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Analysis of Spit-Beach Migration and Armour Stone Placement, and Recommendations for System Sustainability at Dominion Beach Provincial Park, Cape Breton County, Nova Scotia

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1.0 Abstract

Dominion Beach is a 2 km long, arcuate spit facing northeast toward the open Atlantic Ocean. Eroding cliffs of incompetent Carboniferous sedimentary rocks have historically provided a sustained sediment supply to the system. Extensive sand mining during the 20th Century removed the natural dune system of the spit.

The seaward-facing, southern half of the spit is eroding at an average 40 year rate of approximately 0.7 m/year, but with large decade-scale variability. The back side of the spit facing Lingan Bay has remained stationary. Due to long-term erosion and thinning of the spit, it is in danger of breaching, with potential breakdown of the overall sedimentary system. If this were to occur, the spit would likely re-establish farther landward in Lingan Bay, though the time required for this to occur is uncertain.

Armour stone placed to prevent erosion along the shoreline immediately south of the main spit has been successful and demonstrates multi-decade stability. The armour stone is interrupting natural sediment supply to the spit, however, and is further enhancing erosion and overwash of the southernmost end of the spit.

It is recommended that the armouring should be extended to enhance shoreline protection and protect infrastructure at the southern end of the beach, and that the armour stone should be reconfigured to allow sediment to pass down current and nourish the primary spit. The second recommendation is that a rubble mound should be constructed along the southern end of the main spit. It should be placed landward of the naturally occurring cobblestone storm ridge. This would further stabilize the natural process of storm ridge formation and allow the beach to build upward and possibly seaward. It would also blend into the natural system over time.

2.0 Background

Dominion Beach has long been a very popular and important asset to Dominion and its surrounding communities (e.g. Sydney). Over the last five years local residents and park staff have reported significant erosion of the beach and spit. In addition, park infrastructure has been destroyed or damaged to such an extent that a redevelopment plan and action are required. In order to assist in the creation and implementation of a redevelopment plan, the Geological Services Division (GSD) of the Nova Scotia Department of Natural Resources (DNR) has carried out a geoscientific analysis of Dominion Beach. This includes, but is not limited to, an analysis of beach processes, erosion rates, sea-level rise, effects of storms and other factors affecting the Provincial Park. The study provides geoscientific advice to park planners assisting in development of a long-term, sustainable redevelopment plan for Dominion Beach Provincial Park.

This study is part of a recent initiative between DNR's Parks Division and the Geological Services Division to incorporate specific geoscientific information into long-term planning. The objective is to better understand coastal processes that impact the province's many coastal parks and, in doing so, to reduce the maintenance cost and need for replacement of coastal park infrastructure. This report is a reference document providing information that formed the basis of discussion and advice provided to the Parks Division by the Geological Services Division as part of the deliberations for the formation of a park redevelopment plan.

3.0 Location and Local Geology

Dominion Beach is located approximately 15 km northeast of downtown Sydney, at the westernmost edge of the town of Dominion **(Fig. 1)**. The beach proper is the seaward-facing side of a 2 km long,

Figure 1. *Map and air photograph showing the location of Dominion Beach.*

arcuate spit **(Fig. 1).** The spit is oriented approximately northwest-southeast. The spit is anchored to the shore at its southeast end, indicating that the major direction of sediment transport is to the northwest. The sediment is derived from actively eroding rocks of the Late Carboniferous Sydney Mines Formation (Boehner and Giles, 1986). The rocks are mainly well-bedded mudstones, shale, siltstone, sandstone and major economic coal seams (Boehner and Giles, 2008). The beds are jointed and fractured. Due to the broken and soft nature of the individual beds, erosion by pounding surf, freeze-thaw cycles and precipitation events creates actively eroding, vertical to sub-vertical cliffs.

The southeast end of Dominion Beach is predominantly composed of openwork cobbles. At depth the voids between the cobbles are probably filled with sand. A low storm ridge of cobbles is being over-washed during moderate and larger seasonal storms. The majority of the beach to the northwest is composed of varying sizes of sand. Active erosion of the dune – upper beach interface is widespread. At the northwest end of the spit a section of the beach face is composed of large cobbles and small boulders. These have stabilized the spit, but are foreign materials that are dispersed southeastward from the extreme northwest, seaward side of the spit. Armour stone was placed in this area sometime in the past to anchor the end of the spit, because the entrance to Lingan Bay is at this location.

The channel at the end of the Dominion Beach spit is tide dominated. The maximum local tide range is approximately 1.5 m. This results in significant ebb- and flood-tide currents between the end of the spit and the community of Lingan on the opposite shore. At low tide, waves break over a partially exposed ebb-tide sand bar seaward of the northerly end of the Dominion Beach spit. The sand bar exists in dynamic equilibrium with sediment transported seaward by the ebb tide. It is a permanent feature, where sediment input equals seaward loss of sediment to deeper waters. It also serves as a sand reservoir, recycling sediment back to the beach face. In many jurisdictions, this sediment sink is mined for sand to be used for beach nourishment. Since it is a semi-permanent feature, removal of sediment simply causes sediment transported seaward by the ebb flow to be deposited, rather than being transported into deep water and out of the system. The flood-tide bars exist in a similar fashion, but are located landward inside of Lingan Bay. They exist in balance with the flood tide. Sediment moving out of the bay simply bypasses the bars. This explains why the bars do not appear to have grown or eroded significantly over many decades.

