Protecting the Trans-Canada Highway at Souris with Inter-tidal Reefs

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Project Description

Shoreline erosion and relative sea level rise are increasing the risk of flooding and storm damage to Highway 2 as it approaches the Town of Souris. Climate change with the associated rising sea levels, reduced ice cover and changing storm patterns threaten to exacerbate this problem.

In order to improve protection of the PEI portion of the Trans-Canada Highway (Hwy 2), PEI Transportation Infrastructure and Energy (PEI-TIE) worked with Coldwater Consulting Ltd. to develop and construct a two-part shore protection scheme that combined hard protection for the highway infrastructure with beach restoration works that would improve the resilience of the beach and dune system:

1. A timber/piled seawall was constructed parallel to Highway 2. This seawall allows for protection of the highway, while also extending the existing promenade along the top of the seawall. The wall was set back from the beach face to allow adequate space for beach restoration.
2. Dune restoration and shoreline stabilization works were undertaken to restore and strengthen the existing sand beach – dune system. The beach restoration works included the construction of two ***inter-tidal reefs***.

This is the first time that inter-tidal reefs have been used on the Island. An example of 'building with nature', the sandstone reef structures provide two primary functions: wave attenuation, dampening the effects of storm waves on the beach area and highway infrastructure; and, creating an area of calmer water on the landward side of the reefs where sand that is moving along the shore area will slow down and deposit and, over time, accumulate and cause the beach to grow / extend offshore towards the reefs. The result is increased beach width and protection of the dunes and coastal / highway infrastructure. Sediment supply to the reef area comes from the waters of Colville bay as shown by the sediment transport patterns in Figure 1. These transport patterns are supported by computer modelling of sediment transport along the beach as well as by the empirical evidence that the beach glass that accumulates along Souris Beach comes from the former town dumpsite to the east of Souris Harbour.

The use of PEI sandstone for the reefs provides a natural marine substrate for the development of benthic flora and inter-tidal pools. It also offers the aesthetic benefit of blending-in with the exposed sandstone found elsewhere along the coast. While not as durable as, say, concrete or imported granite, the sandstone is locally available (reduced haulage costs and associated CO_2 emissions) and, will eventually break down into beach sand.

The project has been undertaken as a demonstration project, with the financial support being shared between the Province of Prince Edward Island and the federal government through Public Safety

Canada's Natural Disaster Mitigation Program. The project is consistent with 'adaptation' principles outlined in the Province's Climate Change Strategy, and the intent is to demonstrate techniques for the protection of coastal infrastructure against flooding and erosion hazards through the use of nature-based design principles.

The project was completed in early 2018 and a monitoring program has been implemented to document shoreline conditions using both RTK-GPS surveys and drone-based ortho-photogrammetry. Monitoring to date is showing that beach changes are consistent with the numerical modelling predictions used in the design process. Figures 2 through 4 illustrate the successful performance of the reefs to-date. Figure 5 shows the colonization of the sandstone with benthic macroalgae and eel grass and the development of inter-tidal pools around the base of the reefs.

Souris Beach is an important local tourist and recreational attraction, and the beach improvements have led to increased use and enjoyment of the shore.

Supporting Information

Provincial Highway 2 forms part of the Trans-Canada highway system and forms a vital link to the Town of Souris and to the Inter-Provincial ferry to the Magdalene Islands. This link crosses the Souris River just west of the town of Souris and runs along Souris Spit, a sand barrier that separates the Souris River estuary from the waters of Colville Bay and the Northumberland Strait. This sand spit is low-lying and its eastern terminus has been erosional for the past thirty years. A combination of storm surge, tides and wind waves from storms in 2016 eroded much of the small dune system along the beach, bringing flood waters to the edge of the highway.

Ongoing erosional hazards, combined with the prospect of worsening conditions under climate change (rising seas, less ice, changing storm patterns) suggest that the risk of flooding and temporary closure of the Trans-Canada at this location will increase over time. These considerations, along with the erosion and inundation observed during the 2016 storms, led to a decision by the Province to protect the highway.

With increasing concern over the effects of climate change, there is an increased interest in developing durable, resilient shore protection works. Too often, coastal protection works involve the armouring of a shoreline to protect land and infrastructure, while often destroying the beach. From both ecological and societal perspectives, the sandstone bluffs and sandy beaches of Prince Edward Island are too important to allow them to be lost beneath concrete and imported stone. The development of innovative protection works that can stabilize and build beaches and enhance dunes is an essential step in the Province's development of truly resilient and sustainable measures to address coastal hazards and climate change.

