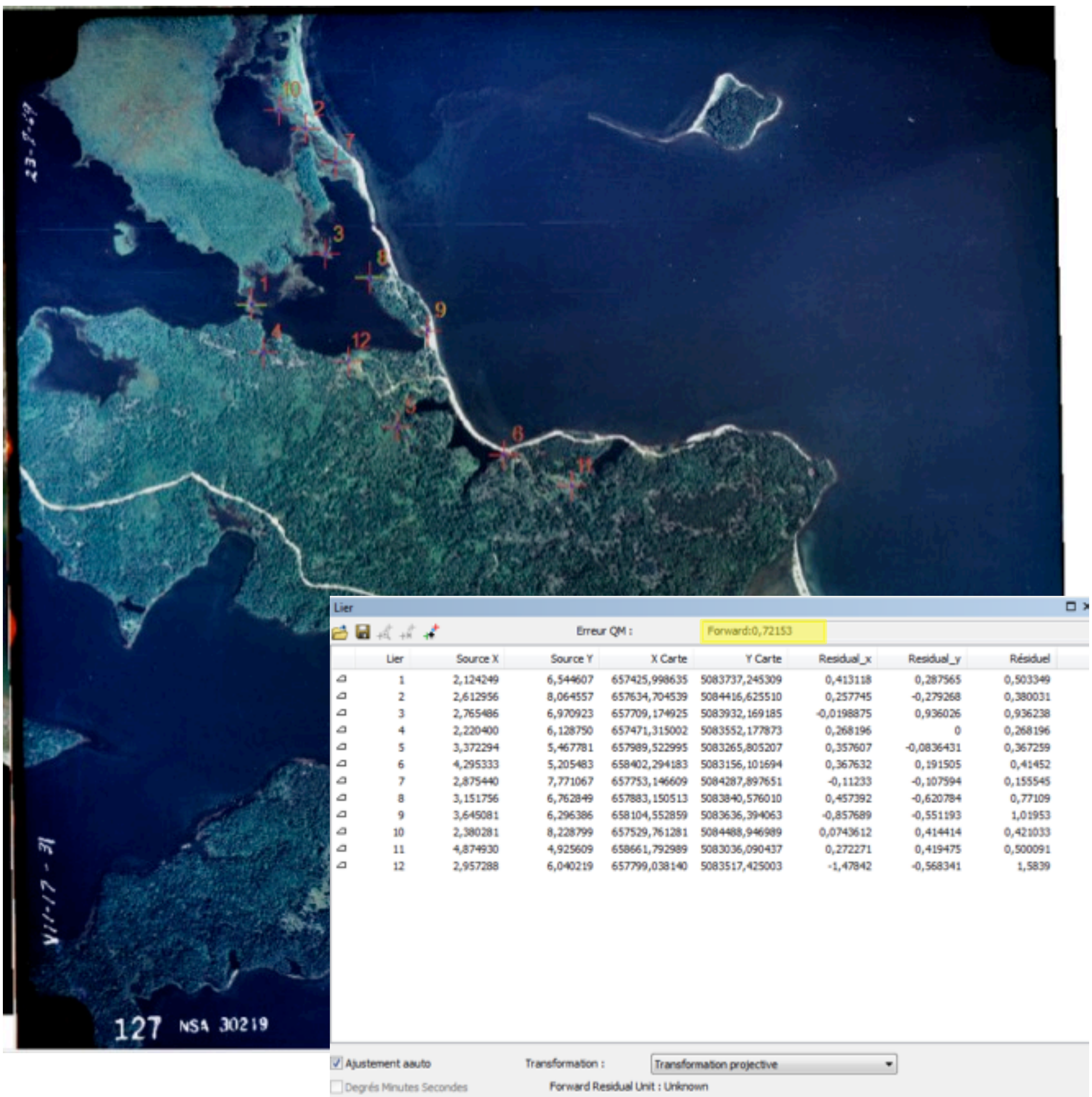
Lier	Source X	Source Y	X Carte	Y Carte	Residual_x	Residual_y	Résiduel
1	2,486742	6,229562	657412,936769	5083720,375053	-0,0272636	0	0,0272636
2	2,982979	7,804853	657609,036918	5084397,777302	-0,0174572	0	0,0174572
3	3,827532	5,126574	657989,292947	5083264,391559	0,201067	-0,468386	0,509719
4	3,984340	6,235815	658047,066755	5083742,706463	0,218462	-0,326983	0,393248
5	3,604131	6,474729	657882,705451	5083840,371076	-0,0280802	0,188198	0,190281
6	5,344546	4,949656	658645,063254	5083204,378483	-0,213723	0,532465	0,573756
7	5,074308	4,877977	658527,958173	5083171,229691	-0,332564	1,13616	1,18383
8	3,242473	7,444577	657721,252225	5084249,083857	-0,213559	0,211024	0,300231
9	4,449756	4,917758	658257,785642	5083180,927385	0,0355641	-0,276431	0,27871
10	2,964826	8,815645	657593,462220	5084826,972447	0,0901171	-0,0775393	0,118884
11	5,835187	4,852190	658861,108905	5083165,376934	0,287437	-0,930262	0,973657

