Infrastructure Risk Assessment of Coastal Roads in Nova Scotia

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ABSTRACT

This paper considers applying sound planning and engineering to reduce risk and lower maintenance costs along roadways affected by coastal erosion in Nova Scotia. This study reviews existing hazards and adaptive measures that have been applied at three coastal road sites. Conceptual engineering designs are provided for the installation of improved coastal protection structures. The implications of hardening shorelines are reviewed. Alternative engineered and non-engineered solutions are addressed. Three sites on Nova Scotia's South Shore that have installed beach and roadway protection measures were selected for the study. The existing protection measures range from simple armouring, with ad hoc piling of mixed stone sizes, to placement of modular concrete retaining blocks. Field studies of the three beaches included profile surveys on each beach, measurement of armour stone size, and review of stone and block placement. The paper discusses sound planning and engineering applied to sustainable solutions that can reduce the long term costs of coastal infrastructure and highways. The designs address short-term needs such as maintaining egress and beach access along with long-term issues such as sea level rise and coastal subsidence.

1.0 Introduction

Nova Scotia has 5,934 km of coastline [1]. In many places roads were established along the shore in coastal communities or to connect between them. Not uncommonly roadways were established along barrier beaches. Roads along the shore are subject to the hazards of shoreline erosion, wave overtopping and flooding. These events are a hazard to traffic on the roadway and can cause damage or complete loss of the paved surface.

When a road is damaged by wave action there is an expectation that the pavement should be replaced rapidly and that something should be done to prevent a repeat of the damage. This is most important where the damaged road is the sole or most convenient access to an area. In addition, not uncommonly, there are buildings, homes, and other infrastructure on the landward side of damaged roads. Hazards to the road are also hazards to this infrastructure and the expectation for erosion protection is more intense.

Beach erosion is a natural process that has been reshaping the Nova Scotia coastline since its postglacial submergence some 10,000 years ago. At Halifax the historic rate of submergence is 0.32 m/100 y [2], which is about half from worldwide sea-level change and half from continuing regional post-glacial subsidence.

In Nova Scotia rural roads are provincial. Nova Scotia Transportation and Infrastructure Renewal (TIR) field crews are required to repair roads and provide erosion protection following storm damage to rural roads at the coast. Generally, erosion protection based on simple in-house designs is completed at the same time as road repairs.

Given the expected accelerating rise in sea level and the potential for increased storm frequency, TIR identified the need to evaluate the adequacy of the methods of erosion protection in use and identify alternatives to those methods.

1.1 Study Background and Methodology

The focus of the study was on coastal hazard risks on roadways. Existing hazards were studied for three sites where there have been recent damages and repairs. Science and engineering practices were applied to provide conceptual solutions to reduce future risk.

The three study sites are all on the South Shore at Queensland Beach, Green Bay, and Western Head. Queensland Beach and Western Head are representative of barrier-beach shorelines and Green Bay is typical of a low bank eroding coast.

The following activities were completed: from analysis of the coastal conditions at each site, a definition of the applicable coastal hazards was created; acceptable risk criteria from published resources were consulted to determine design constraints; conceptual designs were prepared to provide protection against the applicable coastal hazards within the acceptable risk criteria; and possible adaptive solutions were identified as alternatives to engineered solutions.

2.0 Physical Processes and Coastal Hazards

This section identifies the generalized coastal hazards that Nova Scotia's roadways and other infrastructure in close proximity to the sea are subject to. A brief introduction to the governing physical processes is provided.

2.1 Physical Processes

There are many factors that influence coastal hazards, but the governing driving forces generally narrow to waves and water levels. Waves impact the shoreline and infrastructure causing damage as well as natural shoreline evolution. High water levels increase the risk of flooding and allow larger waves to impact the shoreline closer to the infrastructure. The waves and water level fluctuations have an impact upon beach processes and shorelines.

2.1.1 Waves

Waves are the dominant form of short-term coastal change as they drive erosion and sediment transport. In addition to eroding the soil that supports infrastructure, waves themselves are also capable of damaging infrastructure through direct impacts and inundation.

There are three types of waves to consider: sea (wind) waves; swell waves; and waves associated with tropical events. The wave data used for the study sites in this project are part of the Environment Canada MSC50 spectral wave hindcast, covering the time period of 1954 - 2008. Further details on this wave model can be found in Swail et al. (3).

2.1.2 Water Levels - Present

Static water levels along the Nova Scotia coast have three essential elements: tides, surges, and longer term influences, such as sea level rise. Tidal predictions are made on the basis of statistical periodic representations (called tidal constituents) derived from measured water level data. Storm surges are short-term increases or decreases in the water level associated with the passage of storm events. Their frequency and intensity are often related to the frequency and severity of storms in the area.

2.1.3 Water Levels – Long term

Over the long term, there are two factors influencing the elevation at which the sea interacts with the shoreline. The first is long term sea level rise, and the second is subsidence/tectonic change.