Coldwater Consulting has been working with PEI-TIE since 2010 on coastal protection works such as those at Souris; some of these project locations include Panmure Island Causeway, Crowbush Golf Course, and Basin Head Beach. The emphasis has always been on only building shore protection when it is economically and logistically imperative, and on integrating beach and dune protection within any such works ("Shore protection, if necessary, but not necessarily shore protection", to paraphrase McKenzie-King).

The use of offshore, detached breakwaters for beach stabilization and protection has gained widespread use internationally, and this project provided a unique opportunity to apply experience from other regions to the PEI shoreline. Previously, Coldwater has been involved in similar works in the Great Lakes, the Caribbean, the US Gulf of Mexico coastline and in the US Pacific Northwest.

The design for the Souris reefs is based on numerical modelling of waves and sediment transport along Souris Beach in conjunction with geomorphic assessments of coastal processes. The Town of Souris and the Souris Area Branch of the PEI Wildlife Federation were consulted extensively as part of the design process, through both public sessions and inter-agency consultations.

Figure 1 Sediment pathways in Colville Bay

Figure 2 Oblique aerial April 2018

Figure 3 Inter-tidal reefs at mid-tide July 2018

Figure 4 Inter-tidal reefs at low tide, August 2018 showing sediment accumulation in lee

Figure 5 Inter-tidal reefs at low tide, August 2018 showing benthic colonization

Prior Works

An armour-stone revetment was placed in front of the washrooms following the severe storms of December 2001 - January 2002. Continuing erosion to the shoreline immediately downdrift (to the east) of the revetment triggered further shore protection works in 2012 wherein a timber crib / steel pile seawall was built, known locally as a Langley Wall.

The wall is constructed of cambered steel H-piles supporting a timber lattice. The lattice is somewhat open (8cm vertical spacing between 15cm wide boards). The backfill of the wall is riprap stone. This combination of a cambered, open-faced wall, and stone backfill helps to reduce wave reflections from the face of the wall. Recent surveys indicate that the seabed in front of the wall has not changed significantly since the wall was built. Typically, it is undesirable to build a seawall such as this at the water's edge without any compensatory beach restoration.

As part of the 2012 works, Park facilities were upgraded to include a visitor access point including a small retail outlet, parking, seating and viewpoints. Dune restoration work (sand fencing) was also constructed at this time to the west of the seawall. These sand fences have been affected and were virtually completely buried in captured sand prior to the recent storm.

Storm of January 2016

A winter storm struck on January 13-14 2016 that caused significant erosion of the dunes just west of the Langley wall. This raised concerns about the vulnerability of the highway to damage in subsequent storm events.

Post-Storm Survey

The following photos show taken by Don Jardine of the UPEI Climate Lab, who visited the site on January 19th to inspect and photograph post-storm conditions.

Dr. Adam Fenech's team at the University of PEI's Climate Lab conducted a post-storm survey of the beach using an aerial drone on January 23rd. Data from the drone survey was post-processed to create an ortho-rectified composite aerial photograph of the site as well as a high-resolution digital elevation model that shows the elevations of the beach and dunes within an accuracy of a few centimetres.

The aerial photo mosaic from the drone survey is shown on the next page, followed by the elevation map produced by the drone survey. The map and images show that the beach dune is quite low and narrow for a distance of approximately 150m.

Photos showing beach conditions post-storm.

Sand fencing had previously been almost completely buried by dunes that had grown since construction of the Langley wall in 2012.

January storm removed almost all of the dune, leaving very little remaining dune between the shore and the highway.