4.0 Effects of Sea-level Rise and its Impact on Sustainability

4.1 Background

The Atlantic coast line of Nova Scotia exists in a state of dynamic equilibrium with respect to local sea-level changes (sea-level rise in this case). Sea level has risen over the last 18,000 years, following and synchronous with melting of the last Wisconsinan continental ice sheet. As melting occurred, the coastline evolved, but always out of sync with sea-level rise. In effect, the shoreline evolution is continuous as it attempts to ‘catch up’ with sea-level rise. It is only in isolated areas of the world where there is no net sea-level rise or fall that beach systems exist that are illustrative of a true equilibrium shoreline.

Sea-level rise over the last century is only part of the reason for the disintegration and retreat of Dominion Beach. The rate of sea-level rise has potential for rapid change, however, which may have an increasingly destabilizing effect on the spit and beach.

4.2 Past, Present and Future Sea-level Rise

"It is *very likely* that mean sea level rise will contribute to upward trends in extreme coastal high water levels in the future" (IPCC, 2012, p. 13). The "very likely" qualification indicates that the statement is well supported by research literature, data and obvious trends in sea-level rise over the past century. An increase in sea level will result in incrementally higher tides and increased flooding. In Nova Scotia, rising sea level has been recognized for over a century, since early researchers identified submerged tree trunks along the coast of Nova Scotia. Coastal Nova Scotia communities have also successfully adapted to sea-level rise for centuries.

The best estimate of historical rates of sea-level rise along the Atlantic coast of Nova Scotia is from a paper published by Gehrels et al. (2005) and shown in **Figure 2**. During the period 1800 to about 1900 the rate of sea-level rise was 16 cm/100 years. The rate of sea-level rise accelerated to 32 cm/100 years between 1920 and 1930 and has remained remarkably constant on a multi-decadal scale since that time (**Figure 2**). The 1920 acceleration in the rate of sea-level rise was a global phenomenon occurring at different times in different regions, but generally occurring between the mid– to late-1800s to 1930.

In discussing present sea-level rise the author is referring to late Twentieth and the first decade of the Twenty-first centuries. Local, regional and global rates of sea-level rise are important factors to consider when planning redevelopment of the Dominion Beach Park. The global average rate of sea-level rise has been measured by satellites since 1993. Assuming a simple single linear sea-level rise, the global rate of sea-level rise between 1993 and 2012 is 31±4 cm/100 years (**Figure 3**).

Accurate local sea-level rise data for the Dominion Beach area is available from tide gauge records at North Sydney. These records were examined from 1975 to 2011 **(Figure 4).** Prior to the mid-1970s the tide data from North Sydney are too fragmented to be useful. The data were smoothed using a 31 day

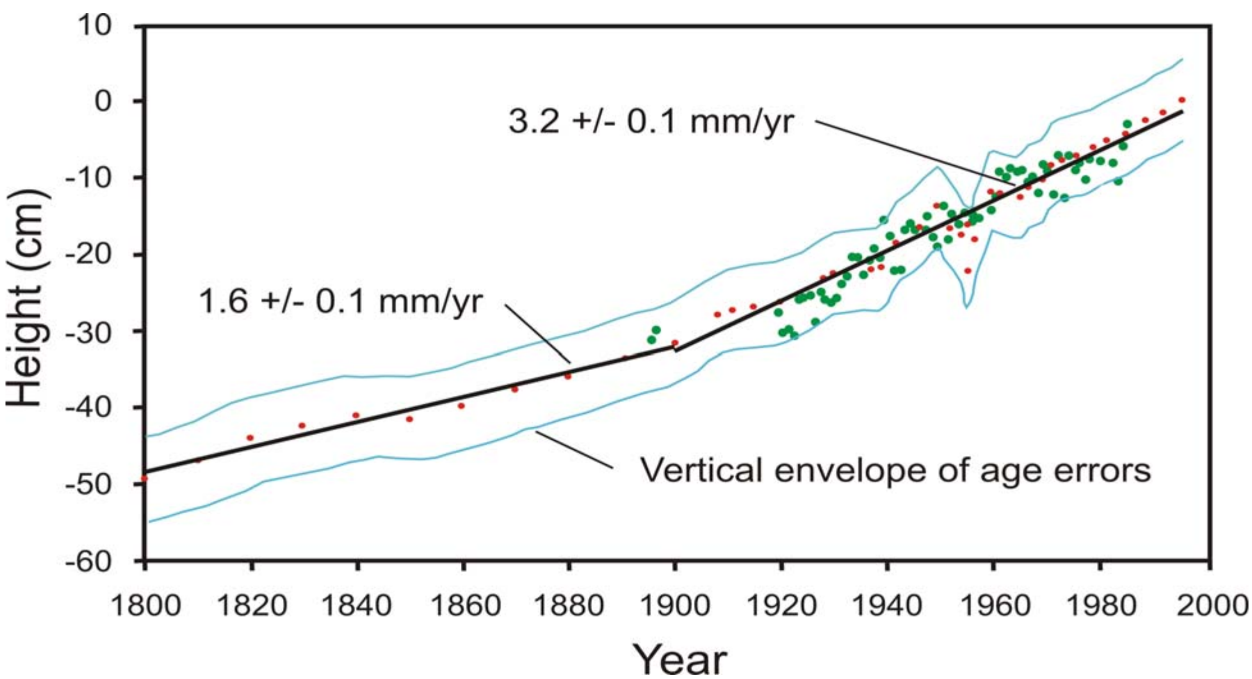

Figure 2. *Historical reconstruction of the rate and observed amount of sea-level rise along the eastern shore of mainland Nova Scotia. Green dots indicate tide gauge data from Halifax. Modified from Gehrels et al. (2005).*

