Coastal Erosion Risk to Infrastructure for the Municipalities of Petit-Rocher and Pointe-Verte, New Brunswick

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1. INTRODUCTION

The coastal zones of the world will for the most part be subject to the sea level rise announced for the present century, a phenomenon which accompanies the current global warming responsible for the melting of the ice caps and the thermal expansion of the oceans. In addition, this increase may accelerate erosion in some areas. Other factors related to global warming will also affect erosion: changes to storm regimes that may be more intense and perhaps more frequent and the decrease in winter ice cover that naturally protects the coast during the cold season. Coastal populations will therefore have to adapt to new environmental conditions that will affect the flooding and erosion regimes in coastal areas. Some areas in the Atlantic Provinces of Canada are among the most vulnerable to flood and erosion hazards, in this case northern New Brunswick characterized by sometimes low and physically vulnerable terrain, subsidence (or depression) of the Earth's crust , a climate favoring storm surges causing frequent and sometimes severe occasional floods and erosion, and a fairly populated coastline.

The study area is part of the Chaleur Regional Service Commission (CRSC), which covers an area of 3,307 km^2 and includes a coastline facing the Chaleur Bay (Figure 1) and where the potential for future coastal floods is likely to increase with the gradual increase in sea level. This region must also deal with coastal erosion, the spatial variations of which are poorly known, as it is poorly documented as can be seen from the province's erosion data (http://geonb.snb.ca/erosion/index_en .html). In addition, information that is sometimes contradictory or confusing does not make it possible to clearly envision the future in the face of new environmental conditions, making it more difficult to take decisions in the measures to be taken to adapt. Municipal and regional authorities are aware of this and need more comprehensive data for better land-use planning, particularly in developing the CRSC climate change adaptation plan in line with the Government of New Brunswick action plan with which it collaborates.

Figure 1. Map of Northeastern New Brunswick showing the CRSC territory.

The future impact of flooding on coastal infrastructures was assessed during phase 1 of the climate change adaptation process that began in 2018 in this area (Aubé et al., 2018). Thus, the main objective during this second phase is to address the lack of information on erosion and to provide the CRSC medium- and long-term erosion scenarios based on the latest available scientific data as well as identify coastal infrastructure at risk under these scenarios. The sector covered by this project is however limited to a portion of the CRSC's territory: the municipalities of Petit-Rocher and Pointe-Verte, as well as the LSDs of Petit-Rocher-Sud and Petit-Rocher-Nord. Other municipalities and LSDs will be studied later. It should be noted that the city of Bathurst, which is also part of the commission's territory, already has an adaptation plan that uses data produced a few years ago (Simard et al., 2015).

The final product will consist of a series of geospatial data representing erosion risk to coastal infrastructure. The purpose of this information is to facilitate decisions for better adaptation to climate change by municipalities and unincorporated areas of the CRSC, particularly in relation to the potential impacts of erosion on coastal infrastructure. This research is being done in parallel with a study on erosion protection structures also produced as part of the CRSC's Climate Change Adaptation Plan, in collaboration with the NB Department of Energy and Resource Development and with NBETF funds, the results of which have been largely presented in a recent report (Diouf et al., 2019). The results of this research will also be published in a master's thesis in environmental studies at the Université de Moncton (author: Simon Diouf, director: André Robichaud, title: Impacts of rigid coastal protection structures on the coast of the Chaleur Regional Service Commission).

The goals, objectives and deliverables of this project are presented with more detail in the RFP documents no. PL2018-02 (CRSC, 2018) and Service Offer - Coastal erosion risk analysis for part of the Chaleur RSC territory (Simard and Chelbi, 2019). They include the following elements[1] :

1) Arc GIS Layers presenting the following information:
   - Orthophotos used for georeferencing and mapping work;
   - Rectified aerial photos used for mapping work;
   - Baselines and transects used for calculating movement rates;
   - Coastlines and shorelines used to calculate movement rates;
   - Coastlines and shorelines projected according to pre-approved scenarios.

2) Arc GIS databases presenting the following information:
   - Transect identification numbers used to calculate movement rates;
   - X and Y coordinates of the point of intersection of the transects with the coastlines;
   - X and Y coordinates of the point of intersection of transects with shorelines;
   - Type of coastline at points of intersection (e.g. cliff, dune);
   - Type of shoreline at points of intersection (e.g. marsh, beach);
   - Presence of coastal protection structure at the point of intersection;
   - Average annual movement rates of shoreline along transects;

[1] The geospatial data produced in this project must follow the standards established by Service New Brunswick and be based on the Canadian spatial reference system ("North-American Datum 1983") and a map projection adapted to the provincial territory ("double stereographic") .

- Margin of error on shoreline movement rates;
- Average annual movement rates of shoreline along transects;
- Margin of error on shoreline movement rates.

2. SUMMARY DESCRIPTION OF THE STUDY AREA

This study covers the municipalities of Petit-Rocher and Pointe-Verte and the LSDs of Petit-Rocher-Nord and Petit-Rocher-Sud. These are coastal villages in Gloucester County and the Chaleur Region of northeastern New Brunswick on the Acadian Coastal Highway (Figure 2). Collectively, the population of this region is close to 3550 inhabitants and occupies an area covering an area of about 29 km^2, a density of 123 inhabitants per km^2. The coastline of the study area is 21.3 km long and is quite variable. Indeed, it includes sandy beaches, rocky promontories and cliffs furniture. The main rivers are Nigadoo and Les Ormes, which flow into the waters of Chaleur Bay and drain a large part of the study area.

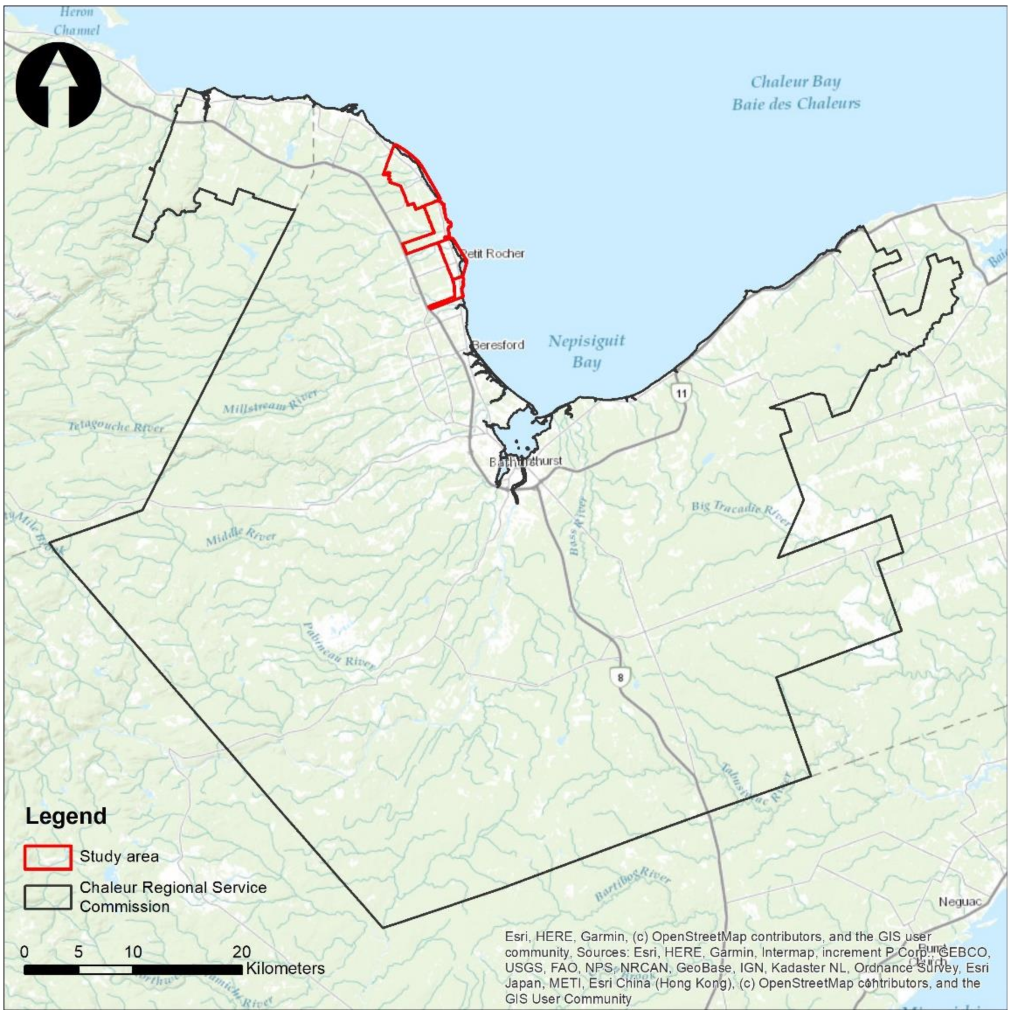

Figure 2. Map of Northeastern New Brunswick showing approximately the administrative boundaries for the municipalities of Petit-Rocher and Pointe-Verte and the LSDs of Petit-Rocher-Nord and Petit-Rocher-Sud (polygon with red boundaries in the map)