Photo credit: D. Jardine, UPEI Climate Lab

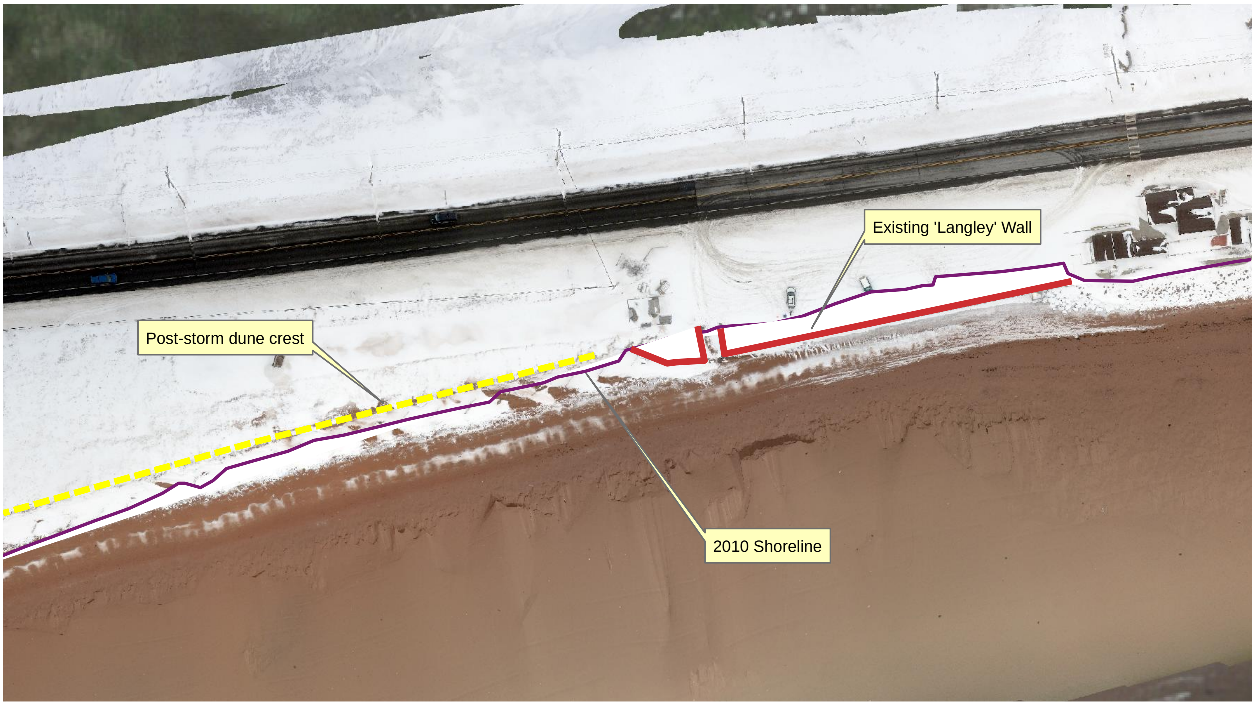


Figure 6 Aerial composite imagery Jan 23 2016

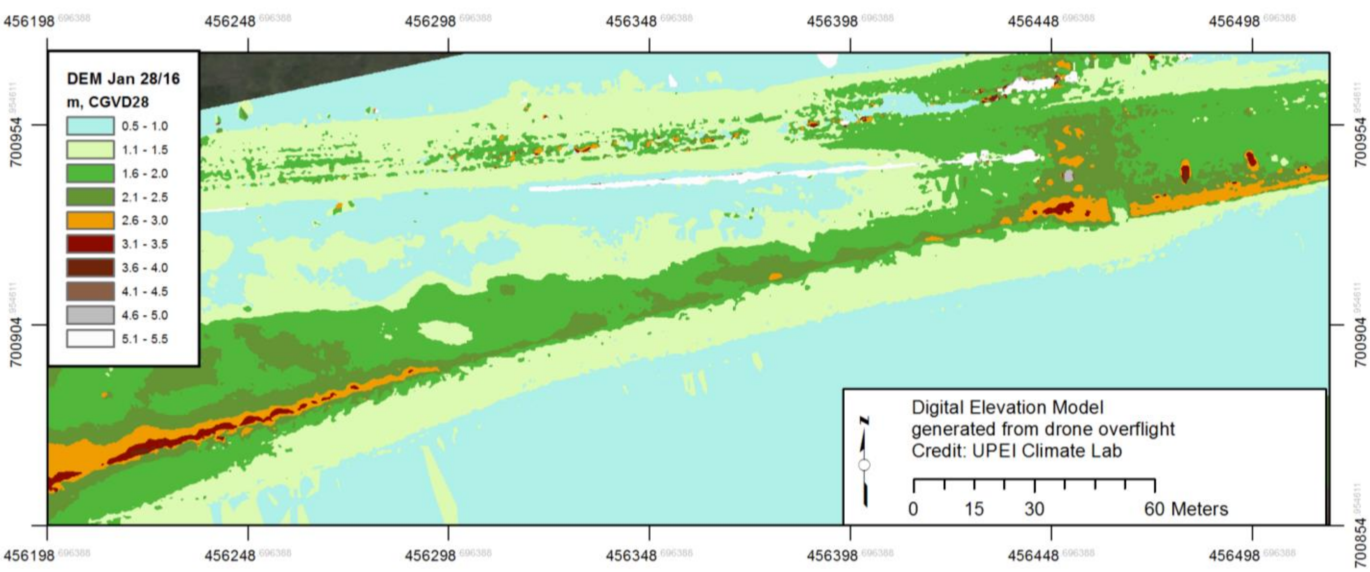


Figure 7 Elevations from drone overflight 23 Jan 2016 – NOTE DEM is presented relative to CGVD28 datum.