Long term sea level rise is an ongoing process throughout the world. Historic rates in the vicinity of Halifax are generally estimated to be on the range of 3.2 mm/year (or 0.16 m over 50 years) (4). The rate of sea level rise is increasing, and while climate change scenarios are not precise, they range from approximately 0.32 m to 0.57 m over the next 100 years (5) (6). While there is great uncertainty in climate change estimates, Rahmstorf et al. (7) suggest that the global climate has been trending towards the upper bound of the estimates over the past 20 years. Prudence requires that some consideration should be given to this finding and it is recommended that values above the historical rates be used for planning purposes.

For the conceptual purposes of this study, the long-term water level impacts assumed for a 50 year planning horizon were 0.25 m for sea level rise and 0.08 m for tectonic change, for a total (relative) water level rise of 0.33 m.

2.1.4 Beach Processes

There are a series of processes related to the dynamics of beach sediment (erosion or accretion). The three most relevant to this study are longshore sediment transport, cross-shore transport, and nearshore downcutting.

Longshore sediment transport is the process of sediment moving along the coast parallel to the shoreline. Waves that approach the shoreline from any direction, other than perpendicular to the shoreline, are the driving force for this process. Obstructing this movement with any structure will cause a surplus of sediment on one side of the structure and a deficit on the other. The deficit often leads to erosion.

Cross-shore processes move particles perpendicular to the shoreline. This is a natural process, and is responsible for the generation of bars, dunes, and beach platforms. This process is dynamic and provides some degree of natural protection for beaches against wave attack, with beaches narrowing in response to events, and rebuilding during periods of low wave energy. In areas with no backshore behind the dunes (as is the case with a barrier beach), beaches and dunes recover landward of the original position after a storm – this is a primary cause of barrier migration.

Nearshore downcutting is an irreversible process that occurs when cohesive sediments make up the nearshore geology. These cohesive sediments erode very slowly, but are too fine to be deposited on the beach and are instead transported into deep water where lower velocities allow them to settle out. Nearshore seabed material lost to cohesive downcutting is lost to the beach system and is a permanent lowering of the nearshore profile. This lowering allows larger waves to strike shore protection structures and shore-based infrastructure, as well as governing erosion for unprotected shores.

2.1.5 Combined Physical Processes

Large offshore waves and surge occur concurrently as the driving forces are the same. As waves propagate towards the shoreline, they refract, shoal, and break. This limits wave height in shallow water to some function of the depth. Waves in these conditions are called "depth-limited" waves. Typically shore protection structures right along the shoreline are subjected to depth-limited waves, meaning that the governing factor is the presence of high water levels. Consequently the selection of appropriate extreme high water levels is critical to designing robust shoreline protection structures. The selection of high water levels should include the effects of tide, surge, sea level rise, and land subsidence. It is prudent to assume that major storm events will strike at high tide for the purposes of design. Long term estimates of sea level rise and land subsidence are typically applied as a function of time, such that structures planned with a longer design life need to accommodate a wider range of sea level rise and subsidence.

2.2 Coastal Hazards

Shore-based infrastructure is exposed to specific coastal hazards that may be grouped into two types: those that result from physical process acting directly on the infrastructure, and those that exist because of a shoreline's response to the physical processes.

2.2.1 Shoreline Morphology- Erosion

Erosion of the nearshore and the subsequent recession of a shoreline's top of bank directly threatens shore-based infrastructure. On sandy shorelines with no deficit in sand supply, the erosion is normally temporary due to short–term beach processes and cross-shore transport. When the erosion occurs on a cohesive material, the nearshore lowering is permanent and unavoidable; designers of any structures must consider the continual lowering of the nearshore seabed in their design. It represents a common failure mechanism for structures built to protect against erosion.

There are two approaches to managing erosion: the first is to protect the shoreline and try to stop the shoreline from eroding; and the second is to apply a setback buffer and restrict or eliminate all development of infrastructure in the area with the expected erosion – essentially allowing the natural process to occur uninterrupted.

2.2.2 Shoreline Morphology – Barrier Migration

Sandy shorelines with low-lying marshland, lakes, or coastal inlets in the lee of the beach are best described as barrier beaches. Barrier migration occurs when the beach and dune recovers landward of the existing dune as described in Section 2.1.4. It is often triggered when a beach is overtopped, breached, or experiences cross-shore wind transport of sand. Another leading cause of barrier beach migration is a change in water levels. As sea levels rise, barrier beaches are likely to migrate landward at a faster rate.

Regardless of the mechanism for instigating barrier migration, when the beach migrates, infrastructure previously supported by this material is at risk of failure. Particularly when a barrier beach is low lying such that it is overtopped or breached during major events, the installation of infrastructure on the barrier crest is not recommended. If infrastructure on the barrier beach is required, it is prudent to place the infrastructure as far landward as possible, and install protection to prevent or slow the migration.

2.2.3 Shoreline Morphology - Regional Sediment Supply Issues

In most cases, shorelines are part of a system called a littoral cell. Sediment may move back and forth within a single littoral cell, but in general it does not exit each individual littoral cell. One cell often covers many kilometres of shoreline. As shorelines in one part of a littoral cell erode, they supply sediment to the system, and this sediment moves along the coast within the littoral cell through longshore sediment transport and may create benefits elsewhere in the system.