3. METHOD

Several steps are necessary in the realization of erosion risk evaluation for infrastructures:

1) **Determine erosion scenarios based on past erosion rates and a projection of the coastline in the future.** For this project, historical erosion rates and coastline projection in the future (2050 and 2100) were prepared following the methodology developed by the CZRI and its research partners, which was used in similar projects along the northeastern coast of New Brunswick.

2) **Digitization of infrastructures.** As part of this project, the infrastructure was provided by the CRSC Geomatics Service. The infrastructure database includes data such as buildings, roads, utility poles, sewer systems, manholes, catch basins, landfills, pumping stations, etc.

3) **Lidar derived digital terrain elevation model** [2]. Lidar data obtained from the GeoNB New Brunswick Geographic Data Portal was used to produce a digital terrain elevation model and a slope map. These products have been used to improve recent shoreline identification and interpretation. This allowed enhanced determination of whether the digitized coastline was cliff-type or not.

4) **Infrastructure erosion risk determination.** This step involves combining the erosion scenarios and the infrastructure database. The risk to infrastructure was assessed using the infrastructure erosion risk index presented later in this report.

5) **Prepare the data in a distributable format (geodatabase) showing the infrastructures at risk.** A digital data product that can be easily used on the ArcGIS platform is delivered to CRSC.

[2] Light detection and ranging, a remote sensing technology based on pulsed laser.

Preparation of historical aerial photographs

a. Selection of historical aerial photos

Historical aerial photos are very useful for mapping the coastline position and measuring its evolution over time. Coastal erosion studies conducted in New Brunswick have shown that a minimum period of 25 years is normally required to confirm trends in historical rates of shoreline movement. These studies also suggest that the larger the interval between historical photos, the more reliable and representative the data on trends in coastal evolution.

For this project, the two oldest series of aerial photos available at the National Air Photo Library in Ottawa were those of 1934 and 1944. Although the 1934 series allows a longer measurement interval (1934-2018), the 1944 series was preferred because of its superior quality (Figure 3) and offered a long enough period to be valid (74 years). In addition, the use of the 1944 series of photos makes it possible to detect the coastline with greater precision and thus to have a combined margin of error (scanning, georeferencing) of less than 5 m. Finally, the insufficient overlap amongst the available 1934 photos made it nearly impossible to align them properly with the 2018 orthophotography of 2018 during georeferencing. Figure 3 shows a photograph of 1944 which visibly has a better resolution than that of 1934. It is also observed that it has less overexposure, especially at the level of sandy beaches. This allows for a much better interpretation of the coastline position, including in cliff and micro-cliff areas.

Figure 3. Difference in quality between the 1944 series (left) and the 1934 series (right).

The flight lines making up the 1944 series of photographs cover the entire shoreline of the study area except for a 300-meter segment in the southern portion of the study area. This segment was projected according to the rates of the homogeneous sector to which it belongs. A total of 17 aerial photographs spread over six flight lines perpendicular to the coast (Figure 4) were used to extract the 1944 coastline.

Although not used for erosion rate assessment, the 1934 aerial photos were also digitized and georeferenced. Georectification was done using the 1944 photos as a reference because it was easier to find ground control points between these two series than with the 2018 orthophography. They were useful in supporting photo interpretation of the historical coastline elements.

b. Digitization of historical aerial photos

The 1944 historical photos, in paper format, were scanned using an *Epson 1000XL* scanner at a resolution of 600 dpi. This corresponds to a pixel size of 0.8 m^2 which remains below the actual resolution of 1944 photos, ie 1 m^2. The use of this resolution is more than enough to reproduce all the details of the photo without increasing the size of the resulting files. This makes it easier to store historical aerial photos without losing the detail of the photo.

c. Georeferencing historical photos

The 1944 aerial photographs were aligned on 2018 orthophotos through a selection of control points (or anchor points). On average, seven well-distributed control points on each of the 1944 photographs were used to position them relative to those of 2018. The average georeferencing error is less than 1 m.

Table 1 illustrates the georeferencing quality for each 1944 series (RMS: Root Mean Square error), the number of control points used (GCP: Ground Control Points), the pixel size per photo, as well as the transformation method used for georeferencing.

Digitizating the coastline

a. The coastline

In order to calculate erosion rates for the Petit Rocher - Pointe-Verte study area, the 1944 and 2018 coastlines must be extracted in a vector format. Although theoretically associated with the land-sea interface, the coastline can be interpreted in different ways depending on the environment being studied. Table 2 presents a description of the different benchmarks used in this project for the positioning of the coastline.

According to our method, during the digitization of the coastline, two criteria prevail in the choice of the reference used:

- The landmark used must have a direct link with the risk to the infrastructures. E.g.: In the case of a cliff, the top rather than its base is used, because the risk of damage to infrastructure is determined by the proximity to the edge of the cliff.

- The landmark must be easily identifiable on both historical photographs of 1944 as well as on the recent orthophotography of 2018. E.g.: the vegetation line in the case of sand dunes may be a more easily identifiable element from one photo to another, in color and/or black and white.