Profiles taken from this DEM have been compared to previous survey results for this shoreline. The prior surveys (from 1999 and 2010) pre-date the dune restoration works that were undertaken in 2012.

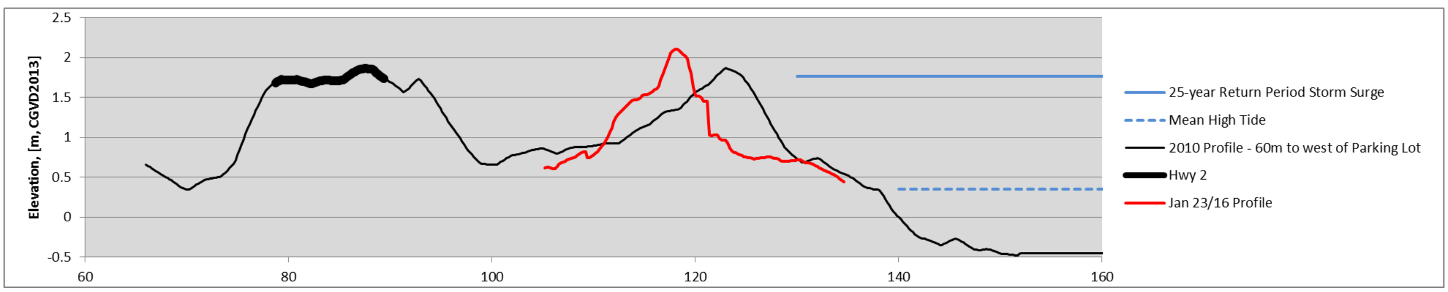
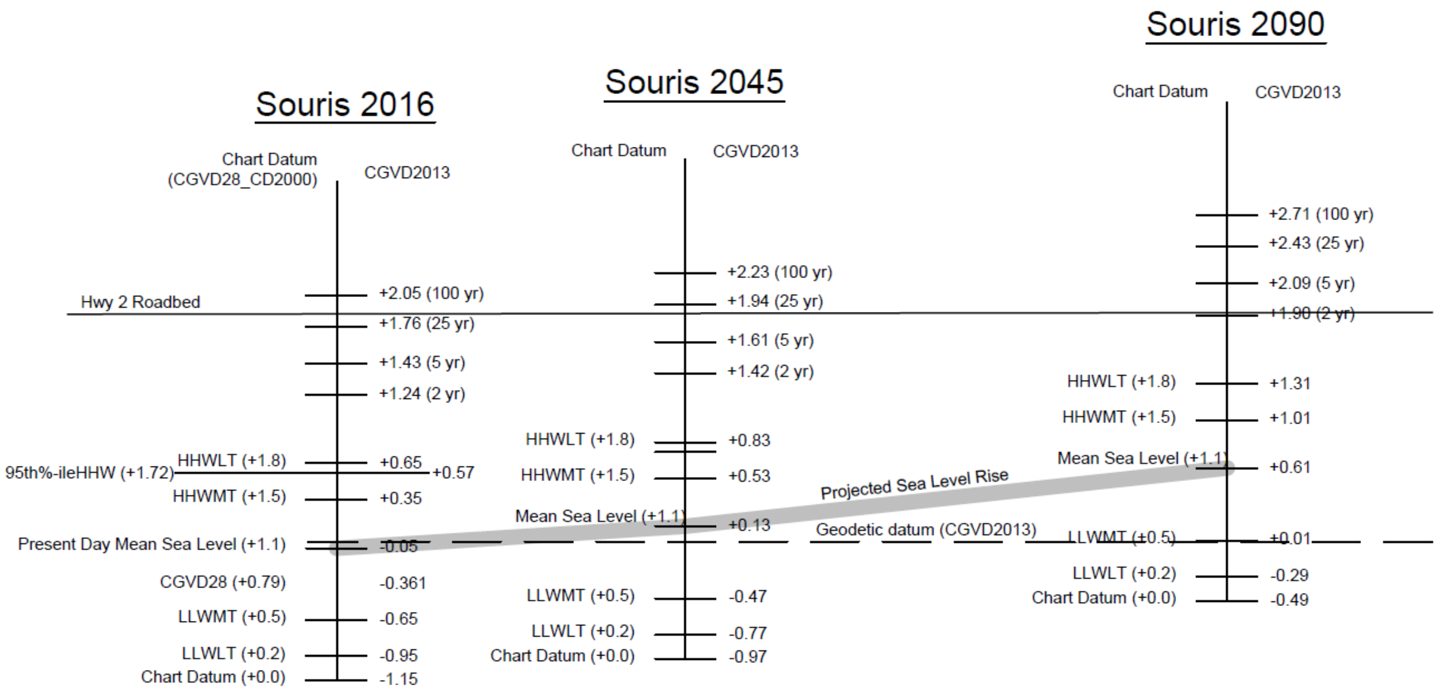