The installation of structures that prevent erosion at one stretch of shoreline, or any structures that trap sand to provide a wider beach in one location may starve another area of sand and lead to increased erosion. On a project-by-project basis, these issues should be considered, but over the scale of the entire littoral cell, regional coastal zone policy is the only effective mechanism to reduce or mitigate the impacts of this hazard.

2.2.4 Scour

Scour is a direct threat to the stability of coastal structures, as it represents the erosion of supporting sediments caused by the presence of the structure itself. Without the presence of the structure, the erosion pattern that leads to the structural failure would not occur. This scour is caused by the structure modifying the hydrodynamics; it is a common failure mechanism for coastal protection structures and other infrastructure exposed to coastal hazards.

2.2.5 Flooding

The two primary factors influencing sea water flooding are inundation due to high water levels and wave runup. Inundation occurs when the sea surface elevation exceeds the protection measures and the level of the surrounding land, resulting in infrastructure being inundated with sea water. When there is flow associated with this inundation, additional damage can occur due to erosion of supporting soils.

Wave runup is the vertical distance that a wave travels up the shoreline above the still water level. Wave runup is a local phenomenon and depends upon the local nearshore wave climate, the nearshore slope, and the slope of protection measures.

Flooding elevations should be taken from high tide, and should include the effects of sea level rise and tectonic change. Storm surge should be estimated using appropriate calibrated models or gauge data and the return period surge event should match the level of tolerable risk for the application.

2.2.6 Overtopping

Although closely related to flooding, overtopping is the flooding that occurs solely due to the crest of a wave, or the wave runup, exceeding the crest of the protection structure. The impacts of overtopping and the associated flow of water over and around infrastructure cause damage to the infrastructure and supporting soils. Published thresholds for this damage are related to the discharge of water over the structure per unit length of shoreline. The most commonly published values are from the Coastal Engineering Manual (8).

Direct wave impact on infrastructure causes damages best represented through the overtopping thresholds presented in the Coastal Engineering Manual. Conventional infrastructure is generally not expected to be designed against wave impacts; as a result wave impacts are typically expected to be resisted by shore protection structures prior to the wave energy reaching conventional infrastructure.

2.3 Cumulative Impacts

The cumulative and combined effect of coastal hazards must be considered in the design of infrastructure that will be exposed to the coastal environment.

Regional sediment management issues are generally continuous and cumulative. Until sand begins to bypass updrift retention structures, erosion rates increase, which may not return to pre-project rates without human intervention to replace the lost sediment.

The processes of erosion and nearshore downcutting are typically continuous and irreversible. The downcutting in front of infrastructure allows larger waves to propagate towards the protection measures and therefore exposes the infrastructure to a greater risk of overtopping and wave impacts. Anticipating downcutting and allowing for these larger waves over the life of the structure is the only way to design for this impact.

Breaches in shore protection from previous storm events expose less stable material and normally result in more rapid and severe damage during subsequent storm events.

3.0 Study Sites

Three representative study sites were selected to demonstrate typical coastal risks to roads currently in place at the coastline. The study sites were selected to illustrate a receding coastline (Green Bay), a low barrier beach (Queensland Beach) and a higher barrier beach (Western Head).

During the analysis of shore protection features, 50 year return period events have been assumed. When combined with commonly accepted risk tolerances for coastal structures, the corresponding likely design life is 25 years. These design conditions are: 50 year design offshore wave condition: H_S = 9.75 m, T_P = 16 s; 50 year design water level at +3.75 m (C.D.) plus local wave runup, without climate change; and, 50 year design water level at +4.05 m (C.D.) plus local wave runup, which includes 0.3 m of sea level rise due to climate change and subsidence over the next 50 years.

3.1 Green Bay

Green Bay is a summer cottage and residential community in Lunenburg County. A provincial road runs along the back of the beach. The stretch investigated is a beach segment some 175 metres long with 6 cottages close to the road on the landward side. Some of these are at a lower elevation than the road. Overtopping of the road results in flooding of the developed area behind it. Prior to the current elevated rock armouring there was loose rock protection that rose only to the road shoulder elevation. Following a storm event that removed much of the paving and washed rock over the road, NSTIR added armour stone as protection for the road and cottages behind it.

3.1.1 Description

The roadway is protected by a revetment with the characteristics provided in Table 1. Two profiles were measured at Green Bay (Figure 3). Shoaling bedrock in some locations of the site's nearshore provide some degree of natural protection, since wave energy will dissipate as it propagates over the shoals. Revetments such as this one are classified as ad-hoc dumped stone and typically have a useful life in the range of 10-15 years.

3.1.2 Subject Hazards and Design Conditions

The revetment, roadway and adjacent cottages are subject to the following hazards: *wave impacts* - stones in the revetment are slightly undersized, but a higher risk tolerance would make them acceptable; better placement of stone combined with the use of filter layers could use less stone and provide the same degree of protection; *overtopping damage* - some road sections are lower than others, and would be subjected to overtopping damage to revetment and/or road, as well as flooding some cottages; e*rosion* - beyond the life of the revetment, or if it is damaged during a storm event, it is anticipated that erosion and overtopping events will continue, threatening the roadway.