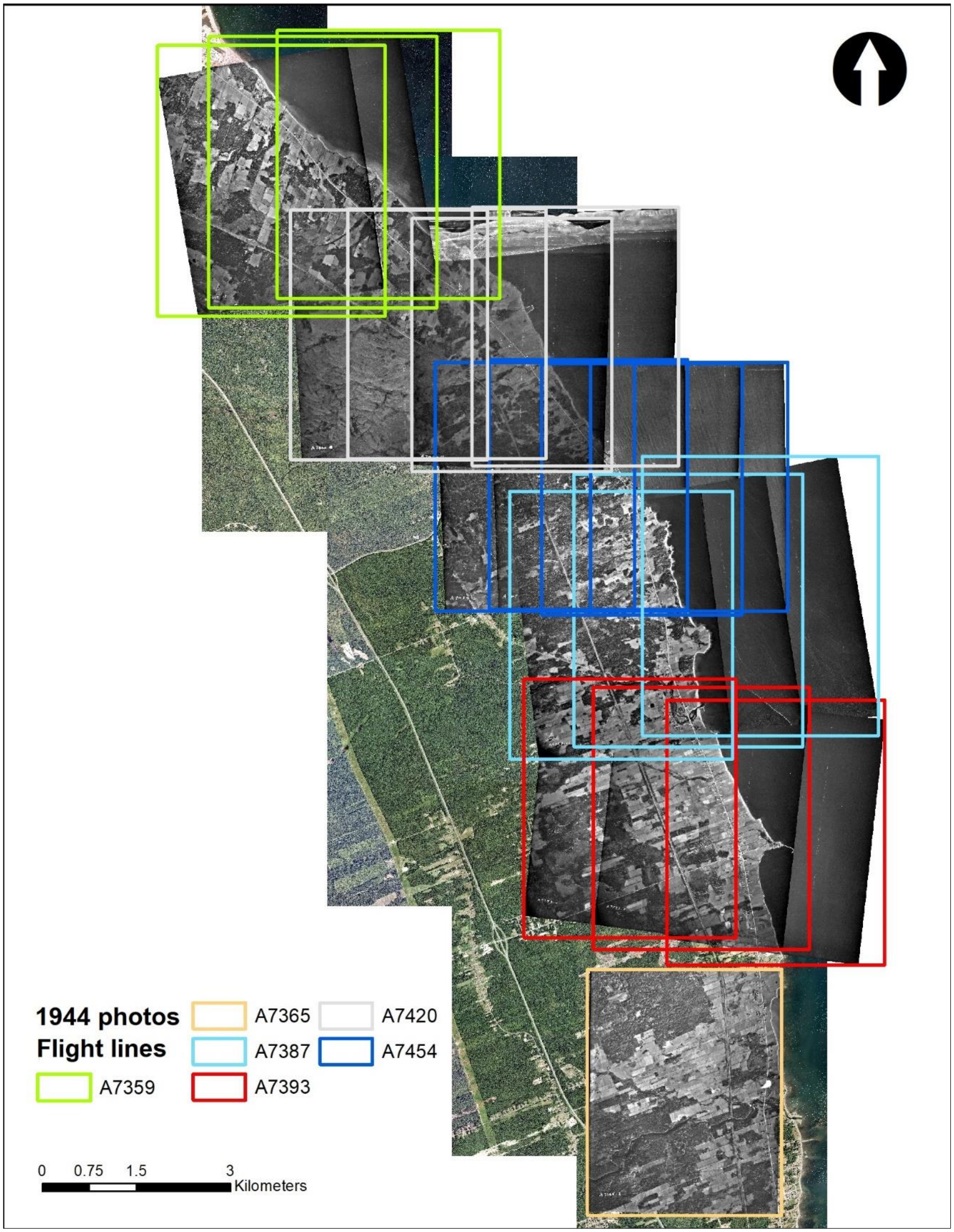

Figure 4. Location of flight lines and aerial photos of 1944.

Table 1: Quality of 1944 aerial photography georeferencing.

Low w	*FLIGHT LINE*	*PHOTO*	*LOCALITY*	*GCP*	*RMS*	*PIXEL (m)*	*TRANSFORMATION*
1944	A7359	36	Pointe Verte	6	1.1	0.8	Projective
1944	A7359	37	Pointe Verte	7	0.7	0.8	Projective
1944	A7359	38	Pointe Verte	7	0.8	0.8	Projective
1944	A7365	2	Petit Rocher-S	7	0.8	0.7	Projective
1944	A7387	51	Petit Rocher-N	7	1.0	0.9	Projective
1944	A7387	52	Petit Rocher-N	8	0.6	0.8	Projective
1944	A7387	53	Petit Rocher-N	7	0.5	0.8	Projective
1944	A7393	2	Petit Rocher	7	0.5	0.8	Projective
1944	A7393	3	Petit Rocher	10	0.3	0.8	Projective
1944	A7393	4	Petit Rocher	8	0.6	0.8	Projective
1944	A7420	15	Pointe Verte	7	0.8	0.8	Projective
1944	A7420	16	Pointe Verte	7	0.7	0.8	Projective
1944	A7420	17	Pointe Verte	7	0.8	0.7	Projective
1944	A7420	18	Pointe Verte	7	0.9	0.7	Projective
1944	A7454	2	Petit Rocher	6	0.9	0.7	Projective
1944	A7454	3	Petit Rocher	6	0.5	0.8	Projective
1944	A7454	4	Petit Rocher	7	0.9	0.7	Projective
1944	A7454	5	Petit Rocher	6	0.9	0.7	Projective

Table 2: Coastline characterisation and classification.

TC_TYPES*	DESCRIPTION
ARTIFICIEL	Internal limit of the protection wall. Internal limit of the embankment material. Internal limit of the coastal stone wall and protective structures. External limit of the spur.
ARTIFICIEL ACCES	Access to the landscaped coast (also includes boat launching ramps).
ARTIFICIEL FIXE	Contour of the port infrastructure. Road base built on the coast now constituting a coastline. Public riprap summit. Fixed dock (built and having an impact on sediment dynamics) not part of a harbor.
DUNE	Peak of the dune cliff. Soft slope dune front: Ammophila limit on the top of the beach. Limit of the overflow table.
DUNE ACCES	Access to the beach (ORV or pedestrians) that overwrites the dune edge.
FALAISE MEUBLE	Summit of the cliff or micro-cliff in loose materials (unbound). Cliff top or micro-cliff in peat.
FALAISE ROCHEUSE	Cliff top or rocky micro-cliff.
FERMETURE	Any virtual segment (not corresponding to any natural form) used to close a stream.
FLECHE LITTORALE	Ordinary level of high water; contact dry sand / wet sand (sandy beach).
MARAIS	Limit of water-marsh contact indicated by swamp vegetation limit.
MEUBLE	Soft coastline (riverbank, field boundary, etc.)

b. Digitization scale

A scale of 1: 250 was adopted arbitrarily to digitize the coastline. It is estimated that the digitization error associated with this scale is 0.6 m on the 2018 orthophotos. However, this scale is not a rule and can be modified if necessary. Thus, the user adapts the scanning scale, according to the marker to be scanned, if he judges that this enables him to better identify the position of the coastline. For example, a larger scale is used when scanning a homogeneous and easily identifiable landmark while a smaller scale is used if the coast is more rugged.

c. Orientation of digitization

As part of the Petit Rocher - Pointe-Verte project, coastline digitization is done in a constant direction from east to west and from south to north, as much as possible in a continuous manner. This avoids wasted time inverting the baselines during the step of creating transects in DSAS (see below), so that they are numbered in one direction.

d. Vertex placement along the coastline

No rule has been adopted on the number of vertices (construction points) to be placed to digitize a line (e.g. 2 vertices per 5 meters). Rather, an approach requiring as many vertices as possible to faithfully reproduce the coastline has been used. The vertex density thus varies according to coastline environment (homogeneous, variable) and geometry (rectilinear, sinuous, zigzag, etc.), and from one cartographer to another. On average, during this project, 6.7 vertices per 10 meters of coastline were digitized.

Coastline Change Rates Calculation

The calculation of annual shoreline movement has been performed in the DSAS (Digital Shoreline Analysis System) module of the USGS (Himmelstoss et al., 2018). To determine the annual rate of change, the software applies a simple formula that consists of dividing the distance between the two coastlines used by the number of years between them (2018-1944 = 74 years). The measurements (expressed in meters / year) are made on transects perpendicular to the coastline of 2018, spaced 30 m apart and distributed along the coastline studied following recommendations from the NB Department of Energy and Resource Development.

The margin of error associated with change rates is calculated by combining all the sources of error in the steps that led to the calculation of the rates. Thus, it includes:

- The georeferencing error for 1944 photos (0.7 m),
- The actual pixel resolution for 1944 photos (1 m),
- The resolution for 2018 aerial photos (0.1 m),
- The 2018 coastline scan quality estimated at 5 pixels (0.5 m), and
- The 1944 coastline scan quality estimated at 2 pixels (2 m)

Regarding the margins of error associated with the position of 1944 and 2018 coastlines, they are:

- 3.8 m for the 1944 coastline, calculated as follows: the georeferencing error for the 1944 photos (0.7 m) + the actual pixel resolution for the 1944 photos

(1 m) + the resolution of the 2018 aerial photos (0.1 m) + the scan quality of the 1944 coastline estimated at 2 pixels (2m).

- 0.6 m for the 2018 coastline, calculated as follows: 2018 aerial photos resolution (0.1 m) + 2018 coastline scan quality estimated at 5 pixels (0.5 m).

On average, the total margin of error of the coastline position is 4.3 m. Thus, annual change rates calculated over 74 years have a margin of error of ± 0.06 m / year.

Erosion scenarios

In order to determine the future erosion risks to the infrastructure located inside the study area, it is necessary to produce scenarios for the evolution of the coastline position. These scenarios include projected average future coastal erosion rates based on time horizons selected from the most recent shoreline position. In this project, these horizons are 2050 and 2100.

The coastline projection was carried out using a method that uses sectors with homogeneous evolution. Thus, in a first step, we determine the sectors that have very similar rates of change and that are of the same type (Table 2) and form (linear coastline exposed to the action of the waves, winding coastline, etc..). In a second step, we calculate an average rate for each determined sector.