centred box smoothing average to remove the effects of lunar cycles on the tide data. A 365 day centred box moving average smoothing was also applied to remove the yearly variation in tide gauge data caused by thermal expansion and contraction of the southern hemisphere oceans during summer and winter months, respectively. The rate of sea-level rise thus measured was 36.5 cm/100 years (**Figure 4**).

Glacial melting and thermal expansion have been suggested as potential contributors to an increased rate of sea-level rise, but the data are ambiguous and will not be used here. The author concludes that the rate of sea-level rise in the Dominion Beach area will remain in the range of 30 to 34 cm/100 years, including the rate of crustal subsidence, for the foreseeable future**.** This rate is similar to that observed at North Sydney for the last 36 years.

Readers must recognize that opinions on sea-level rise are diverse within both the international scientific community and among local researchers in the Atlantic Provinces. The Climate Change Directorate of the Nova Scotia Department of Environment has commissioned independent work that concluded sea-level rise represents a greater risk than the present author's opinion. Readers are encouraged to contact the Climate Change Directorate for that information and review the department's web site. Interested readers are also encouraged to search out peer reviewed scientific literature that presents a variety of opinions on this matter.

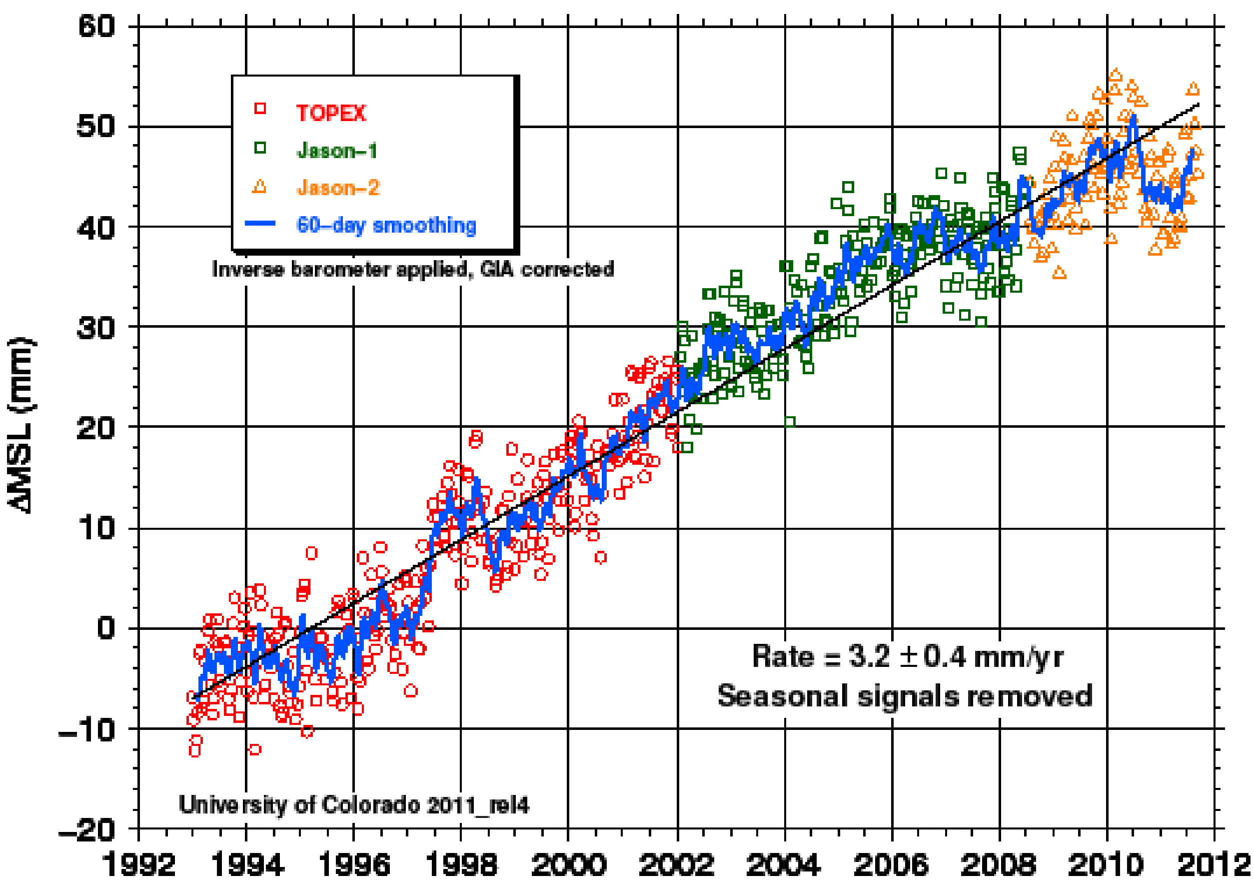

Figure 3. *Average global sea-level rise between 1993 and late 2011, as measured by satellite. Figure reproduced with permission from the University of Colorado (2012), based on data from Nerem et al. (2010).*