1969 30219-127

12 GCP used

Projective Transformation

RMS error: 0.72 m



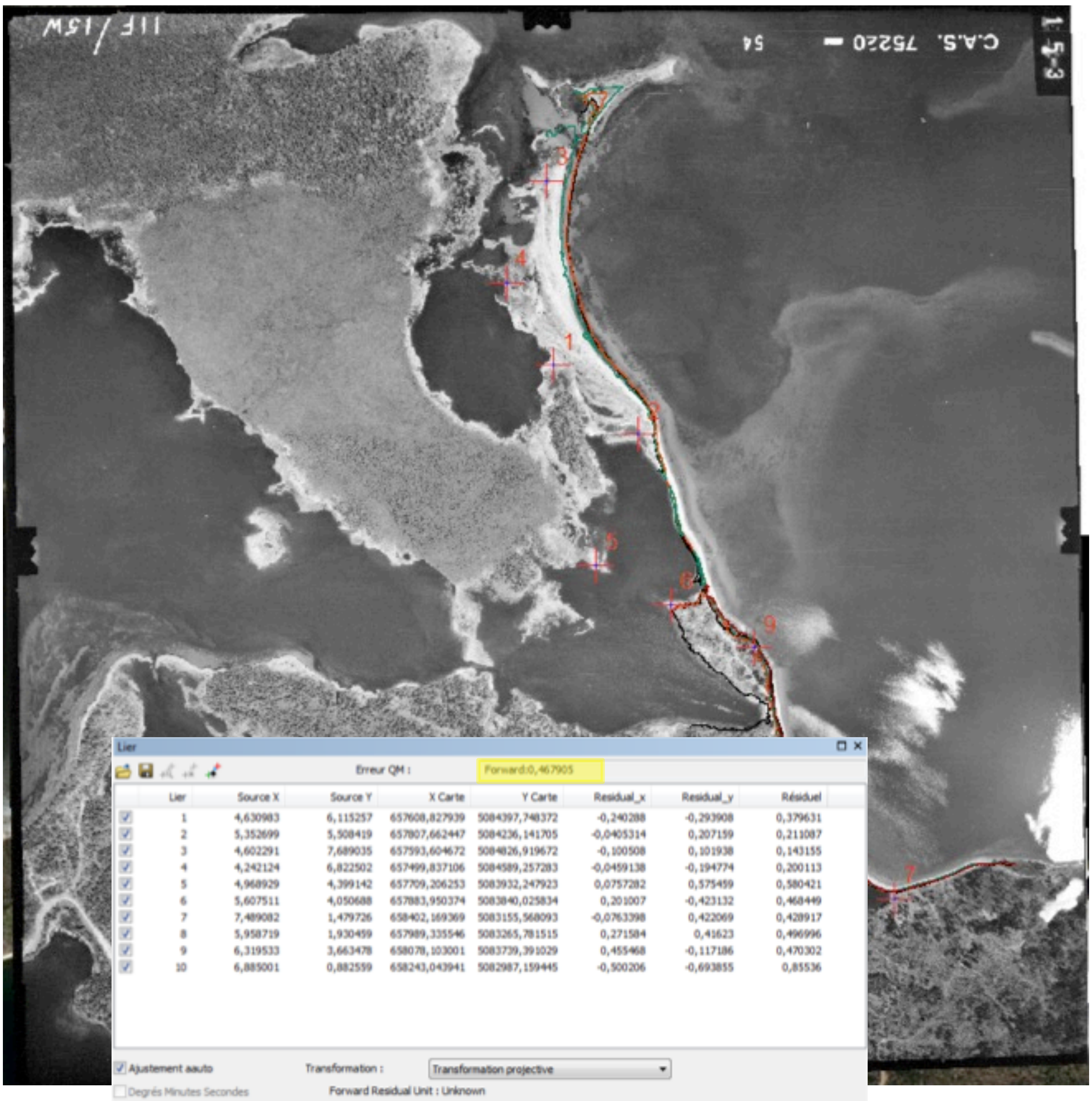
Lier	Source X	Source Y	X Carte	Y Carte	Residual_x	Residual_y	Résiduel
1	2,124249	6,544607	657425,998635	5083737,245309	0,413118	0,287565	0,503349
2	2,612956	8,064557	657634,704539	5084416,625510	0,257745	-0,279268	0,380031
3	2,765486	6,970923	657709,174925	5083932,169185	-0,0198875	0,936026	0,936238
4	2,220400	6,128750	657471,315002	5083552,177873	0,268196	0	0,268196
5	3,372294	5,467781	657989,522995	5083265,805207	0,357607	-0,0836431	0,367259
6	4,295333	5,205483	658402,294183	5083156,101694	0,367632	0,191505	0,41452
7	2,875440	7,771067	657753,146609	5084287,897651	-0,11233	-0,107594	0,155545
8	3,151756	6,762849	657883,150513	5083840,576010	0,457392	-0,620784	0,77109
9	3,645081	6,296386	658104,552859	5083636,394063	-0,857689	-0,551193	1,01953
10	2,380281	8,228799	657529,761281	5084488,946989	0,0743612	0,414414	0,421033
11	4,874930	4,925609	658661,792989	5083036,090437	0,272271	0,419475	0,500091
12	2,957288	6,040219	657799,038140	5083517,425003	-1,47842	-0,568341	1,5839