It is important to note that some transects have been excluded from the calculation of the rate of change to avoid problematic or erroneous interpretations. The main cases are:

- A positive rate of change in the case of an artificial coastline; in fact, the natural coast may have receded here in the past and at best it would be fixed in the future but would not advance. This happens when the protective structure has been constructed so that it overflows beyond the natural coastline, giving a false signal that this coast is in accumulation. In fact, coastal dunes and coastal marshes are the only types of natural coast that can prograde, even in a context of rising sea levels.

- A positive rate of change when the coastline is a loose cliff. A cliff is a form of erosion and, by definition, it recedes, but it is possible that the distance between the two reference coastlines is too small and within the margin of error for DSAS to calculate realistic rates.

Based on the average annual change rates by sector with homogeneous evolution and the direction (advanced, stable, retreat) of the displacement along the transects, the position of the projected coastline is calculated using each established transect using DSAS. Thus, on the extension of each transect, a point is placed according to the established displacement rate of the corresponding sector and these points are connected to form the projected shoreline. The new traced line is then smoothed in the limits between each two sectors to represent a shoreline with a more realistic "natural" shape (Figure 5).

Figure 5. Erosion scenario for 2100 (a) without smoothing in the left side, (b) with smoothing at the connections between the homogeneously changing sectors in the right side.

It should be noted that certain sectors have been kept fixed in the coastline projections. They mostly include the coastline protected by public infrastructures (port installation, riprap along a road, embankments ...).

Erosion risk determination and representation

An erosion risk index for the infrastructures of three municipalities was developed during the 2011 SACCA-ICAR-Acadian Peninsula project (Robichaud et al., 2011, p.37). It has proved very useful in the interpretation and mapping of risk to infrastructure. This index was later re-used and slightly modified to better suit subsequent study needs in various municipalities and LSDs in northeastern New Brunswick.

The basic principle underlying the erosion risk index is to evaluate the possibility that an infrastructure will be affected by the coastline retreat in a distant future. The index is based on (1) arbitrary, but relevant and useful safety margins, as indicated by clients where applicable and (2) the position of the infrastructure in relation to the coastline position or the projected shoreline at different years in the future.

For the municipalities and LSDs considered in this study, the risk index has been adapted to consider shorter projection horizons than those considered in previous studies in other municipalities (i.e. Simard et al., 2015, Robichaud et al., 2011 and 2012).

Thus, the current risk of erosion will be considered as maximum (grade 3) for any infrastructure within 5m of the coastline or 2018 shoreline, with the obvious exception of protective works. For example, a building or road within 5m of the coastline or 2018 shoreline will be in danger of immediate erosion, or at risk of erosion in the very near future (less than 10 years) (Figure 6).

Future erosion risks have been assessed based on the position of the coastline and shoreline as projected for the 2050s and 2100s, and within an arbitrary 5m safety margin. For example, infrastructure located within a distance starting 5m behind the 2018 coastline and ending 5m behind the projected 2050 coastline will be given a grading of 2. These infrastructures could therefore be in danger of erosion by 2050 and should be monitored primarily with a grade of 3.

Similarly, an infrastructure graded 1 on the risk index will be located in an area defined by a line 5m in front of the coastline or 2050 shoreline and a line 5m behind the coastline or the 2100 shoreline and will therefore be considered at risk of erosion between 2050 and 2100 (Figure 6).

Decision-makers in the municipality will and may need to establish broader safety margins than the 5m used in this study, which is very conservative as this safety margin does not consider a possible intensification of coastal storms and erosion rates related to climate change.

The risk index assigned to infrastructure is color-coded on map products to facilitate interpretation of results (Table 3).

Table 3: Erosion risk index for infrastructure.

3	**Risque d'érosion actuel** ***Currently at risk of erosion***
2	**Risque d'érosion d'ici 2050** ***Erosion risk before 2050***
1	**Risque d'érosion entre 2050 et 2100** ***Erosion risk between 2050 and 2100***
0	**Potentiellement sans risque avant 2100** ***Potentially no erosion risk before 2100***

The risk categories defined in Table 3 are applied to the infrastructures in order to represent the risk of erosion and to be able to easily identify them. Figure 6 shows an example of the application of these risk categories to buildings.

Figure 6. Example of application of the erosion risk index to buildings.

(See Table 2 for the legend)

4. RESULTS AND DISCUSSION

Coastline

The coastline of the study area is 21.2 km long (Table 4). While cliffs and micro-cliffs dominate the northern portion of the study site, there is a high concentration of protective structures in the southern portion. This means that about 57% of the coastline is artificialized.

Table 4: Coastline distribution by type.

Coastline type	Length (km)	(%)
ARTIFICIEL	10.1	47.5
ARTIFICIEL ACCES	0.6	2.7
ARTIFICIEL FIXE	1.6	7.7
DUNE	3.0	14.2
DUNE ACCES	0.1	0.3
FALAISEMEUBLE	1.9	8.9
FALAISEROCHEUSE	0.8	3.5
FERMETURE	0.2	0.8
FLECHELITTORALE	0.1	0.5
MEUBLE	2.9	13.7
PLAGE	0.0	0.2
Total	**21.2**	**100.0**

* see table 2 for the definitions

Sectors with homogeneous evolution

The 2018 shoreline of the study area that covers the Petit Rocher Sud shoreline at Pointe-Verte has been divided into 67 homogenous areas. A total of 46 of these sectors are eroding, 8 sectors have positive average rates and are therefore accreting, while 13 sectors are fixed.

The identifier of the sectors has been established according to the name of the municipality to which it belongs, with an identification number as well as the letter F when it concerns a fixed sector. The following maps (Figures 7 to 10) show the division of the study area into different homogeneous sectors.