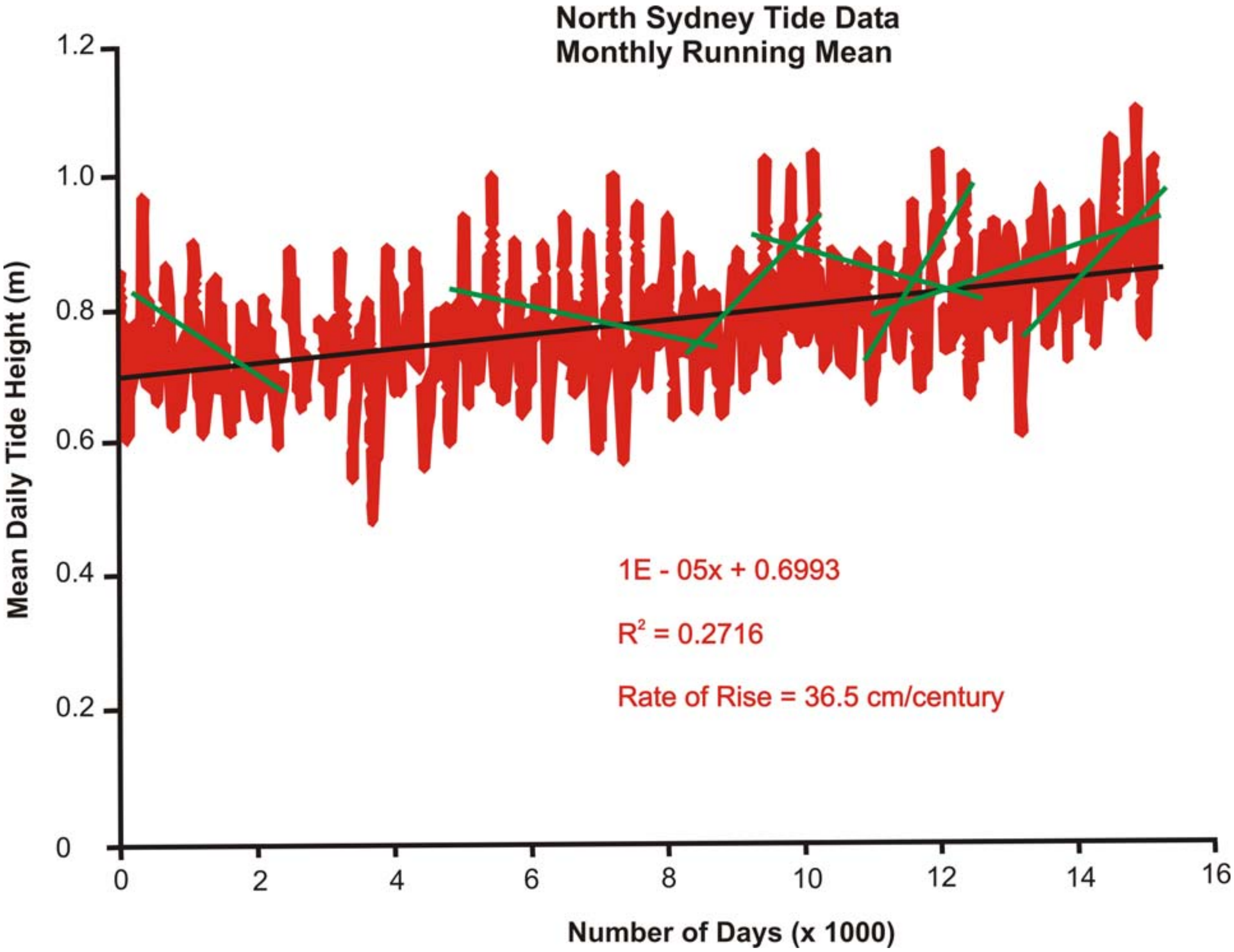

***Figure 4**. Tide gauge data from North Sydney between the mid-1970s and 2011. Lunar and seasonal yearly variations were removed using a box-smoothing technique. Green lines show large variations in short-term data trends. Data are from the Canadian Hydrographic Survey (2012).*

5.0 Long-term Variation in Storm Intensity, Frequency and Damage, and Impacts on Sustainability

It is generally accepted in the literature that the best measure of trends in hurricane strength and frequency over time is given by the number and intensity of land-falling hurricanes. **Figure 5** shows the distribution of land-falling hurricanes and named storms in Atlantic Canada since 1851. These data indicate that there has been no significant increase in intensity or frequency of such storms making landfall in the Atlantic Provinces.