3.2 Queensland Beach

Queensland Beach is a low barrier beach with a roadway and parking lot used by seasonal beach users. The beach and parking area are a provincial park operated by the NS Department of Natural Resources. The proximity to Halifax, lifeguard services and relatively warm water make it a crowded beach in the summer. The road provides year round access to a residential community to the west of the beach.

3.2.1 Description

The roadway at Queensland Beach is built across a relatively low barrier beach with varying degrees of protection along the beach. There are two distinct areas from a coastal perspective: a low-lying area through most of the barrier (Profiles 1 and 2 as seen in Figure 5, and a higher area immediately east of the barrier portion (Profile 3 in Figure 5). Throughout the whole area, an ad hoc armour stone revetment has been installed with no visible evidence of toe protection.

Three profiles were surveyed at the site, with the results plotted in Figure 5, and physical characteristics summarized in Table 2. The east end of the site (near Profile 3) consists of much larger stone, placed to a greater elevation than the central or west end of the barrier beach, illustrated in Figure 4.

3.2.2 Subject Hazards

At present the roadway crossing Queensland Beach is at a low elevation and is subject to severe inundation and overtopping damages. The following is a list of the hazards that the roadway, parking lot, and pedestrian access structures are exposed to: w*ave impacts*- the existing armour stone revetment in the low areas consists of stones that are generally undersized; increased stone size with better placement would provide for better protection and would last longer; *overtopping and flooding*- the roadway is too low, is subject to severe flooding and overtopping damages, and it is likely that this road will be damaged in the future due to an overtopping event; and, b*arrier migration*- the beach exhibits many signs of a migrating barrier beach, with historic breaches and overtopping events, and this process is likely to continue.

3.3 Western Head

The Western Head barrier beach carries a coastal roadway. The beach is used by surfers but is unlikely to attract many swimmers and has no lifeguard services.

3.3.1 Description

The Western Head roadway crosses a sand and cobble barrier beach, as depicted in Figure 1 and Figure 7. The roadway is near the landward side of the barrier beach and is lower than the natural crest of the beach. Two profiles were measured at Western Head (see Figure 8). Profile 1 was measured in an area where the roadway has not been threatened by prior events and Profile 2 was measured in an area where a recent breach occurred and caused significant damage. During the field survey, repairs were underway to reinstate the roadway as well as protect the roadway from future storm events. The crest of Profile 1 was found to be at the same elevation as the crest of the newly installed protection measures.

Upon review of the profiles, it was noticed that a full barrier dune is seaward of the roadway in the Profile 1 location, and that the roadway at the Profile 2 location is in the approximate location where a dynamic beach dune crest would be, if it were present at this location. The profile shape observed at the western end is closer to what would be expected with a natural barrier beach. These facts are indicative of a situation where part of the roadway infrastructure exists within the dynamic beach zone (area near Profile 2) and other portions of the roadway infrastructure exist landward of the dynamic beach zone.

Recent works to protect the roadway using modular concrete retaining blocks and boulders have been moderately effective, but maintenance is still likely required over the short term. Toe protection for the blocks has been installed in the form of a "fronting revetment", a revetment placed immediately seaward of a vertical wall. This toe protection is undersized and as a result may require maintenance or repositioning following a major event. The block crest elevation is close to the natural crest elevation for the barrier dune; this may limit overtopping discharges to white water (spray) overtopping, which is generally less destructive to roadways.

3.3.2 Subject Hazards

The roadway and installed block seawall with fronting revetment is exposed to the following coastal hazards: w*ave impacts and scour-* block sizes are of a reasonable size to resist wave attack; however, toe and scour protection stones installed seaward of the block wall are undersized, possibly subjecting them to movement during large events, and exposing the blocks to scour; keying-in the block seawall to something more stable than the uncompacted granular road shoulder will provide for greater protection against scour; in the western end of the beach, the existing dynamic beach should respond to large wave events and protect the roadway from direct wave attack; o*vertopping damage-* is likely to still occur; however it is expected to be much less frequent than previously, particularly in the Eastern portion (near Profile 2) where the beach is narrower; b*arrier migration-* eastern portions of the barrier beach are migrating landward; raising the crest elevation with the concrete block seawall may slow or reduce this migration to acceptable levels; r*egional sediment supply-* to this beach is in question, and it may be possible that historic sand and gravel sources to this beach have disappeared or been cut off as residential and cottage builders to the east of the beach have armoured some of the beach in recent years.

4.0 Conceptual Solutions

This section provides some conceptual solutions for protecting transportation infrastructure from coastal hazards within a framework that emphasizes sustainable solutions. Although the decision process itself is beyond the scope of this document and not described, there are two viable paths associated with the analysis of existing infrastructure that is exposed to coastal hazards: one where the approximate infrastructure location needs to be maintained to provide a sustainable solution, and one where the road in its existing position is not sustainable. Various solutions within these paths are presented in Sections 4.1 and 4.2 respectively.