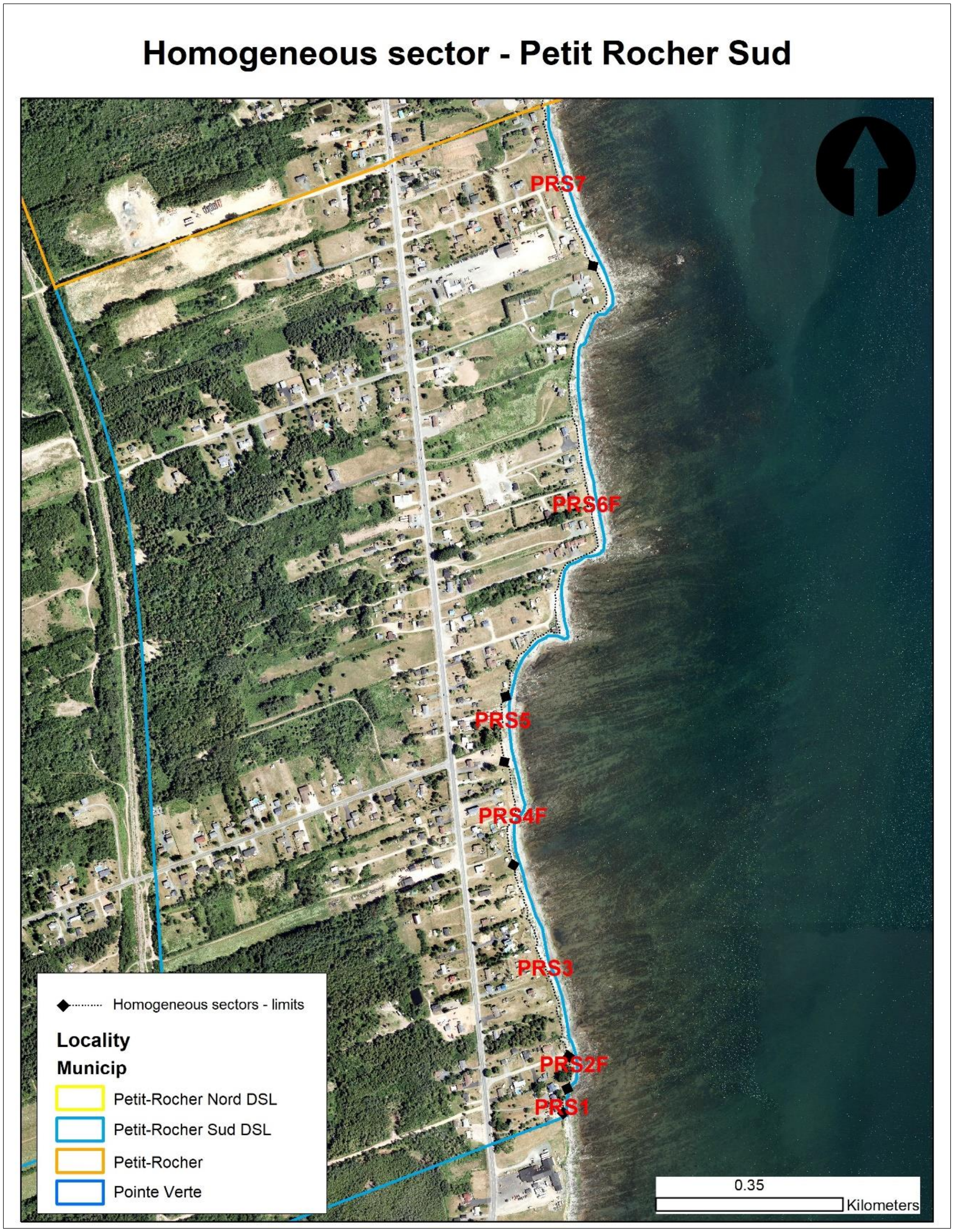

Figure 7. Map of sectors with homogeneous evolution in Petit-Rocher-Sud.

The labels are shown in red, for all the figures that follow as well.

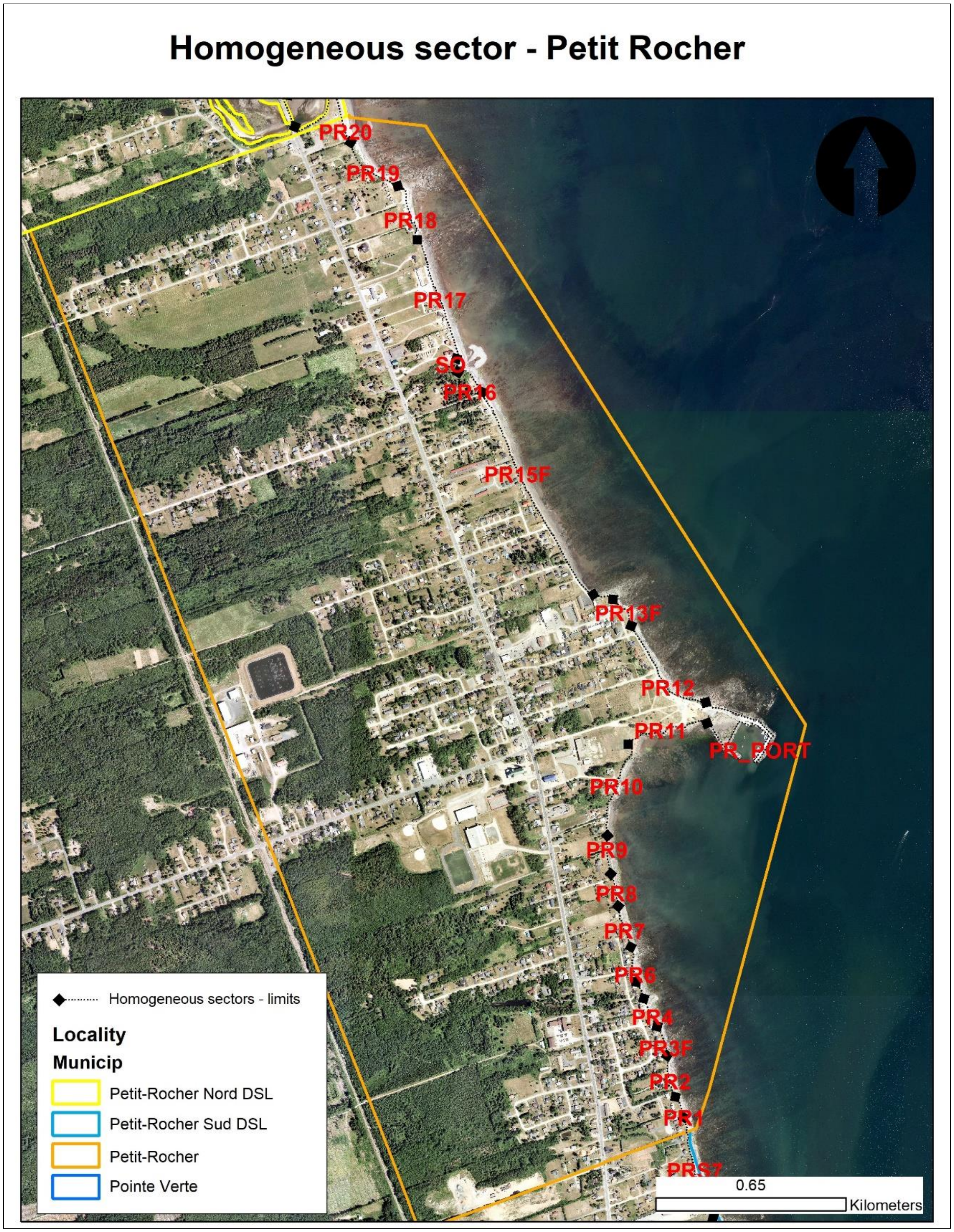

Figure 8. Map of sectors with homogeneous evolution in Petit-Rocher.

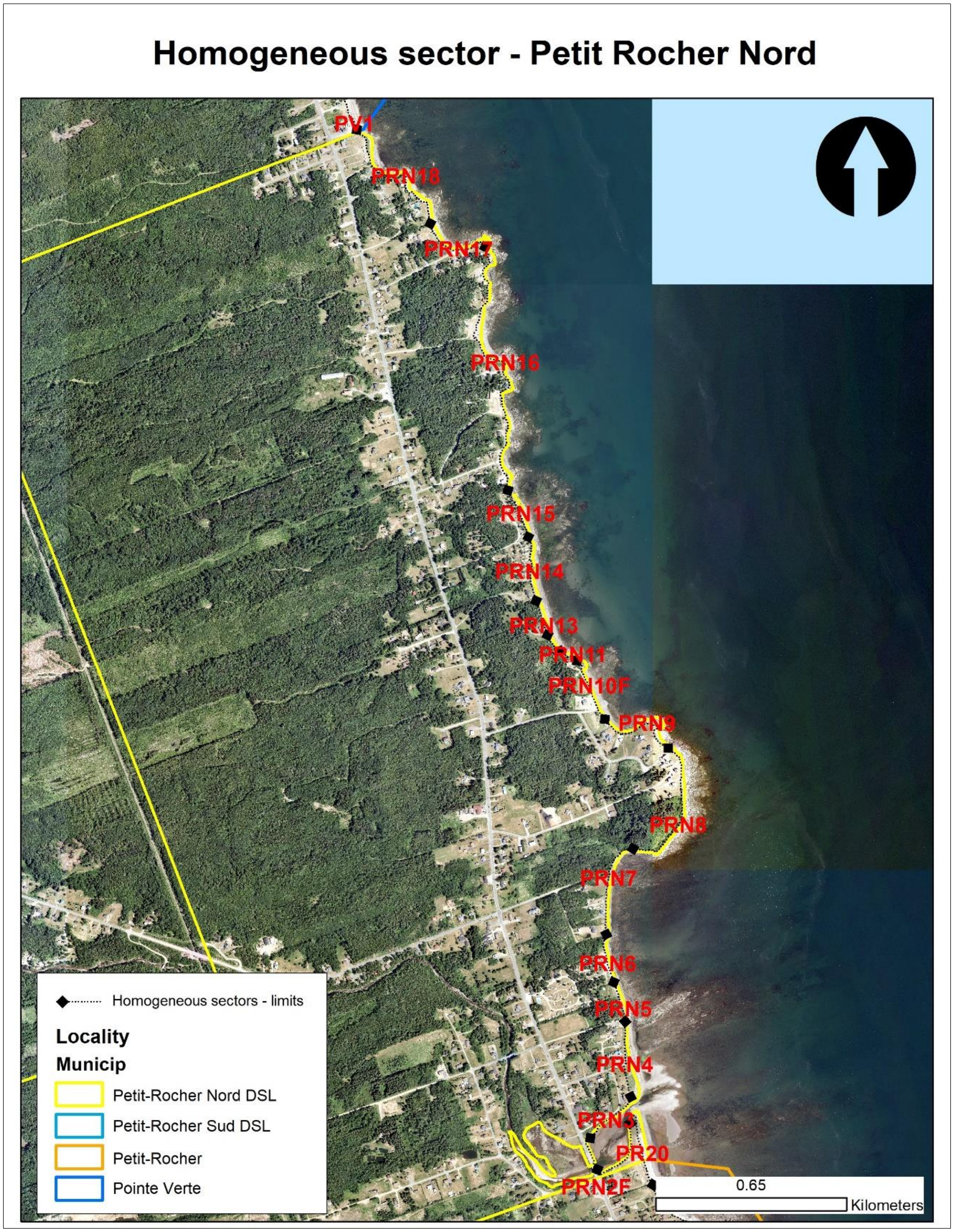

Figure 9. Map of sectors with homogeneous evolution in Petit-Rocher-Nord.