Late fall, winter and spring storms will continue to cause significant damage to coastal infrastructure. This is particularly true where there are increases in the value of coastal properties, an increase in the number of coastal properties, and where infrastructure is increasingly built in locations susceptible to storm damage. In areas where fixed-location infrastructure has been present on multi-decade and century scales, this infrastructure is at high risk due to long-term erosion and sea-level rise.

Areas where winter ice has become less frequent in recent years, or where the ice moves on and off the shore more frequently, may experience significant erosion. The orientation of Dominion beach make it

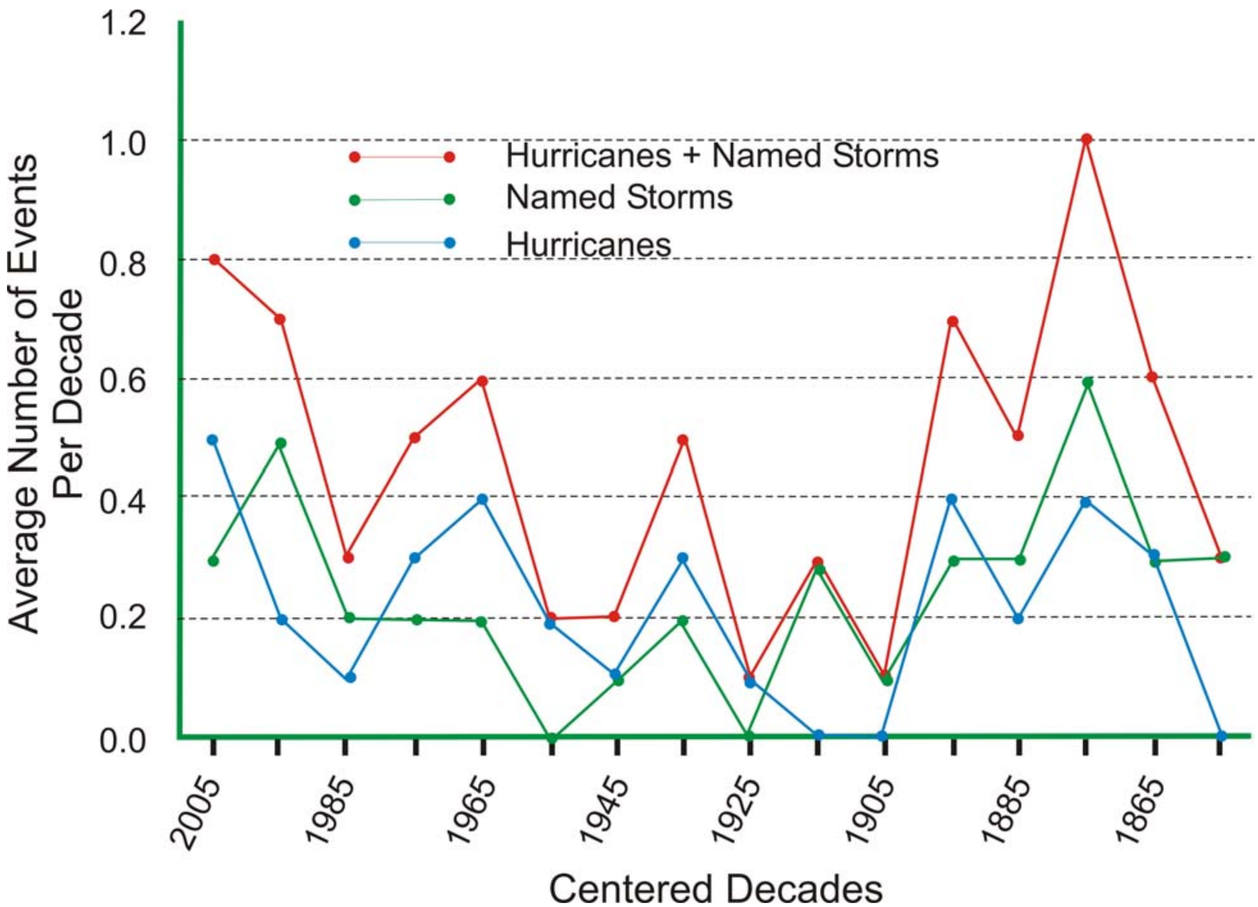

Figure 5. *Frequency of named storms and hurricanes making landfall in the Atlantic Provinces between 1951 and 2010, inclusive. Raw data from the National Oceans and Atmospheric Administration (2012) hurricane database, 1951 – 2012.*

especially vulnerable to nor'easters. However, this trend of reduced ice at the shoreline over the last decade or two should not be assumed to be a long-term phenomena. The re-occurrence of severe winter cold in Nova Scotia with associated increases in coastal ice pack is possible.

6.0 Historical Evolution of Dominion Beach

Dominion Beach is a dynamic system and will continue to change its shape and size on time scales of several hours, decades and centuries, including the influence of individual storms and periods of 'fine' weather. In this section, however, evolution of the beach and spit over a 40 year time frame, 1969 – 2009, will be specifically discussed.