1975 75220-54

10 GCP used

Projective Transformation

RMS error: 0.47 m



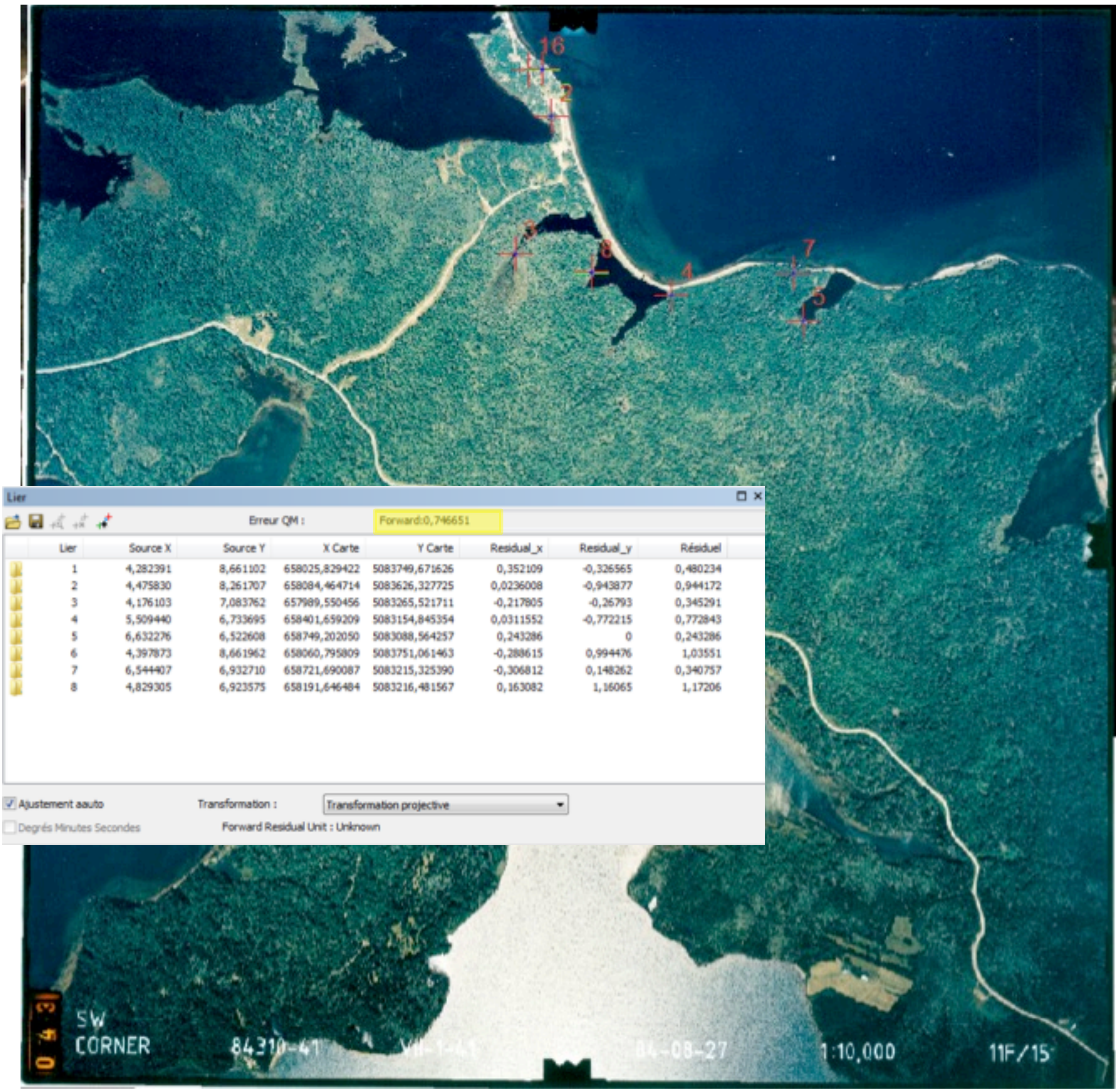
Lier	Source X	Source Y	X Carte	Y Carte	Residual_x	Residual_y	Résiduel
1	4,630983	6,115257	657608,827939	5084397,748372	-0,240288	-0,293908	0,379631
2	5,352699	5,508419	657807,662447	5084236,141705	-0,0405314	0,207159	0,211087
3	4,602291	7,689035	657593,604672	5084826,919672	-0,100508	0,101938	0,143155
4	4,242124	6,822502	657499,837106	5084589,257283	-0,0459138	-0,194774	0,200113
5	4,968929	4,399142	657709,206253	5083932,247923	0,0757282	0,575459	0,580421
6	5,607511	4,050688	657883,950374	5083840,025834	0,201007	-0,423132	0,468449
7	7,489082	1,479726	658402,169369	5083155,568093	-0,0763398	0,422069	0,428917
8	5,958719	1,930459	657989,335546	5083265,781515	0,271584	0,41623	0,496996
9	6,319533	3,663478	658078,103001	5083739,391029	0,455468	-0,117186	0,470302
10	6,885001	0,882559	658243,043941	5082987,159445	-0,500206	-0,693855	0,85536