Figure 8 Beach profiles

Analysis of beach profiles at several locations from the end of the existing seawall to 200m west show that the beach lost between 4.5 to 6.0 m^2 of cross-sectional area between 2010 and 2016. The remaining dune (as of January 23rd) had a crest elevation of between 2.1 and 2.5m with some spots as low as 2.1m. With the very small volume of remaining sand, a single storm would now be capable of breaching the dunes, allowing wave action to reach the edge of the highway. Given that the highway is lying at approximately the 25-year return period still water level, this placed the highway at considerable risk of storm damage.



Notes:

1) CGVD2013 is the new Canadian Geodetic Vertical Datum which replaces CGVD28
2) Chart Datum in Canada, is targeted to Lower Low Water Large Tide (LLWLT). This is the "lowest predicted water level, averaged over several years".
3) This diagram uses MSL of -0.024m CGVD2013 in 2016 (based on Charlottetown tide gauge)
4) Relative Sea Level RIse scenarios are based on James, T., Henton, Leonard,J., Darlington, L., Forbes, D. & Craymer, M. (2014). Relative Sea-level Projections n Canada and the Adjacent Mainland United States. Geological Survey of Canada, Open File 7737, 72 pp.

Figure 9 Water levels at Souris including relative sea level rise

Figure 9 shows the water levels considered in this study. Levels are expressed in terms of the geodetic datum (CGVD2013) (right-hand side) and hydrographic chart datum (left-hand side).

The three water level sets represent (from left to right), water levels in 2016, in 2045 and in 2090. The +1.10m geodetic water level from the January 2016 storm comes in at just less than the 2-year return period storm (1.24 m).

The highway between the bridge and the Town of Souris has a typical elevation of 1.8 m geodetic which is below the present-day 100-yr design water level of 2.05 m. Long-term planning for the bridge and road link will likely need to consider raising the elevation of this roadbed. In the meantime, some improved protection of the highway was deemed warranted.

Prior Assessment

Previously, a review of erosion conditions along the Souris Beach Provincial Park was conducted by the Atlantic Geoscience Centre of Natural Resources Canada (Forbes, 1999). This work included detailed sidescan sonar surveys of Colville Bay, which have helped in delineating sand resources on the seafloor. The key findings of Forbes' report are:

- Forbes' report indicates that the sidescan sonar does show sand accumulation along the offshore side of the breakwater but states that "even in the absence of the breakwater (and other harbour structures), it is probable that relatively little sand would be added to the beach from outside the bay."

- Net transport of sand along the beach is from east to west and much of the sediment lost from the beach over the past century appears to have accumulated in flood-tidal deposits in the estuary behind the beach.

Further examination shows that the general configuration of a sandy shore transitioning to a bluff face is substantially unchanged from 1880 – it is possible that the sand beach previously extended as much as 50 m further to the east but no more than that. The wharf at Souris has been in place since at least 1880 given that it appears in the Meacham Atlas in the same location and configuration as present.

Existing Groynes

A series of 6 low elevation groynes were placed along the spit shoreline by the Provincial government in the early 1980s. These groynes are composed of small gabion baskets with an elevation only approximately 30cm above the seabed. The gabions have remained in place for some 30 years but have had minimal influence on the shoreline. A groyne field would typically be expected to contain sand between each pair of groynes (cell) and eventually establish cuspate pocket beaches within each cell. Groyne effectiveness typically comes to an end once wave action is able to reach behind the groynes. The groyne placement never created these pocket beaches since the groynes did not extend high enough (vertically), nor far enough inland to contain sediments.

As discussed in Coldwater 2011, these groynes are not considered to have been a significant factor in overall beach stability.