6.1 Sand Mining and Dune Formation

It is very important to note that during the early part of this time period Dominion Beach was actively mined on a large scale for sand. The sand was not only used locally, but also exported to markets in other provinces. Residents informed the author that the beach once had several-metre-high sand dunes, and this is consistent with earlier reports on Dominion Beach. Sand dunes may form and 'move' over time frames of several years and decades. They do not require century to millennium time frames. They simply require a sediment source and proper climatic conditions. For example, a severe drought can cause vegetation to die, exposing the soil and allowing wind erosion and transport of sediment to form dunes, either locally or many miles away.

Sand mining effectively removed the dunes. The dunes were not necessarily actively forming, however. In other locations, such as Carters Beach in southwest Nova Scotia (Basquill et al., in preparation), modern active dunes exist in tandem with large paleo-dune fields. The paleo-dunes now host mature forest and are clearly no longer actively forming and moving. This is important with respect to historic and future evolution of the Dominion Beach spit. If the dunes were active features at the time they were mined, over time they would have rebuilt, in particular since sand mining has not occurred for several decades. This would occur if there is or was a sufficient sediment supply to the beach. There is no reason to believe that sand supply to the beach is insufficient to provide sediment for dune formation. Minor dune formation was observed, as shown by sand up to 1 m thick overlying recent polymer rope and plastic shopping bags. The mined sand dunes were probably relict features, however, like those near Carters Beach, and the immediate local environmental factors are no longer suitable to support major long-term dune-forming processes. Once the dunes are gone, they are gone until local environmental factors favour reformation, even if a sufficient sediment supply is available or the spit migrates to a different location. In the author’s opinion, those environmental conditions may not be an eventuality that the local community should wish for, given it would probably reflect cold, windy and dry conditions.

6.2. Beach and Spit Erosion

The library at DNR has an archive of historic air photographs from the late 1920s through to present. The photographs were taken at different scales, however, and like all photographs, the image becomes progressively more distorted toward the edges. The position of the dune-beach interface can be located and superimposed on one image **(Illustration 1).** This process is called rectification, but is particularly subject to error along shorelines and beaches. In this specific case, distortion is difficult to remove since areas of interest were located on the margins (the most distorted) of the photographs. In addition, the dune-beach interface is difficult to determine since the photographs were taken in different months with varying amounts of vegetation, as well as overexposure of the film. Staff of the Geographic Information Services Section at DNR were able to orthorectify the images within varying margins of error. Because of the inherent problems, only the southern half of the spit could be rectified with reasonable accuracy. On **Illustration 1**, the dune-beach interface is shown for the years 1969, 1976, 1983, 1993, 1999 and 2009. In addition, the dune-beach interface on the landward side of the spit facing Lingan Bay was located and plotted. By measuring the distance between the different shoreface positions, the author was able to calculate an average yearly rate of erosion over the forty year time interval.

The dune-beach interface on the seaward side of the spit eroded and moved landward toward Lingan Bay at an average rate of 0.74 m/year, with individual decadal rates of erosion varying dramatically. Due to inherent errors in this methodology, attempts to interpret the varying decadal rates of erosion are not warranted. Looking at the position of the back side of the spit over 40 years, there is little pattern or change in the position of the dune-beach interface. Apparent variations are considered to represent random internal error in the process of interpretation and measurement. Movement of the back side of the spit for the 40 year time span is considered to be zero.

Given the extensive sand mining discussed in the previous section, it is the author’s opinion that little remains of the true historic surface morphology of the spit. The spit is in essence a naturally reclaimed mine site, similar to what one might see if an abandoned rock quarry is visited 30 years after mining has ceased. About the only original (very old) feature that exists is the trace of the road that once connected Dominion to Lingan over a bridge built at the armoured northwest end of the spit.

7.0 Existing Coastal Armour

7.1 Description of Armour Stone

The armour stone at Dominion Beach generally ranges in mass from 1 to 2 metric tonnes, but includes individual boulders up to several tonnes. The wall (abutment) from the landward-most top edge to a vertical projection of the seaward toe of the abutment appears to be up to 20 m wide. The overall length of the abutment is approximately 100 m.

Terry Amirault (P. Eng.) of DNR's Parks Division designed the revetments. He indicated that there were two phases of armour stone placement along the shoreline immediately facing the southern-most parking lot, and provided the following construction history. The initial project was placement of 180 ft. (55 m) of armour and was completed in 1991. The armouring started at the southern Crown–municipal land boundary. The scattered armour stones to the south of the line were placed at an earlier date before his employment with DNR. The second section was completed on the request (and with the funding) of the municipality, which was warned that the intended work would probably result in an increase in the rate of erosion at the flank. This section of armouring was 140 ft. (43 m) long and was completed in 2003. DNR was not in favour of this second phase of armouring.

The specifications for the initial 1991 armour placement included grading of the slope, placing geotextile, then a 2 ft. (0.6 m) thick layer of 6" to 18" (0.15 – 0.46 m) sized filter stone, which was then covered by about 5 ft. (1.5 m) thick (two layers) of 1 to 2 t armour stone. The toe and top were keyed into the slope. Total height of armour was 13 ft. (4 m), the height recommended in an earlier 1989 report on Dominion Beach. The bottom elevation was at the - 0.4 m level, again as in the 1989 report. The second section built in 2003 had the same specifications but without a geotextile.