1984 84310-41

8 GCP used

Projective Transformation

RMS error: 0.75 m



Lier	Source X	Source Y	X Carte	Y Carte	Residual_x	Residual_y	Résiduel
1	4,282391	8,661102	658025,829422	5083749,671626	0,352109	-0,326565	0,480234
2	4,475830	8,261707	658084,464714	5083626,327725	0,0236008	-0,943877	0,944172
3	4,176103	7,083762	657989,550456	5083265,521711	-0,217805	-0,26793	0,345291
4	5,509440	6,733695	658401,659209	5083154,845354	0,0311552	-0,772215	0,772843
5	6,632276	6,522608	658749,202050	5083088,564257	0,243286	0	0,243286
6	4,397873	8,661962	658060,795809	5083751,061463	-0,288615	0,994476	1,03551
7	6,544407	6,932710	658721,690087	5083215,325390	-0,306812	0,148262	0,340757
8	4,829305	6,923575	658191,646484	5083216,481567	0,163082	1,16065	1,17206

1993 93325-81

12 GCP used

Projective Transformation

RMS error: 0.62 m

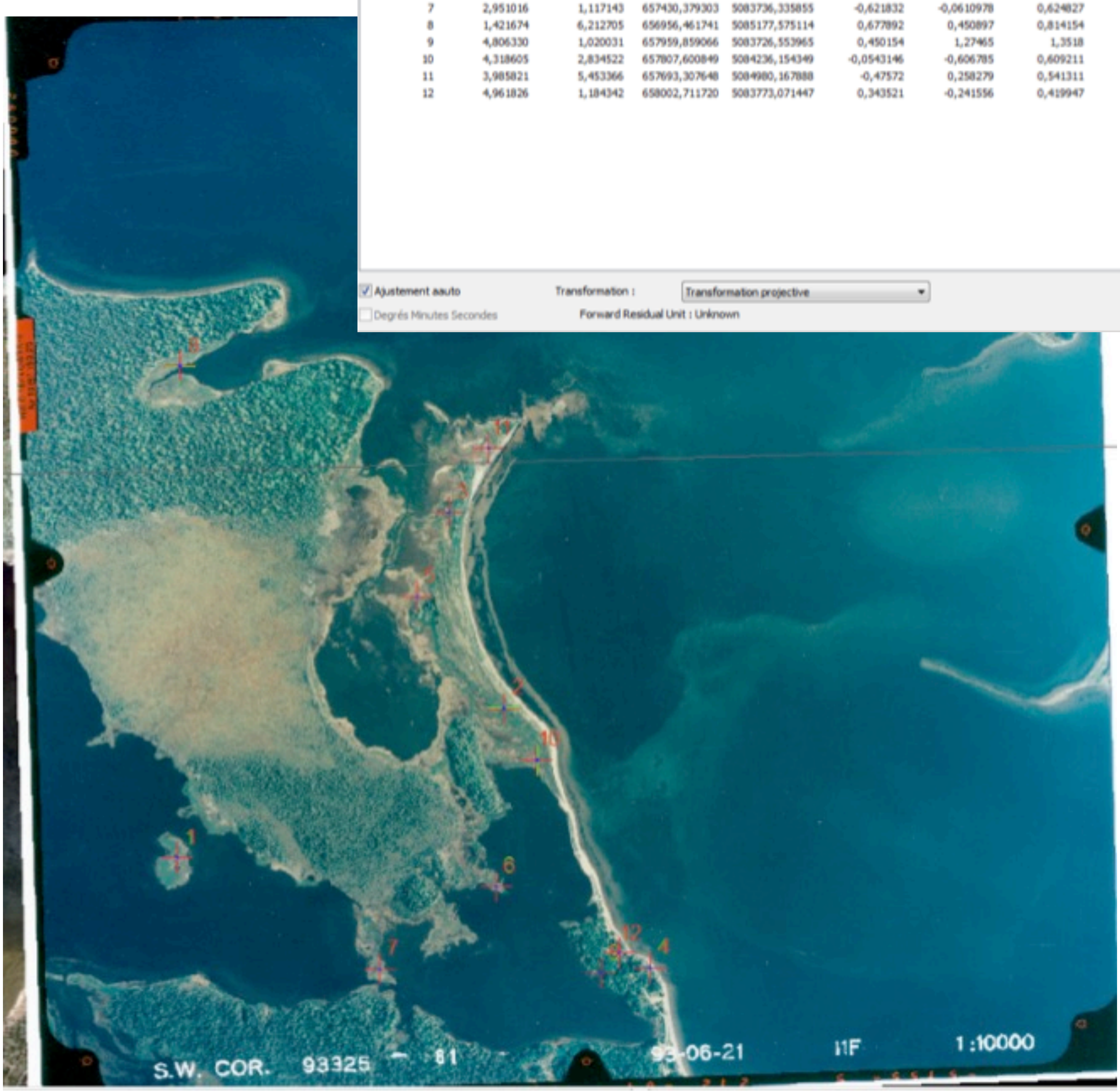
Lier

Erreur QM : Forward:0,62185

Lier	Source X	Source Y	X Carte	Y Carte	Residual_x	Residual_y	Résiduel
1	1,289060	2,097363	656949,316554	5084000,951326	0,058408	0	0,058408
2	4,054024	3,275407	657728,900356	5084359,718996	-0,265087	-0,285563	0,389637
3	3,633541	4,929469	657597,230247	5084827,670398	-0,031932	-0,122357	0,126455
4	5,224853	1,055142	658078,331834	5083739,154839	0,391535	0,193845	0,436893
5	3,346548	4,225286	657520,535979	5084624,534476	-0,128693	-0,23508	0,268001
6	3,946510	1,777030	657709,201255	5083932,215362	-0,343931	-0,605831	0,696649
7	2,951016	1,117143	657430,379303	5083736,335855	-0,621832	-0,0610978	0,624827
8	1,421674	6,212705	656956,461741	5085177,575114	0,677892	0,450897	0,814154
9	4,806330	1,020031	657959,859066	5083726,553965	0,450154	1,27465	1,3518
10	4,318605	2,834522	657807,600849	5084236,154349	-0,0543146	-0,606785	0,609211
11	3,985821	5,453366	657693,307648	5084980,167888	-0,47572	0,258279	0,541311
12	4,961826	1,184342	658002,711720	5083773,071447	0,343521	-0,241556	0,419947