Shoreline Change Analysis

Analysis of air photos from 1935 through 2000 was presented in Coldwater 2011. At that time the focus of attention was from chainage 0-200m (the eastern-most end of the spit). Shifting the focus slightly westward to chainage 200-400m (the area immediately to the west of the existing Langley Wall), results in the following:

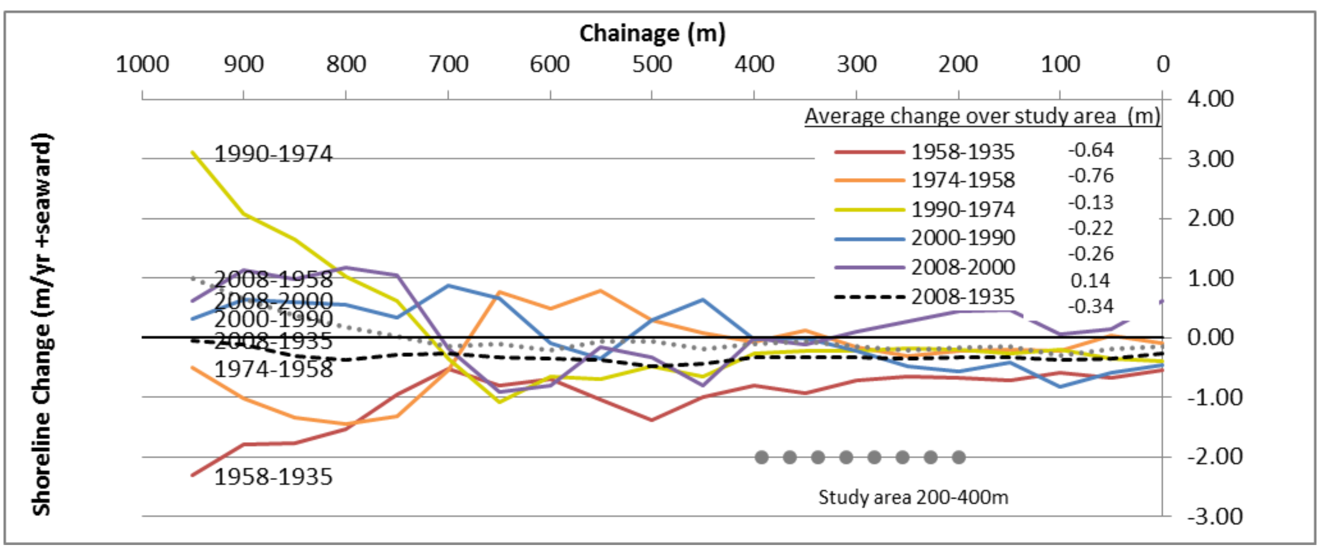


Table 1 Average erosion/accretion rates from shoreline change analysis

Time	Average change (m/yr)	
Interval	400-200m	400-950m
1958-1935	-0.76	-1.255
1974-1958	-0.13	-0.344
1990-1974	-0.22	0.417
2000-1990	-0.26	0.403
2008-2000	0.14	0.163
2008-1958	-0.34	0.130

The general findings with respect to long-term erosion of this shoreline are:

- The spit experienced large-scale erosion between 1935 and 1958 in response to bridge realignment
- Long term erosion rate west of the existing Langley wall (chainages 200-400m) is about 34cm/yr.
- The rest of the spit (chainages 400-950m) is relatively stable (accretion rate of 13cm/yr since 1958)

Shoreline Change Modeling

In order to determine the impacts of post-project condition on shoreline, both pre- and post-project conditions was analyzed using the US Army Corps of Engineers GENESIS model (GENEralized Model for SImulating Shoreline Change) (Hanson & Kraus, 1989). This model computes changes to beach plan-shape in response to sediment supply, waves, and the presence of sediment control structures.

Calibration of the GENESIS model was based on reproduction of observed historical shoreline changes. The results of the calibration process are shown in Figure 10. The agreement between the GENESIS predictions and the observed beach behaviour is deemed sufficient to allow the GENESIS model to be used as a predictor of future beach response following construction of the proposed reefs.