The armouring was placed in front of a surface cobble-sandy till (glacial sediments), which is easily eroded by wave action. Farther south along the shore a grey, more clay-rich till underlies the surface till. This clay-rich till overlies and in places grades downward into bedrock. The till is also exposed where the shore face is presently eroding to the north between the existing armouring and the change house and canteen (**Fig. 6**)**.** This erosion is consistent with the warning provided to the municipality by DNR Parks Engineer Terry Amirault that the second phase of armouring would probably increase erosion on the flanks.

7.2 Effects of the Armouring

The present armouring has been highly effective in preventing any further erosion of the shoreline directly behind the abutment. At the south end of the abutment, however, erosion of the shore face continues, possibly at a slower rate than was occurring previously (**Illustration 2**). The boulders placed along the low tide area prior to 1991 may be trapping some cobbles on the landward side, but the overall effect appears to be minimal in preventing erosion. This is further illustrated by the lack of a fillet beach on the south end of the abutment. Sediment eroded from the shoreline south of Dominion Beach (e.g. toward Glace Bay) is transported northward until it encounters the southward end of the abutment. At this point the sediment is forced offshore around the lower end of the abutment since the abutment is acting like a small groin. In addition, sediment that might otherwise be deposited to form a fillet beach is remobilized and also transported seaward by plunging waves. This has the effect of moving the sediment offshore into deeper water and to some extent out of the natural transport system that would otherwise be nourishing (depositing on) the down-current spit.

Figure 6. *Boulders strewn near the low-tide level of the beach is evidence of erosion of the north end of the abutment at Dominion Beach.*

The northern end of the abutment is eroding, and boulders are strewn northward (down current) of the abutment along the mid-tide to low-tide mark (**Fig. 6; Illustration 2**). Severe erosion is occurring immediately northward (down current) of the abutment and even behind the end of the abutment. This is caused by the seaward displacement of sediment discussed above, and also by turbulence caused by the end of the abutment. With the current configuration of the abutment, the erosion will continue. As the erosion continues, the back side of the abutment will eventually collapse. Over an extended period of time the abutment will likely become detached from the shoreline at high tide.

8.0 Future Evolution of Dominion Beach

In the section on beach and spit erosion, the average yearly rate of erosion of the centre and southeast end of Dominion Beach was calculated as being approximately 0.7 m/year. It was determined that the back side of the beach spit has neither eroded nor built landward; it has been stationary since 1969.

Two critical observations are the active erosion of the seaward face of the spit and the absence of landward migration of the spit into the bay. Together these indicate that the spit will eventually be breached at different places and at different times. Ultimately, it will be overtopped. At that point it could erode completely, but more likely would become a sand ridge that is slightly emergent (or slightly submerged) at normal low tide.

At present the least stable part of the spit is in the area immediately northward of the abutment and near the change house along what is now a cobble beach with little or no sand. In this area, the cobble berm is commonly overridden during storm events and it is the most likely place for a breach in the spit. It is the author's opinion that given such an occurrence there are three possible scenarios:

- Sudden movement of the cobble storm ridge landward into the saltwater pond, followed by gradual re-establishment of the cobble beach ridge and re-alignment of the southern end of the spit.
- Breaching of the cobble storm ridge so that at regular high tides the breach is just above that level (or slightly below normal high tide).
- Severe breaching of the cobble storm ridge, creating a second passage where waters from Lingan Bay drain out through the channel as a partially tide-dominated to wave-dominated channel.

There is a large amount of sediment present and available within the system, both seaward of Dominion Beach and also immediately behind the spit in Lingan Bay. There is also an abundant sediment supply from the eroding cliffs found to the south toward Glace Bay. Given the presence of these sediment sources, the spit would likely be re-established should it collapse due to a gradually rising sea level. It would re-establish farther inland and likely in a different form. It is recognized, however, that this is of little consolation to the present community as this process could take many decades.

9.0 Mitigation of Erosion at Dominion Beach

Slowing or preventing erosion at Dominion Beach involves more than one solution, as the actual area is composed of two geologically different environments. On the southern end of the 'beach,' the shoreline is a steep scarp eroding into bedrock, which is in turn overlain by stony glacial sediments. To the north (past the present change house) there is a well developed cobble and sand beach (spit). As discussed previously, armouring is highly successful in preventing erosion on the 'land end' of Dominion Beach. Thus, as a general statement, additional armouring is recommended in that area.

Specifically, consideration should be given to extending the current armouring southward from the southern end of the existing armouring. In doing so, it is recommended that the base of the revetment be located closer to the present scarp than is the case with the existing armouring. The revetment should taper toward the land on the southern end in an attempt to reduce the likelihood of erosion occurring at the end of the revetment. This action would require that armouring take place above the ordinary high water mark on property owned by the municipality.

Similarly, it is recommended the current armouring be extended northward to protect the land where the present change house and parking lot are located. It is important to note that this armouring is not designed specifically to protect the beach. It is again recommended that the base of the revetment be located closer to the present scarp than is the case with the existing armouring (i.e. the toe should be located and dug down about half way between the low- and high-water mark).