4.1 Solutions to Maintain Approximate Road Position

In many cases, maintaining the approximate location of the existing roadway is sustainable, viable, and preferred. Two specific approaches to this solution are presented here: one where the road alignment or elevation is adjusted, and the second where shore protection measures are installed.

4.1.1 Slight road re-alignment

This is the process of moving the infrastructure (roadway) landward away from the ocean, such that beach processes are not interfered with and the natural erosion and recovery of the beach within the dynamic beach zone is allowed to occur. In many places where a progressively eroding shoreline is present, the natural recovery does not occur; however, the roadway can be shifted far enough to allow erosion to occur naturally over the planning horizon for the area.

With barrier beaches, this type of solution is only viable when breaches are unlikely. In other cases, there is simply not enough space to re-align the road effectively; examples include narrow barrier beaches, or when space-use conflicts occur landward of the existing roadway position.

In the event of an eroding shoreline, typically setbacks are established using the following simple formula: *Planning horizon in years* X *Average Annual Erosion Rate = Setback Distance.*

Average annual erosion rates are location-specific due to variable wave climates, nearshore conditions, and soil types. The rates are normally established using historic aerial photography, data from profile/erosion monitoring stations, or numerical modelling.

4.1.2 Raising the roadway elevation

Raising a roadway elevation is typically done by bringing in fill and installing a new road surface at a high enough elevation that the coastal hazards do not reach. This type of approach makes breaches much less likely, and usually reduces the ongoing maintenance cost as there are fewer overtopping damage events. The elevation is usually selected based upon overtopping criteria (typically similar to those found in the Coastal Engineering Manual [9]) and calculated or modeled estimates.

When the elevation has already been increased, any additional shore protection measures are often more expensive to install because they must protect a higher slope. Furthermore, due to space constraints, it may force the beach to accept a steeper-than-natural beach slope, or a very wide barrier may need to be constructed in the cases of barrier beaches. When the natural beach processes are restricted due to the roadway, the beach may require nourishment to maintain its position.

4.1.3 Shore Protection – Revetment

Revetments are stone protection placed along (parallel to) the shoreline in a fashion that is designed to protect the toe of the slope from wave-induced erosion. In coastal environments, they are typically constructed using armour stones or concrete armour units rather than rip rap as may be observed on the sides of rivers or drainage channels. Revetments have the advantage of not impeding longshore sand transport as do groynes and offshore breakwaters. However, stopping erosion eliminates the addition of sediment to the local littoral system that would have been provided by the stretch of eroding shore.

Engineered revetments are normally more cost effective as they protect the shoreline using less stone and last considerably longer. Key engineering features in revetments include the use of geotextile and toe armour. Engineered sections are usually two layers of *placed* armour, or one layer of *specially placed* armour. Placed armour is rock that has been positioned one stone at a time by the contractor. Specially placed armour is rock that has been positioned one stone at a time, with care taken to select appropriate stones that will fit particular voids and the direction of an engineer or foreman is used for placing each stone. A photograph of an engineered revetment under construction is illustrated in Figure 9. Dumped armour units without filter layers or toe protection normally get classified as ad-hoc structures.

The typical design life for engineered revetments is 30 or more years, whereas the ad hoc revetments typically have a functional design life of 10-15 years. Revetments generally have better reserve capacities than seawalls and steel structures. When they are damaged, the material settles and adjusts into a new stable position, providing some (albeit reduced) degree of continued protection against incoming wave energy.

4.1.4 Shore Protection – Seawall

Seawalls are vertical (or near vertical) walls placed along (parallel to) the shoreline. They protect the toe of a bank or bluff from erosion. They are constructed from a variety of materials; however, the common materials are concrete, steel, and stone.

Concrete seawalls are constructed either from stacked modular blocks or cast-in-place walls. Cast-in-place walls are more rigid and are typically designed as retaining walls. The modular block walls are more flexible and more readily repaired following damage events; however, there is a lack of sound engineering guidance to support well designed concrete block seawalls that are fully exposed to the sea. Stacked armour stone block seawalls are similar in nature to concrete sea walls.

Steel sheet pile walls are alternatives to concrete sea walls and involve driven or pinned steel sheet piles. They are generally less cost-efficient than concrete or stone seawalls.

Timber crib seawalls are not normally designed for regular wave attack as they do not dissipate wave energy as effectively as revetments, but also do not reflect the energy as efficiently as concrete seawalls. They can however, be designed as ad hoc gravity structures to extend protection against wave impacts near critical infrastructure. The horizontal timber elements would not be expected to withstand the vertical pressures and impacts associated with direct wave impacts from breaking waves in a large storm event, so maintenance would be expected after storms.

Vertical wall seawalls are generally not preferred in areas exposed to continuous wave attack as they reflect close to 100% of the wave energy back towards the sea, resulting in potentially dangerous navigation conditions in the vicinity of the structure, as well as increasing the risk of toe scour adjacent to the structure. As a result of the scour risk and short time scale of scour, seawalls should be installed with some degree of toe protection to prevent the loss of supporting soils.

Seawalls typically have lower reserve capacities than revetments, as when they fail, they tend to topple and provide very little additional protection to the backshore after failure. Due to this lack of reserve capacity and the risks of undermining, a typical design life for seawalls is slightly less than that of a revetment, and is often on the order of 20 years.