Ajustement auto Transformation : Transformation projective

Degrés Minutes Secondes Forward Residual Unit : Unknown

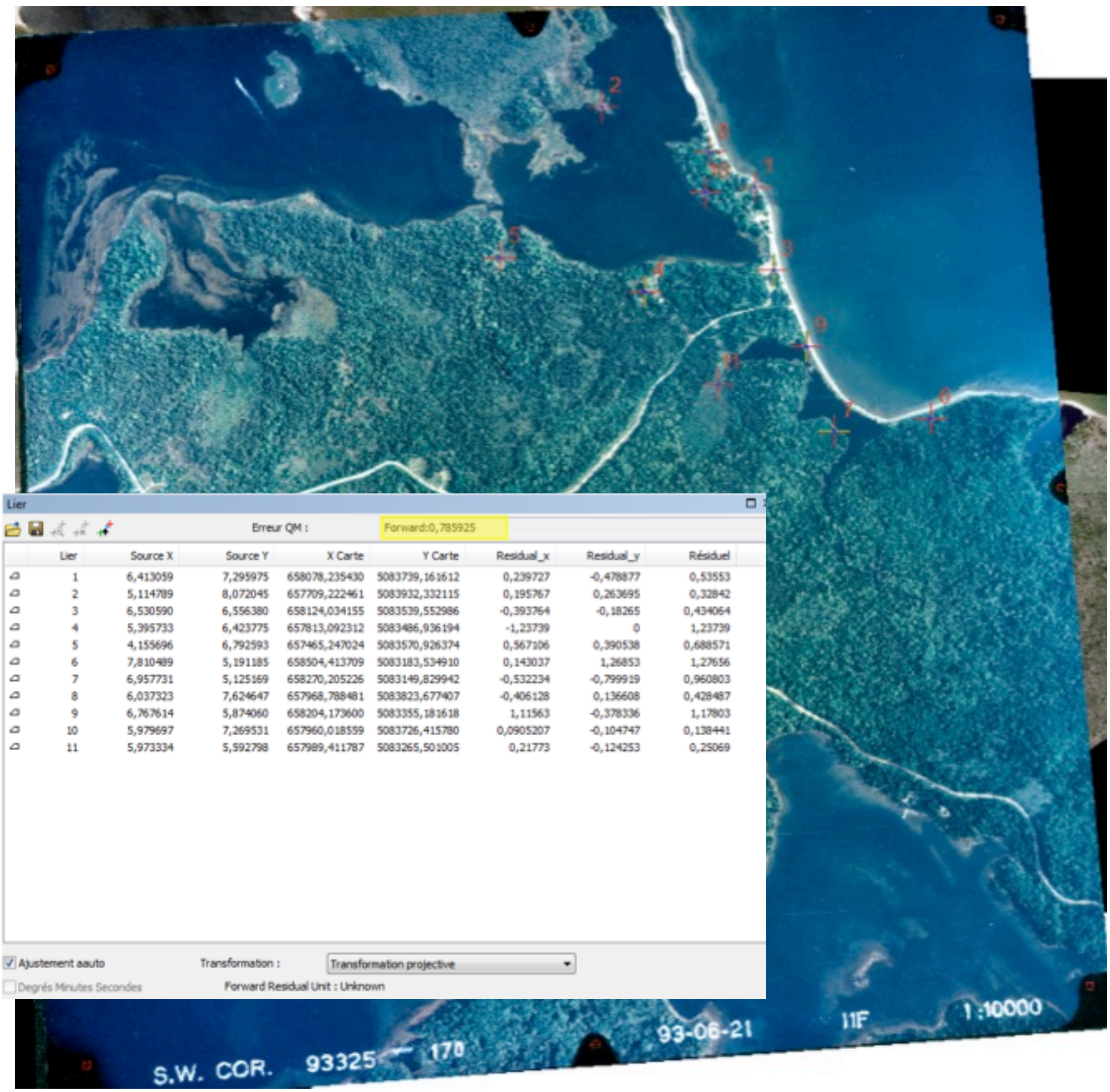


1993 93325-170

11 GCP used

Projective Transformation

RMS error: 0.79 m

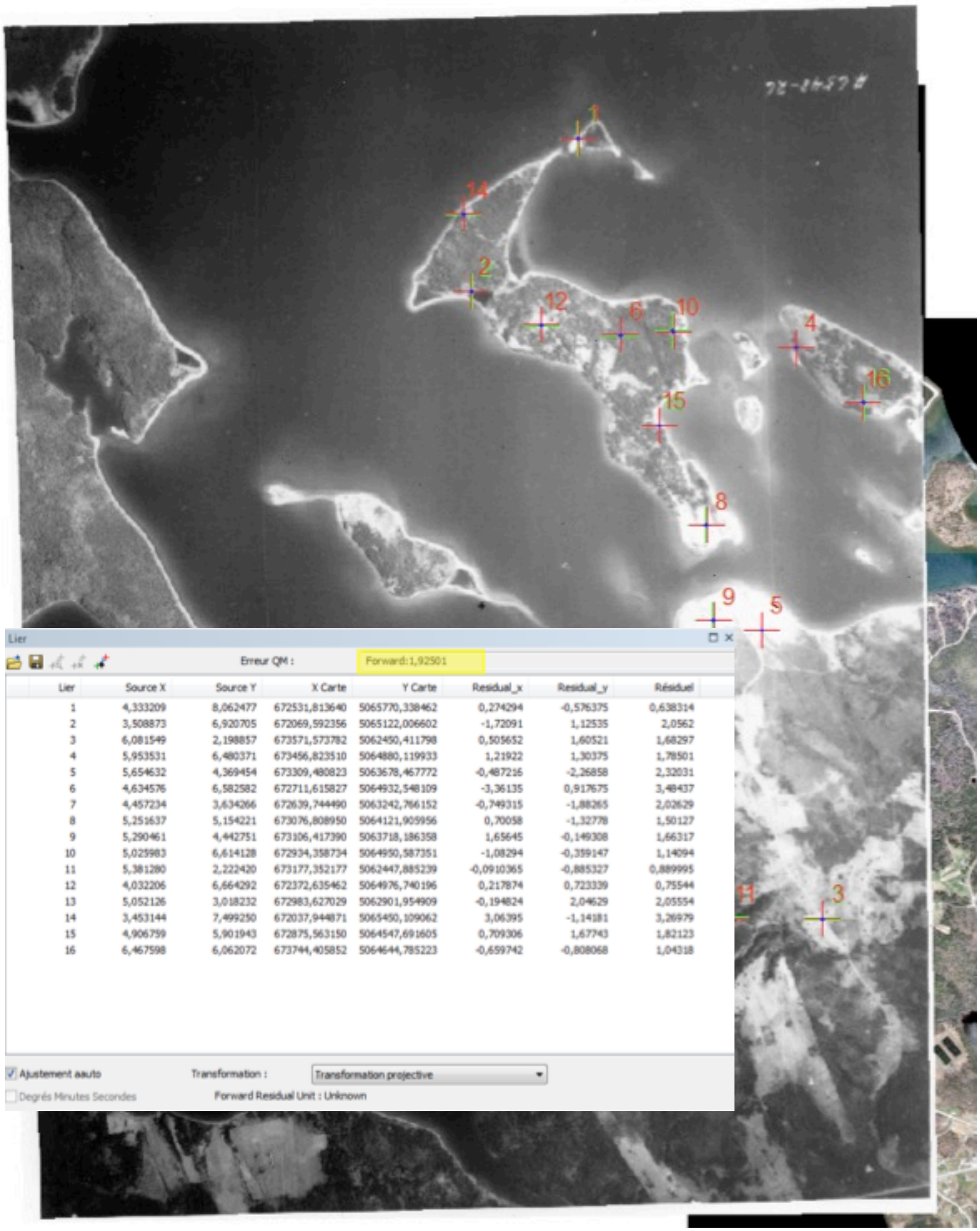


Lier	Source X	Source Y	X Carte	Y Carte	Residual_x	Residual_y	Résiduel
1	6,413059	7,295975	658078,235430	5083739,161612	0,239727	-0,478877	0,53553
2	5,114789	8,072045	657709,222461	5083932,332115	0,195767	0,263695	0,32842
3	6,530590	6,556380	658124,034155	5083539,552986	-0,393764	-0,18265	0,434064
4	5,395733	6,423775	657813,092312	5083486,936194	-1,23739	0	1,23739
5	4,155696	6,792593	657465,247024	5083570,926374	0,567106	0,390538	0,688571
6	7,810489	5,191185	658504,413709	5083183,534910	0,143037	1,26853	1,27656
7	6,957731	5,125169	658270,205226	5083149,829942	-0,532234	-0,799919	0,960803
8	6,037323	7,624647	657968,788481	5083823,677407	-0,406128	0,136608	0,428487
9	6,767614	5,874060	658204,173600	5083355,181618	1,11563	-0,378336	1,17803
10	5,979697	7,269531	657960,018559	5083726,415780	0,0905207	-0,104747	0,138441