Figure 10. Map of sectors with homogeneous evolution in Pointe-Verte.

Overview of past shoreline evolution

In general, the municipality of Pointe-Verte and the DSL of Petit-Rocher-Nord are, in this order, the most affected by erosion. Indeed, the highest erosion rates by sector were observed in the PV12 sector in Pointe-Verte (-0.3 m / year) and the PRN sector in Petit-Rocher-Nord (-0.23 m / year). an). This is not surprising since this coastline shows forms of retreat (soft cliffs, etc.). The rates of change of the coastline by sector with homogeneous evolution are presented in appendix.

On the other hand, Petit-Rocher-Sud and Petit-Rocher include areas with the lowest erosion rates. This is because the coastline of these two territories is highly artificial and protected by imposing protective structures. Recall that, as Table 4 shows, the entire territory has about 57% of its protected coastline and a large proportion of these protective structures, often in the form of riprap or retention walls, are in the southern part of the study area (Figure 11).

Due to the artificialization and development of the littoral of the study area, eight sectors were kept fixed according to our scenarios. As mentioned previously, these sectors are identified by the letter F (for "fixed") at the end of their name. In accordance with our method, the decision to determine a sector as fixed is taken if, on a long stretch of coast, there is an artificial "advance" of the coastline. It is essential not to interpret these cases as natural accretion.

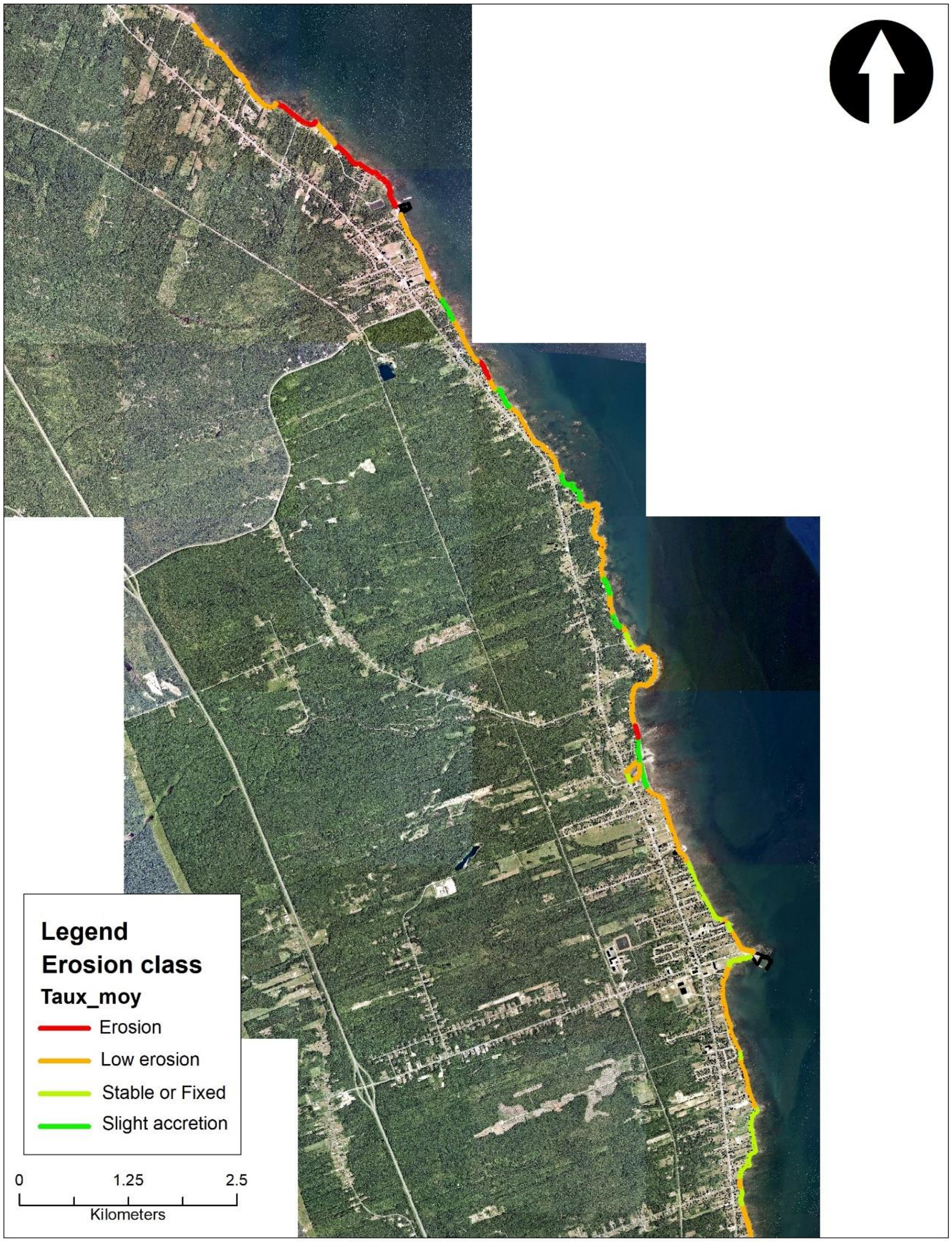

Figure 11. Evolution of the coastline in the region of Petit Rocher - Pointe-Verte between 1944 and 2018.Erosion: a decline> -0.15 m / year; Low erosion: decline between 0.15 and 0 m / year; Stable or Fixed: rate of change = 0 m / year; Slight accretion: advanced from 0 to 0.06 m / year.

Presentation of the results of the erosion risk analysis

The erosion risk analysis was carried out on all the infrastructure layers available for the study area. It is based on the position of the infrastructures with respect to projected shorelines in 2050 and 2100 according to the index described in the methods. Below, we present the infrastructures at risk of erosion according to the type of infrastructure.

It should be noted that the results described below are summary and tabular results. However, the geodatabase produced as part of this project as well as the generated ArcMap map (.mxd extension) allow for a finer geographical analysis and precise localization of the infrastructures at risk.

a. Buildings

A total of 80 buildings, identified during this study, have been identified as infrastructures that could potentially face a risk of erosion by 2100, 37 of which face a current risk, depending on their proximity to the coastline of 2018 (Table 5).

Table 5: Number of buildings per erosion risk index.

Index	Risk of erosion	Buildings
0	*Potentially no erosion risk before 2100*	*2772*
1	Erosion risk between 2050 and 2100	25
2	Erosion risk before 2050	18
3	Currently at risk of erosion	37
Affected buildings		**80**

Note: As an indication the number of infrastructures not affected by the erosion scenarios is also presented (in italics).

b. Sewers

The erosion analysis on the sewer system in the study area was carried out on 5 m sections (Table 6). The results of this analysis show that 197 sections of 5 m, equivalent to 0.98 km, of the network are at risk of erosion by 2100.

Table 6: Number of 5 m sections of sewer per erosion risk index.

Index	Risk of erosion	Sewer (5m)
0	*Potentially no erosion risk before 2100*	*6983*
1	Erosion risk between 2050 and 2100	42
2	Erosion risk before 2050	64
3	Currently at risk of erosion	91
Affected sewer		**197**

c. Electric poles

A total of 31 power poles have been identified as being at risk of erosion by 2100 (Table 7).