Vertical walls also pose an insurmountable interface between the land and the sea. Wildlife and humans alike typically cannot easily access the beach without the inclusion of additional appurtenances like staircases, or pass-through gaps leaving sections of the infrastructure exposed.

4.1.5 Shore Protection – Groynes and Offshore Breakwaters

Groynes are shore-perpendicular structures that protect the shoreline from erosion by providing a wide enough beach to dissipate wave energy. Offshore breakwaters are shore parallel structures that are positioned some distance offshore and not significantly connected to the shoreline. Groynes and offshore breakwaters are mentioned for completeness; however, the specialized analysis and planning requirements associated with their use means that they are not recommended as solutions in general cases and have not been applied for the study sites.

4.2 Solutions When the Existing Road is Unsustainable

In some cases, the existing road location is no longer sustainable under the current conditions or the expected conditions in the future, given sea level rise and the potential for climate change. Three potential options are discussed for consideration when coastal hazards have made a road unsustainable: relocating the road, divesting the road, and closing the road. It is recognized that these would be difficult decisions and would require extensive collaboration with stakeholders and that they would require political will; however, as Nova Scotia meets the challenges associated with climate change, depending on the specific conditions, each of these options may be the only viable solution available in the future at some locations.

4.2.1 Relocate the Road Away from Coastal Hazards

It is possible to eliminate the coastal risk altogether by relocating the road away from the coastal hazards. Existing roadway areas can be returned to more natural conditions, or used for alternative purposes to the benefit of local residents and businesses. A full cost-benefit (or similar) analysis that includes "soft" costs and benefits would be required to justify this type of action. These decisions are likely to face opposition and the planning process must involve all the stakeholders for successful implementation of this solution.

4.2.2 Divest the Road to Local Interests

In cases where the road function is limited to local interests, it may be more economically viable to transfer ownership of the road to local interests as their requirements for quality standards may not need to meet provincial standards. This is most likely to be seen as a viable solution where the regular maintenance and repairs required to keep the road at provincial standards is the only thing making the current road location unsustainable.

The benefits to the local stakeholders is that they get to keep the existing roadway, while also obtaining better control over the future of the roadway and maintenance activities in a manner that is consistent and appropriate with their needs and uses.

Two key elements must be in place before this type of alternative could be considered or implemented. Local groups (private or municipal) must have the structure and capacity to negotiate the transfer of ownership, as well as the capacity to manage the roadway in the future; and, there must be political co-operation between provincial and local governments as well as stakeholders.

The potential to apply this option is very limited in Nova Scotia. Minor roads like those studied would be municipal in most other provinces. In Nova Scotia rural roads generally are the responsibility of, and are owned by the province and cannot be transferred to a municipality.

4.2.3 Close the Road

In cases where the original road function is no longer necessary, or the benefit of the road use does not justify costs to maintain and protect it, it may be viable to decommission the road and remove the maintenance liability from the provincial infrastructure costs. This might be possible at

Queensland Beach or Western Head, where there are alternate access routes to either end of the beach segments in question. This option would be challenging to apply, particularly in locations where the road terminates beyond the coastal section and there are permanent and seasonal homes, as it does in locations such as Green Bay.

5.0 Application to Study Sites

Conceptual solutions were prepared for the three study sites. These do not include a complete cost-benefit analysis to determine their sustainability. They are examples of how solutions might be implemented.

5.1 Green Bay

The existing roadway at Green Bay is in reasonable condition with a relatively new ad hoc armour stone revetment. The ad hoc revetment will likely provide serviceable erosion protection over the short term. When the structure fails, the existing armour stone may be re-used in a newer structure. It would be advisable and more cost-effective to implement an engineered revetment at the time of the next repair. A cross section similar to the one illustrated in Figure 9 is likely to be selected. For protection against flooding, adequate backshore drainage would provide additional benefits to assist in protection against flooding.

The roadway primarily serves a group of residences, seasonal private cottages, rental cottages and, a seasonal restaurant and canteen, as well as providing public access for beach use and other recreation. Conceptually, this location is a possible candidate for divestiture to local interests if the continued servicing of the site is unsustainable under provincial standards. However, divesting to the county municipality is not currently possible and there has been no experience in Nova Scotia with divesting a road to a relatively small collective of some 50 property owners.

5.1.1 Queensland Beach

The existing roadway at Queensland Beach is presently too low, and the barrier beach actively experiences overtopping and breaching events. The roadway will continue to require regular maintenance in response to storm events and shoreline change. Two alternatives have been considered: one that keeps the roadway on the barrier beach, and one that recommends re-locating the road. A full review of the sustainability of this roadway has not been completed, but of the three study sites reviewed, this is the most likely to be deemed an unsustainable roadway.

This location is a possible candidate for shifting the existing road further away from the coastal hazards, and raising the crest elevation to minimize the exposure to the coastal hazards. While this measure would last for several years or even decades, eventually the migrating barrier will "catch-up" with this new road location and the road will need to be moved again. A system of parking spaces could be installed on the seaward side of the roadway; however, this parking would be subject to storm damage. The roadway would be more protected during storm events though as a result of being at a higher elevation and egress during emergencies would be maintained.