11	5,973334	5,592798	657989,411787	5083265,501005	0,21773	-0,124253	0,25069

Potlotek study site (1 historical aerial photo only)

1939 A6548-26

11 GCP used | Projective Transformation | **RMS error: 1.93 m**



Lier	Source X	Source Y	X Carte	Y Carte	Residual_x	Residual_y	Résiduel
1	4,333209	8,062477	672531,813640	5065770,338462	0,274294	-0,576375	0,638314
2	3,508873	6,920705	672069,592356	5065122,006602	-1,72091	1,12535	2,0562
3	6,081549	2,198857	673571,573782	5062450,411798	0,505652	1,60521	1,68297
4	5,953531	6,480371	673456,823510	5064880,119933	1,21922	1,30375	1,78501
5	5,654632	4,369454	673309,480823	5063678,467772	-0,487216	-2,26858	2,32031
6	4,634576	6,582582	672711,615827	5064932,548109	-3,36135	0,917675	3,48437
7	4,457234	3,634266	672639,744490	5063242,766152	-0,749315	-1,88265	2,02629
8	5,251637	5,154221	673076,808950	5064121,905956	0,70058	-1,32778	1,50127
9	5,290461	4,442751	673106,417390	5063718,186358	1,65645	-0,149308	1,66317
10	5,025983	6,614128	672934,358734	5064950,587351	-1,08294	-0,359147	1,14094
11	5,381280	2,222420	673177,352177	5062447,885239	-0,0910365	-0,885327	0,889995