Table 7: Number of electric poles per erosion risk index.

Index	Risk of erosion	Electric poles
0	*Potentially no erosion risk before 2100*	*2220*
1	Erosion risk between 2050 and 2100	8
2	Erosion risk before 2050	5
3	Currently at risk of erosion	18
Affected electric poles		**31**

d. Sumps

According to the erosion risk analysis (Table 8), the 485 sumps that are in the study area will not be affected by erosion by 2100.

Table 8: Number of sumps per erosion risk index.

Index	Risk of erosion	Sumps
0	*Potentially no erosion risk before 2100*	*485*
1	Erosion risk between 2050 and 2100	0
2	Erosion risk before 2050	0
3	Currently at risk of erosion	0
Affected Sumps		**0**

e. Manholes

The erosion analysis of the views in the study area shows that most of these are immune to the risk of erosion (Table 9). In fact, out of the 340 eyes on the territory, nine are at risk of erosion by 2100, six of which are currently of concern.

Tableau 9: Number of manholes per erosion risk index.

Index	Risk of erosion	Manholes
0	*Potentially no erosion risk before 2100*	*340*
1	Erosion risk between 2050 and 2100	1
2	Erosion risk before 2050	2
3	Currently at risk of erosion	6
Affected manholes		**9**

f. Roads

The road erosion risk index was applied to sections of 5 meters in length. Thus, 250 sections of road, equivalent to 1.25 km, have been identified as being at risk of erosion by 2100. A total of 188 sections, or 0.94 km of roads, are threatened with erosion before 2100 (Table 10).

Table 10: Number of road sections per erosion risk index.

Index	Risk of erosion	Roads (5m)
0	*Potentially no erosion risk before 2100*	*340*
1	Erosion risk between 2050 and 2100	1
2	Erosion risk before 2050	2
3	Currently at risk of erosion	6
Affected roads		**250**

Summary of results

The data presented in this report will enable users to better understand the extent of infrastructure damage that could potentially be attributed to coastal erosion in the municipalities of Petit-Rocher, Pointe-Verte and Petit-Rocher-South and Petit-Rocher-Nord LSDs. It is also possible to create maps showing the distribution of erosion-risk infrastructure by sector in the study area from the geospatial data made available to the CRSC.

The following summary table shows the number of infrastructures that will be affected according to the erosion scenarios.

Table 11: Number of infrastructures at risk of erosion by erosion index.

Infrastructures	Index 0	Index 1	Index 2	Index 3	Total
Buildings	2772	25	18	37	2852
Geodetic marks	81	0	0	0	81
Sewer (5m)	6983	42	64	91	7180
Landfill	1	0	0	0	1
Pumping	5	1	1	0	7
Electric poles	2220	8	5	18	2251
Sumps	485	0	0	0	485
Manhole	340	1	2	6	349
Roads (5m)	12384	38	24	188	12634
Valves	68	0	0	0	68

*Index 0: Potentially no erosion risk before 2100

*Index 1: Erosion risk between 2050 and 2100

*Index 2: Erosion risk before 2050

*Index 3: Currently at risk of erosion

5. CONCLUSION

This study focused on the development of erosion scenarios and the identification of infrastructures at risk until 2100 for the municipalities of Petit Rocher and Pointe-Verte and the DSLs of Petit-Rocher-Sud and Petit-Rocher-Nord. It used the most recent data available, including the infrastructure data layers of the Chaleur RSC, as well as tried and tested techniques.

Depending on the coastline projection scenarios, the risk of erosion varies from one sector to another in the study area. Areas to the south are largely protected by "hard" coastal infrastructure including retaining walls and rip rap. The historical erosion rates measured in these areas are lower than those measured in the north where the shoreline is natural (unprotected) and composed mainly of receding loose cliffs.

Although, in general, the rates of erosion observed in the whole territory are relatively low, some interest should be given to the extreme conditions expected in the future. Storms cause a great alteration of the coastline and tear off many sedimentary materials at the coast. It is expected that erosion will be faster due to increased sea level, stronger storms, sediment deficit (sometimes caused by erosion suppression by rigid structures along the coast or by past or current aggregate extractions) and a decrease in winter ice cover. The historical rates of shoreline movement presented in this report reflect the environmental conditions of the past but could be higher in the next century. The fact that protective structures have been established in the study area indicates that there is already an erosion problem in the area.

It should be noted that the coastline projection scenarios developed for this project and similar projects in northeastern New Brunswick are rather conservative because they are based on past and current data and that more problematic or even catastrophic scenarios are possible. This is also partly due to the homogenous sector projection method used which masks the higher or extreme erosion rates and generalizes the shift of the coastline. The scenarios produced by this method assume an evolution continuing at the same rate observed before 2018, whereas the probability is that the erosion rates will be higher in the future, perhaps up to 1.5 times more (or 50% more) (Davidson-Arnott and Ollerhead, 2011). In addition, we must not exclude the possibility of an exceptional event and keep in mind that an extreme scenario like Xynthia (France) (Péret and Sauzeau, 2014) may occur.

Coastal communities around the world, including those in this study, will need to take the time to prepare and plan accordingly and, above all, avoid development in current and future risk areas. Some observers claim that this is the main problem faced by our society. An advantage compared to overcrowded areas is that CRSC municipalities and DSLs have in many cases enough territory to allow development further away from the shoreline. The CRSC's adaptation plan should consider this benefit and the knowledge gained from projects such as this one and those to come.

Regardless of the sector considered, it would be wise in most cases not to succumb to the temptation of settling too close to the coast "where it is so good to live" or to allow the development of commercial or industrial facilities or infrastructures and activities leading to high vulnerability such as the establishment of care homes near the sea. Adaptation to climate change now requires considering that some risks will increase and reach degrees unknown until now. The example of recent river flooding in eastern Canada is an evocative demonstration. We must develop the reflex of thinking that things will not be as before, which is often difficult to imagine when we have lived in a place for a long time, that habits are well established and that we have never seen certain events happen like seeing seawater on one’s land. The risk data presented in this study are intended to help predict future flood and erosion risks in a realistic coastal community such as there is in New Brunswick, but with a warning that the projections proposed are very conservative.

Finally, the geospatial data produced in this study can be used as a decision support tool to identify erosion-risk infrastructure, identify the most vulnerable areas and thus help the CRSC, municipalities and LSDs studied in their adaptation and resilience to the effects of climate change.

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GLOSSARY

« Arc GIS »	means Arc GIS (version ≥ 10.3.1), from ESRI;
« Bidder »	means any person or company who files or intends to file a proposal in response to this RFP;
« Coastline »	is defined as the limit of the large tide higher high water in situation of normal wave runup. Therefore, the coastline represents the seaward limit of bedrock or unconsolidated cliffs, vegetated slopes (along salt marshes), sand dunes and man-made coastal structures;
« Commission »	means the Chaleur Regional Service Commission;
« Committee »	means the Chaleur Regional Committee on Climate Change Adaptation (CRACCCA);
« Consultant or Supplier »	means the bidder or supplier chosen in the context of the present RFP who signs a written contract with the Commission;
« CRSC »	means the Chaleur Regional Service Commission;
« CZRI »	means « Coastal Zone Research Institute », now renamed « Valores »;
« Director»	means the Planning Director of the Commission;
« DSAS »	means « Digital Shoreline Analysis System »
« ESRI »	means « Environmental Systems Research Institute »;
« LSD »	means Local service district;
« NAD83 »	means « North-American Datum 1983 »;
« Project »	means the services and the deliverable to be carried out by the consultant as per the present request for proposal;
« RFP »	means Request for proposal;
« RSC »	means Regional Service Commission;
« Shoreline »	is here defined as the limit of the mean tide higher high water in situation of normal wave runup. Therefore, the shoreline represents the seaward limit of rock platforms, salt marshes, sand or gravel beaches, or man-made shore structures.
« USGS »	means « United States Geological Survey »; and
« Valores »	previously known as « CZRI » or « Coastal Zone Research Institute ».