If the continued replacement or adjustment of the road alignment is deemed to be unsustainable, a longer-term solution that may be viable here would be to consider moving the road off the barrier beach to an alternative location. A roadway would need to be purchased and a new road constructed. Under this scenario, the barrier beach could be converted to passive recreation, with pedestrian trails and/or low-cost infrastructure to maintain the recreational nature of the beach itself. To continue to provide parking, it would be necessary to purchase some land off the east end of the recreational area.

5.1.2 Western Head

Over the winter of 2010 TIR installed a pre-cast concrete block retaining wall on the seaward edge of the existing road, and piled up stone on the seaward side of the retaining wall. The existing solution to the regular overtopping and road damage is viable over the short term, but could be made more permanent with keying in of the structure and installing more robust toe protection to prevent future undermining of the toe. It would also be preferred to place the stone on drained bedding material.

Although beach nourishment is not necessary, it may make the beach wider in the critical overtopping area, and dissipate additional wave energy.

The barrier beach itself will continue to migrate, and may require periodic (decadal time series) shifting of the road further back across the barrier and away from the coastal hazard. The road segment on the beach is close to the outer end of a road loop, roughly 6 km on the western side and 8 km on the east. Closure of the road might be considered. Alternatively, to replace the road with a new alignment around the lagoon would require construction of nearly 2 km of new road.

6.0 Conclusions

Given increasing sea levels with climate change and anticipated increased intensity of wave effects, there will be coastal erosion that will damage roads again. The adoption of design criteria for coastal road protection work could decrease costs and improve the design life of protection measures. In some locations, road grades could be improved to reduce the frequency of overtopping. For some areas, life cycle costs should be completed. From these reviews, the options of road relocation or abandonment could be considered.

Some additional steps to approach and achieve these general goals are: prioritize roads and other infrastructure in need of more detailed risk assessments; develop a process for major infrastructure relocations for use in cases where sustainability of the existing infrastructure is in question; include a participatory framework for stakeholder involvement.

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Tables

Table 1 Elevations and stone sizes from Green Bay Beach

Item	Value
Crest Elevation	+ 5.1 m
Road Elevation	+ 4.0 m
Stone Size	3 - 5 t

Table 2 Elevations and stone sizes from Queensland Beach

Item	Value
Crest Elevation (low area)	+ 3.9 m
Crest Elevation (high area)	+ 5.1 m
Road Elevation (low area)	+ 3.7 m
Road Elevation (high area)	+ 5.3 m
Stone Size (low area)	0.6 - 1.2 t
Stone Size (high area)	1.5 - 5 t

Table 3 Summary of elevations and material sizes at Western Head

Item	Value
Crest Elevation (Natural)	+6.4 m
Crest Elevation (Blocks)	+6.3 m
Road Elevation	~+4.5 m
Block Size	5.5 t
Stone Size	0.2 - 1.0 t

Figures

Figure 1. Installation of concrete block retaining wall near Profile 2 Western Head

Figure 2 Ad hoc revetment at Green Bay, from beach and from road

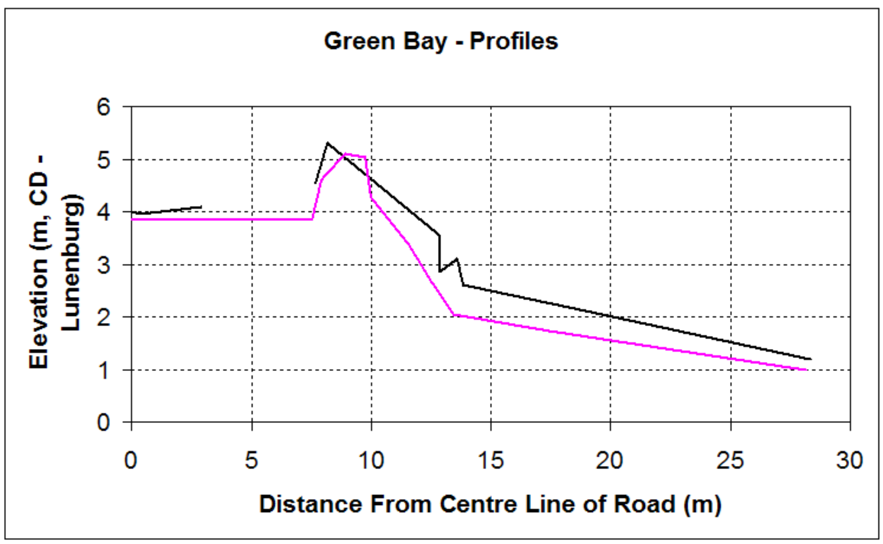

Figure 3 Profiles at Green Bay

Figure 4 Ad hoc armour stone revetment between roadway and beach (lower area – left, and higher area – right), Queensland Beach