12	4,032206	6,664292	672372,635462	5064976,740196	0,217874	0,723339	0,75544
13	5,052126	3,018232	672983,627029	5062901,954909	-0,194824	2,04629	2,05554
14	3,453144	7,499250	672037,944871	5065450,109062	3,06395	-1,14181	3,26979
15	4,906759	5,901943	672875,563150	5064547,691605	0,709306	1,67743	1,82123
16	6,467598	6,062072	673744,405852	5064644,785223	-0,659742	-0,808068	1,04318

APPENDIX E – Erosion Assessment: Shapefiles and Spreadsheets

The shapefiles are copied to the accompanying DVD. For each erosion assessment site, 6 file extensions are generated: .dbf; .prj; .sbn; .sbx; .shp; .shx

Malikewe'j_SL1939 Potlotek_SL1939

Malikewe'j_Transects Potlotek_Transects

For each erosion assessment site, a spreadsheet has been prepared containing the raw data associated to the total shoreline displacement (m), the rate of displacement (m/yr), the margin of error (in m and in m/yr), the Easting/Northing coordinates of the transects used for the measurements.

Rates_Malikewe'j_1939-2014.xls Rates_Potlotek_1939-2014.xls

APPENDIX F – Erosion Assessment: Evolution Maps (1939-2014)

The PDFs are copied to the accompanying DVD.