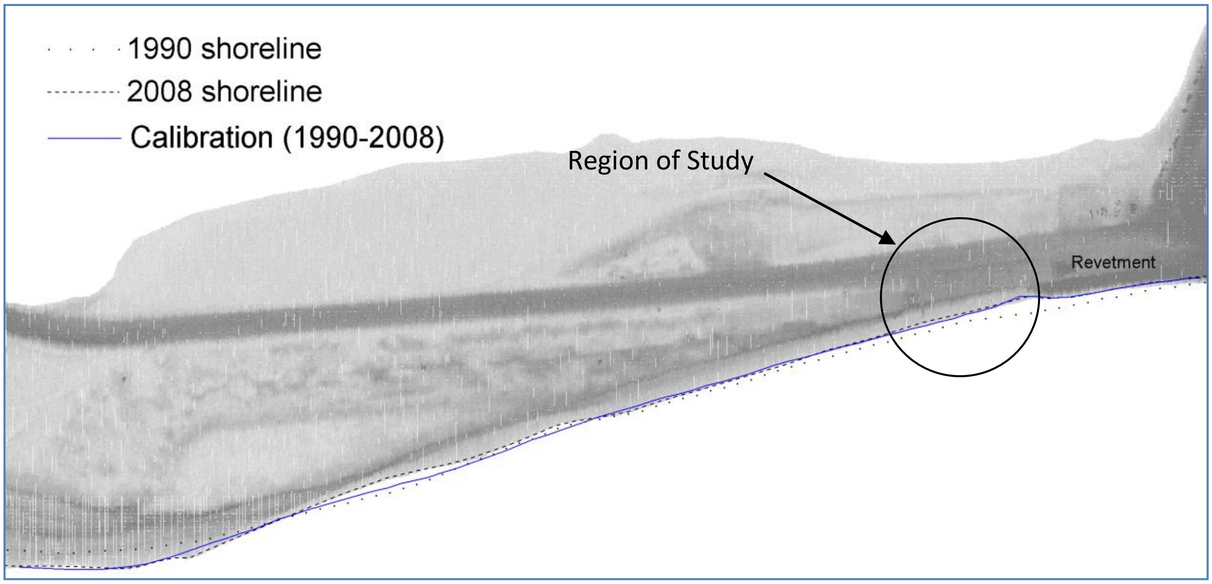


Figure 10 Calibration of the GENESIS model

Following model calibration, a 'do-nothing' alternative was simulated to predict the shoreline shape 5 years from now if no shore protection is built. As can be seen from Figure 11, if no action is taken the shoreline is expected to steadily erode resulting in scarping of the beach face and loss of more of the parking lot.

Figure 12 shows the results of the GENESIS model for the 10-year simulation for the proposed offshore reefs. As illustrated in the figure, an excess of sand is captured landward of the reefs. While this may seem ideal in creating a beach, trapping of sand at the project site creates a loss of sand downdrift, potentially leading to increased erosion in the affected areas. To counter this, reef projects include the placement of sand, or pre-fill, during construction. The pre-fill volume of sand is equivalent to the amount that is estimated to be captured by the structure under average water levels. The results of the GENESIS model for the proposed offshore reefs (breakwaters) and pre-filled beach is shown in Figure 12.