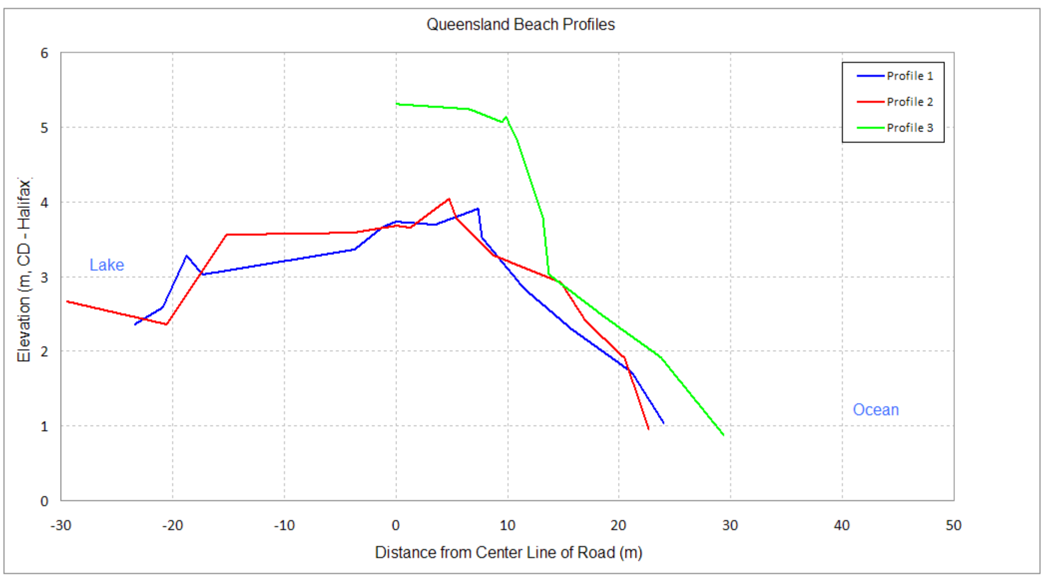

Figure 5. Profiles at Queensland Beach

Figure 6. Damages to Queensland Beach roadway (Images courtesy NRCan 2007, NS Department of Fisheries and Aquaculture)

Figure 7. Sand and cobble beach at Western Head (looking west - left, and looking east - right)

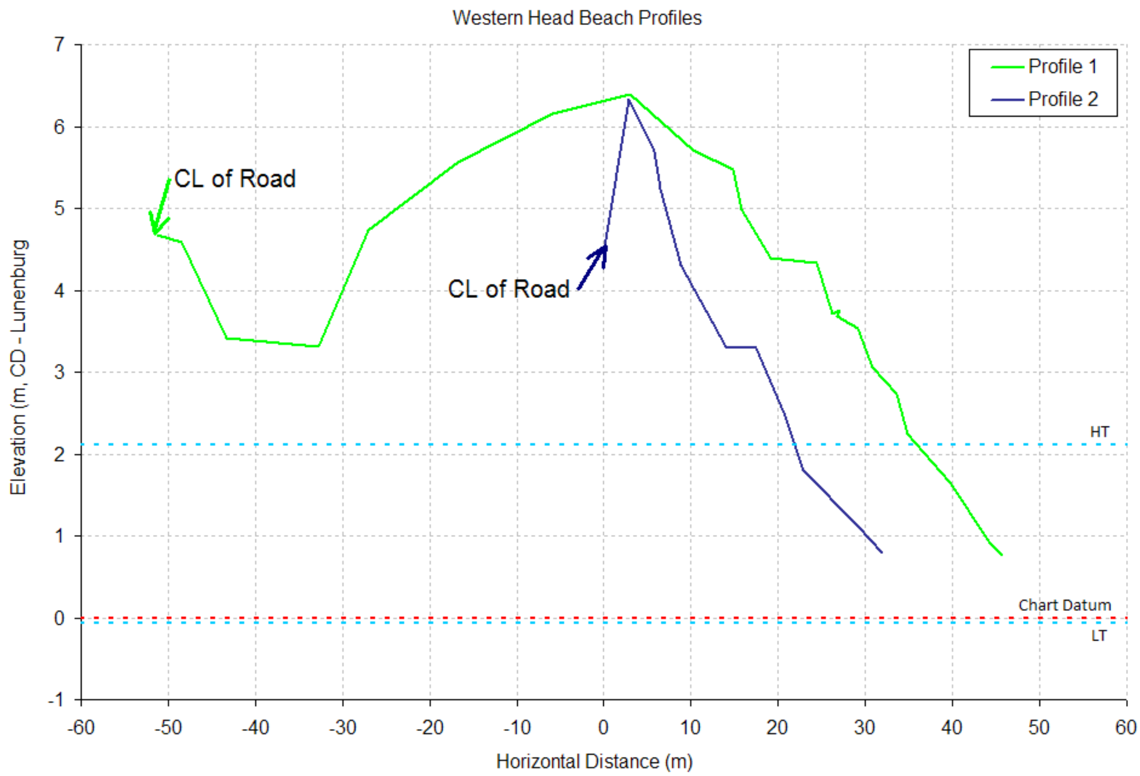

Figure 8. Profiles at Western Head

Figure 9. Example of an engineered two-layer revetment under construction