Appendix F_ShorelineEvolution_1939-2014_Malikewe'j_SheetA.pdf

Appendix F_ShorelineEvolution_1939-2014_Malikewe'j_SheetB.pdf

Appendix F_ShorelineEvolution_1939-2014_Potlotek.pdf

APPENDIX G – 2100 Projected Shoreline: Shapefiles

The shapefiles are copied to the accompanying DVD. For each erosion site, 6 file extensions are generated: .dbf; .prj; .sbn; .sbx; .shp; .shx

Malikewe'j_SL2100_A

Malikewe'j_SL2100_B

Potlotek_SL2100

The Malikewe'j study site has two shoreline projection scenarios (A and B): *scenario A* supposes that the riprap protection structure at the ancestral burial grounds is eventually abandoned and the shoreline is allowed to naturally move landward over the next 86 years (2014-2100), and *scenario B* supposes that the riprap protection structure is maintained in place.

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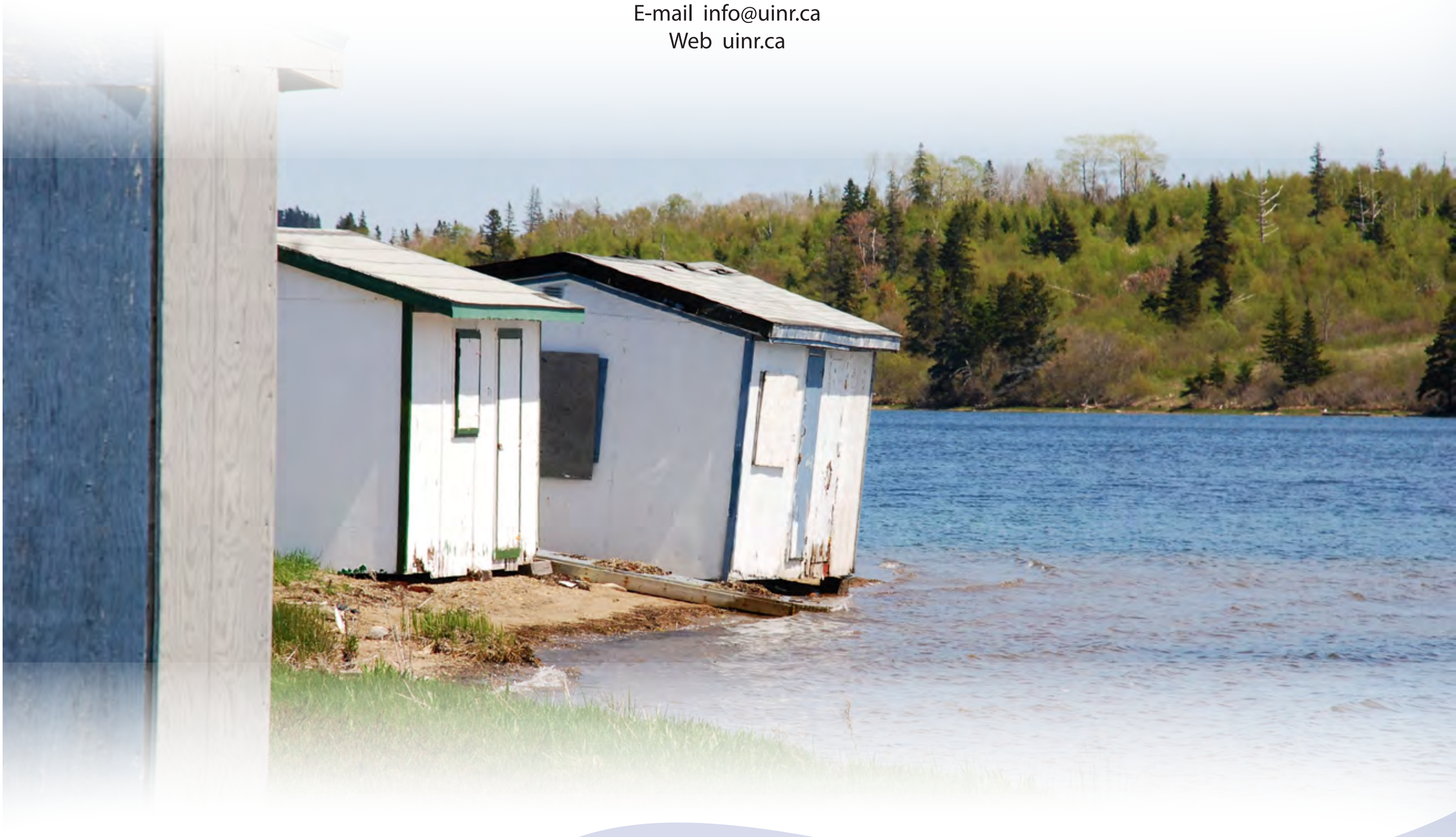

Eskasoni • Membertou • Potlotek • Wagmatcook • We'koqma'q