ANNEXES

ANNEX 1 – Description of attributes of the 1944 shoreline

1944 coastline				
File	**Description**	**Attribute**	**Type**	**Value**
*_TC1944	Type of the coastline	***TC_TYPE***	Text	*ARTIFICIEL* *ARTIFICIELACCES* *ARTIFICIELFIXE* *DUNE* *DUNEACCES* *FALAISEMEUBLE* *FALAISEROCHEUSE* *FERMETURE* *FLECHELITTORALE* *MARAIS* *MEUBLE*
*_TC1944	Aerial photo used to scan the coastline	***PH_source***	Text	The name of the 1944 aerial photograph used in the digitization. Composed of the letter A, the number of the flight line, a dash down '_' and the number of the photo. Ex. A7387**_**37
*_TC1944	Reference year for the coastline	***Year***	Short integer	1944
*_TC1944	Digitization area	***NUM_ZONE***	Text	Center: Digitization was done from the center of aerial photography. Margin: Digitization was done from the margins of aerial photography.
*_TC1944	Vecteur length	***Shape_len***	Double	Length of the vector in meters.

ANNEX 2 – Description of attributes of the 2018 shoreline

2018 coastline				
File	**Description**	**Attribute**	**Type**	**Value**
*_TC2018	Type of coastline	***TC_TYPE***	Text	*ARTIFICIEL* *ARTIFICIELACCES* *ARTIFICIELFIXE* *DUNE* *DUNEACCES* *FALAISEMEUBLE* *FALAISEROCHEUSE* *FERMETURE* *FLECHELITTORALE* *MARAIS* *MEUBLE*
*_TC2018	Level of protection	***PROTECTION***	Short integer	The name of the 1944 aerial photograph used in the digitization. Composed of the letter A, the number of the flight line, a dash down '_' and the number of the photo. Ex. A7387_37
*_TC2018	Behavior during projections.	***FIXE***	Short integer	***0***: Mobile in the projections ***1***: fixed in the projections because protected
*_TC2018	Vecteur length	***Shape_len***	Double	Length of the vector in meters.

ANNEX 3 – Description of transects attributes

FIELD	TYPE	DESCRIPTION
FID	Object ID	Unique identifier generated automatically by Arc Map.
Shape	Geometry	Automatically generated by Arc Map. Value: Polyline
TransOrder	Long	The order of the transects as they were created.
TCTYPE1944	Text (25 Chr)	Type of 1944 coastline that intersects the transect. (See Coastline metadata for a full description of the values used).
TCTYPE2018	Text (25 Chr)	Type of 2018 coastline that intersects the transect. (See Coastline metadata for a full description of the values used).
PROTECTION	Short integer	0: 2018 coastline that intersects the transect is not protected by an artificial structure. 1: 2018 coastline that intersects the transect is protected by an artificial structure.
FIXE	Short integer	0: The 2018 shoreline that intersects the transect is not held fixed in the projections. 1: The 2018 shoreline that intersects the transect is held fixed in the projections.
EXCLUSION	Short integer	0: The transect is not excluded from the calculation of the average rate of change of the homogeneous sector to which it belongs. 1: The transect is excluded from the calculation of the average rate of change of the homogeneous sector to which it belongs.
EPR	Double	The EPR or End Point Rate (meters / year) corresponds to the change rate of the individual transect. It is obtained by the division of the distance of movement of the coastline by the number of years used in the study (2018 - 1944).
SCE	Double	The SCE or Shoreline Change Envelope is the actual distance (in meters) of coastline movement between the two dates used in the study.

NSM	Double	The NSM or Net Shoreline Movement (in meters) is the movement distance between the oldest coastline (1944) and the most recent coastline (2018). A negative NSM value corresponds to an erosion phenomenon, while a positive value corresponds to an accretion phenomenon.
SECTEUR	Text	Name of the homogeneous evolution sector to which the transect belongs. The sector name is a concatenation between a series of letters that represents the name of the locality, followed by a number to distinguish the different sectors of the same locality and possibly the letter F to indicate whether the sector is kept fixed in the localities. projections. EX1: PR1 -> Small Rock - sector 1 EX2: PV11F -> Green Tip - sector 11 - fixed in projections.

ANNEX 4 – Average rates of change in shoreline position

The following tables show the average rates of change in shoreline position by sector with homogeneous evolution.

Table I. Average rates of shoreline position by homogenous sector in the municipality of Petit-Rocher.

Zone	Sector	Length (m)	Average rate (m / year)
Petit-Rocher	PR_PORT	838	S.O.
Petit-Rocher	PR1	77	0.00
Petit-Rocher	PR2	163	-0.07
Petit-Rocher	PR3F	117	0.00
Petit-Rocher	PR4	110	-0.07
Petit-Rocher	PR5	65	-0.02
Petit-Rocher	PR6	130	-0.05
Petit-Rocher	PR7	156	-0.13
Petit-Rocher	PR8	125	-0.03
Petit-Rocher	PR9	135	-0.06
Petit-Rocher	PR10	364	-0.01
Petit-Rocher	PR11	312	0.00
Petit-Rocher	PR12	407	-0.08
Petit-Rocher	PR13F	127	0.00
Petit-Rocher	PR14	78	-0.07
Petit-Rocher	PR15F	853	0.00
Petit-Rocher	PR16	129	-0.03
Petit-Rocher	PR17	471	-0.03
Petit-Rocher	PR18	233	-0.05
Petit-Rocher	PR19	237	-0.04
Petit-Rocher	PR20	307	0.05

Table II. Average rates of shoreline position by sector with homogeneous evolution in the municipality of Petit-Rocher Nord.

Zone	Sector	Length (m)	Average rate (m / year)
Petit-Rocher Nord	PRN1	259	-0.07
Petit-Rocher Nord	PRN2F	130	0.00
Petit-Rocher Nord	PRN3	208	-0.01
Petit-Rocher Nord	PRN4	269	0.06
Petit-Rocher Nord	PRN5	144	-0.23
Petit-Rocher Nord	PRN6	173	-0.13
Petit-Rocher Nord	PRN7	346	-0.09
Petit-Rocher Nord	PRN8	497	0.00
Petit-Rocher Nord	PRN9	322	-0.05
Petit-Rocher Nord	PRN10F	236	0.00
Petit-Rocher Nord	PRN11	84	-0.05
Petit-Rocher Nord	PRN12	72	0.03
Petit-Rocher Nord	PRN13	125	0.00
Petit-Rocher Nord	PRN14	245	-0.03
Petit-Rocher Nord	PRN15	199	0.01
Petit-Rocher Nord	PRN16	1045	-0.06
Petit-Rocher Nord	PRN17	269	-0.01
Petit-Rocher Nord	PRN18	512	0.02

Table III. Average rates of shoreline position by sector with homogeneous evolution in the municipality of Petit-Rocher Sud.

Zone	Sector	Length (m)	Average rate (m / year)
Petit Rocher Sud	PRS1	53	-0.05
Petit Rocher Sud	PRS2F	64	0.00
Petit Rocher Sud	PRS3	421	-0.05
Petit Rocher Sud	PRS4F	223	0.00
Petit Rocher Sud	PRS5	134	-0.03
Petit Rocher Sud	PRS6F	1011	0.00
Petit Rocher Sud	PRS7	390	-0.05

Table IV. Average rates of shoreline position by sector with homogeneous evolution in the municipality of Pointe Verte.

Zone	Sector	Length (m)	Average rate (m / year)
Pointe Verte	PV_PORT	761	S.O.
Pointe Verte	PV1	1058	-0.02
Pointe Verte	PV2	298	0.01
Pointe Verte	PV3	151	-0.04
Pointe Verte	PV4	248	-0.17
Pointe Verte	PV5	389	-0.05
Pointe Verte	PV6	192	-0.11
Pointe Verte	PV7F	316	0.01
Pointe Verte	PV8	148	-0.05
Pointe Verte	PV9	81	-0.13
Pointe Verte	PV10	608	-0.06
Pointe Verte	PV11	302	-0.14
Pointe Verte	PV12	574	-0.30
Pointe Verte	PV13	582	-0.18
Pointe Verte	PV14	203	-0.14
Pointe Verte	PV15	146	-0.06
Pointe Verte	PV16	559	-0.17
Pointe Verte	PV17	483	-0.06
Pointe Verte	PV19	1013	-0.06