The reason for pulling the base of the new armouring closer to the eroding scarp is to reduce the 'groin effect' of the armour, as discussed previously. This leaves the question of whether or not to move the toe of the existing armouring landward to reduce the present 'groin effect' and bypassing of sediment. From a coastal dynamics point of view, re-alignment of the toe of the revetment is recommended.

Simply extending the existing armouring northward will result in the same situation of flanking erosion as is presently occurring (**Fig. 6**). In an attempt to prevent this, it is recommended that the revetment be gradually curved landward so that it wraps around the northern side of the change house. Thus, the northern part of the revetment would actually be constructed in an excavated trench that turns inland rather than along the beach face. The revetment would be of sufficient height to prevent overwashing of future park infrastructure in the area of the existing parking lot.

A different solution is recommended for the southern end of the main spit, where storms regularly over-wash the spit, destroy the walkway, and leave a cobble lag and berm (**Illustration 2**). It is also the area where the spit is most susceptible to breaching. Direct seaward-facing armouring of the beach is strongly not recommended. It would have severe, immediate and long-term negative effects on the beach-spit and could increase the potential for, or directly cause, breaching of Dominion Beach.

In the area of cobble overwash, the beach is migrating landward, as can be seen by the burial of the roofed sitting area **(Fig. 7).** Seaward of the structure, an obvious cobble storm ridge is developed. It is recommended that the natural process of beach stabilization be enhanced. By doing so, the potential for successfully stabilizing the beach is increased while limiting potential damage to the beach system that would occur as described above by using intrusive methods.

It is recommended that stabilization of the beach be accomplished by imbedding a rubble mound within the existing beach but behind the cobble storm ridge (**Fig. 7**). The base of the rubble mound would be set down (buried) in the beach to a depth at which it would be unaffected by severe storms or extensive scouring. The top of the rubble mound would be slightly higher than the existing storm ridge. The concept is that the rubble mound would act as a brace to the existing storm ridge while at the same time reducing overwash and allowing the storm ridge to build higher. In areas where the storm ridge is less well developed more of the rubble mound would initially be exposed above the existing cobble beach. Over time it is likely that it would be progressively buried as cobbles build up seaward of the rubble mound.

Figure 7. *Landward migration of the Dominion Beach spit is illustrated by the progressive burial of park infrastructure.*

It is possible that the rubble mound would stabilize and enhance the cobble storm ridge. It has the potential to allow for seaward migration of the existing beach face. In addition, it is hoped that over-wash of the rubble mound would deposit sediment behind the crest of the mound, cause further burial, and further widen and stabilize the beach. This would have the cumulative effect of providing enhanced protection to any infrastructure, such as walkways, that might be located behind the rubble mound. In order to prevent or reduce flanking erosion at the northern end of the rubble mound it should be turned inward (landward) and the height reduced until it is below the existing level of the spit.

10.0 References

Basquill, S., Utting, D., DeMont, G., Benjamine, L., MacKinnon, F. and Milton, G. in preparation: Coastal geomorphology and ecosystem diversity at Carters Beach, Queens County; Nova Scotia Department of Natural Resources, Open File Report.

Boehner, R. C. and Giles, P. S. 1986: Geological map of the Sydney Basin, Cape Breton Island, Nova Scotia; Nova Scotia Department of Natural Resources, Map ME 1986-001, scale 1: 50 000.

Boehner, R. C. and Giles, P. S. 2008: Geology of the Sydney Basin, Cape Breton and Victoria Counties, Cape Breton Island, Nova Scotia; Nova Scotia Department of Natural Resources, Memoir ME 11, 90 p.

Canadian Hydrographic Survey 2012: Fisheries and Oceans Canada, Integrated Science Data Management, Station 612 (North Sydney); http://isdm-gdsi.gc.ca/isdm-gdsi/twl-mne/inventory-inventaire/sd-ds-eng.asp?no=612&user=isdm-gdsi&region=ATL&ref=maps-cartes accessed July 2012.

Gehrels, W. R., Kirby, J. R., Prokoph, A., Newnham, R. M., Achterberg, E. P., Evans, H., Black, S. and Scott, D. B. 2005: Onset of rapid sea-level rise in the western Atlantic Ocean; Quaternary Science Reviews, v. 24, p. 2083 – 2100.

IPCC 2012: Summary for policymakers; *in* Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, eds. C. B. Field, V. Barros, T. F. Stocker, D. Quin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G. K. Plattner, S. K. Allen, M. Tignor and P. M. Midgley; A Special Report of Working Groups 1 and 2 of the International Panel on Climate Change; Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19. http://ipcc-wg2.gov/SREX/.

National Oceans and Atmospheric Administration 2012: National Hurricane Center Data Archive; http://www.nhc.noaa.gov/pastall.shtml#tracks_all accessed July 2012.

Nerem, R. S., Chambers, D., Chloe, C. and Mitchum, G. T. 2010: Estimating mean sea level change from the TOPEX and Jason Altimeter Missions; Marine Geodesy, v. 33, no. 1, sup. 1, p. 435.

University of Colorado 2012: Global mean sea level time series (seasonal signals removed); http://isdm-gdsi.gc.ca/isdm-gdsi/twl-mne/inventory-inventaire/sd-ds-eng.asp?no=612&user=isdm-gdsi&region=ATL&ref=maps-cartes accessed July 2012.