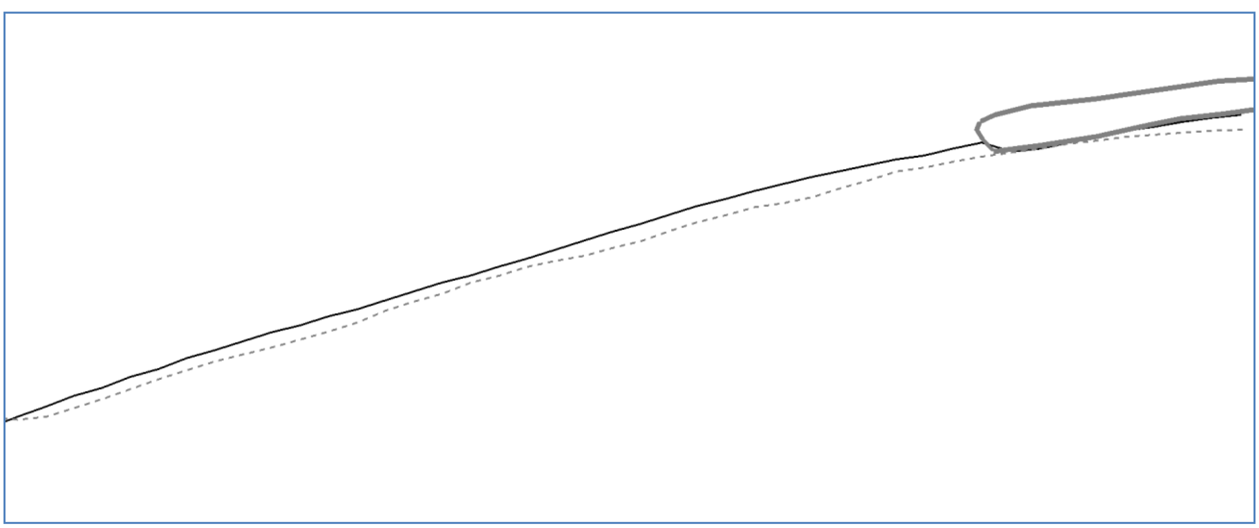


Figure 11 Do-Nothing scenario

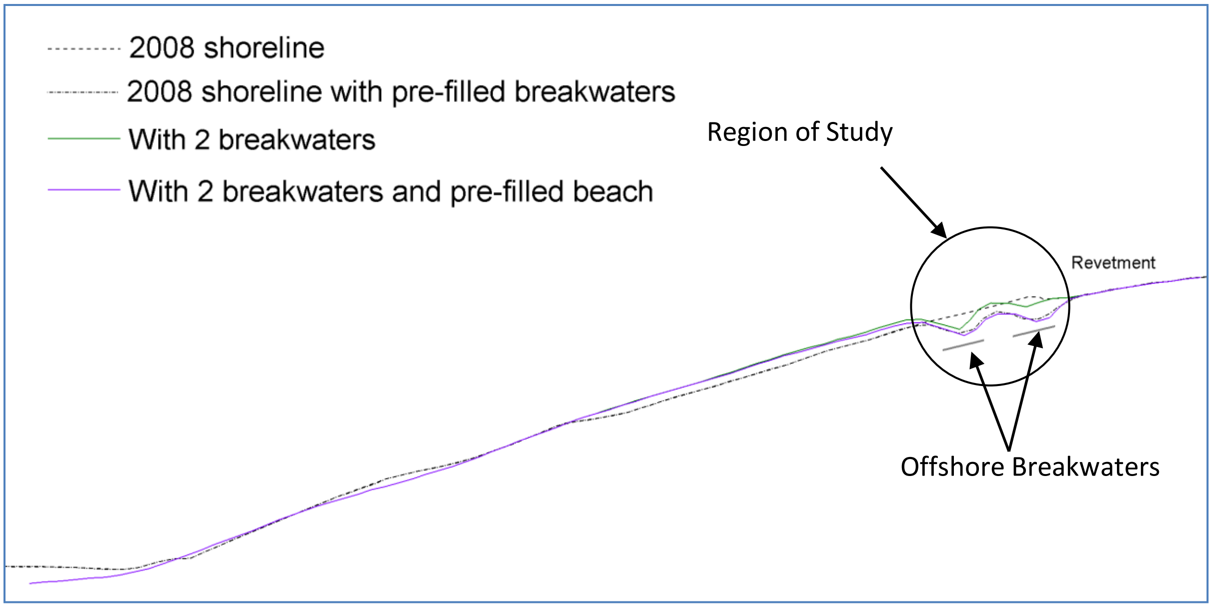


Figure 12 Shoreline model prediction

Review and evaluation of the design alternatives, including the results from the GENESIS modeling resulted in the following conclusions:

- Offshore detached breakwaters provide minimal downdrift erosion effects while offering good protection to the shoreline.
- Given the project constraints an adaptation of the original offshore breakwater design is proposed. Sandstone inter-tidal reefs are proposed to be built in roughly the same location as the breakwaters – these structures will be built completely of Island sandstone and will be generally smaller and more open than the original breakwater design.
- Sand pre-filling of the beach has a small beneficial effect on minimizing downdrift erosion. This effect is sufficiently small that pre-filling could be avoided at first, and then may become desirable in the future based on the results of beach monitoring.
- The offshore breakwaters don't interrupt pedestrian access along the beach.
- The increased dry beach width provided by the intertidal reefs will encourage dune development.

On this basis, intertidal sandstone reef structures were seen to provide the best solution in terms of shore protection, beach preservation and touristic/aesthetic considerations.

Post-Construction

The reefs were built in March 2018. Subsequent monitoring has shown that the reefs have generally performed as anticipated with a small tombolo beach formation growing in the lee of the two structures. This has led to increased dry beach area that has, in turn, led to growth and vegetation of the landward dunes. From a tourism/recreation perspective, the changes to the beach have met with positive feedback from beachgoers and the Souris community. Post-construction monitoring is being conducted using a combination of site visits, RTK-GPS surveys and drone overflights.

To date there have been minimal downdrift changes to the Souris beach and benthic growth in and around the reef structures has been encouraging. While the structure is viewed as an adaptive management strategy – allowing for structural modifications to the reefs as needed to tweak the beach response – to date, no modifications have been required.

Beach surveys are planned to continue for the next few years to monitor performance and to inform any adaptive measures that may be required.

Conclusions

The shoreline restoration and stabilization works at Souris illustrate the potential for 'working with nature' when protecting critical infrastructure against the coastal effects of climate change. Through monitoring and adaptive management, it is hoped that this project will form an important turning point for the development of coastal protection works that preserve and enhance the shoreline while also protecting critical infrastructure.

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