An Investigation into Erosion and Armouring Effects on the Coburg Peninsula at the Esquimalt Lagoon, Colwood BC

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Abstract

The Coburg Peninsula is an eroding landform in Victoria, British Columbia. Methods of armouring have been put into place to slow the effects of coastal erosion. The peninsula is already thin and increased erosion rates could potentially alter and damage the existing evacuation route, Ocean Boulevard, running along the peninsula's length. Esquimalt Lagoon, which is protected by the Coburg Peninsula is a Migratory Bird Sanctuary and very important to First Nations. This fragile lagoon ecosystem is highly vulnerable to changes in peninsula form. This paper looks at shoreline changes over time and discusses the effects armouring has on sediment transport. It will also be investigating how sediment supply and distribution has changed the morphology of the peninsula. Consequences of a shifted sediment regime will be discussed as well as their implications for the City of Colwood. The Digital Shoreline Analysis System (DSAS) was be used to analyze changes in shoreline position over the time series 1954 to 2013. Another component will look at the historical context of the area and see how mitigation management has caused the geomorphic responses. Lastly sediment sorting will be looked at for four different sites along the spit to see if sediment transport is indicative of longshore drift. These samples will be analyzed using GRADISTAT to quantify the sorting.

1 Introduction:

1.1 Objectives

Erosion is an increasing concern to the City of Colwood and its inhabitants. It is important to recognize the changes in erosional and depositional processes and to look at the historical context of the area so as to better predict future changes. This study seeks to answer three research questions:

i) How has the peninsula shoreline changed over time?

ii) How does the peninsula's form respond to these changes?

iii) What are the main causes of these changes?

1.2 Geomorphic History

The peninsula and lagoon it encloses have been undergoing constant geomorphic change since they were formed. It is known that the Straits of Georgia and Juan de Fuca were formed by glaciers passing across the region, leaving deep steep sided troughs (Pickrill, 1983, 195; Herzer & Bornhold, 1982, pp. 287). In some areas these troughs are more than 400m deep (Herzer & Bornhold, 1982, pp. 312). Theories about the formation of the lagoon corroborate with the knowledge of historic glacier presence in the area. Following the Fraser Glaciation thirteen thousand years ago, the peninsula began to form (Yorath & Nasmith, 1995, pp. 146). Evidence suggests that large stagnant pieces of glacier ice sat where the lagoon is today and meltwater streams carved the basin out around the ice. Sediment deposition on the seaward side of the ice provided an input for longshore transport to rework sediment and form the peninsula (pp. 148). The Peninsula almost fully encloses the Esquimalt Lagoon. The northern end of the peninsula is kept from closing off the lagoon by strong tidal flows that keep the lagoon mouth open. The tidal flows have a large influence over sediment movement on the northern tip of the peninsula and surrounding areas.

Continued growth of the peninsula is a result of sediment input via longshore drift, the process by which spits grow as sediment from updrift is deposited downdrift (Aubrey & Gaines, 1982, pp. 258). Coburg Peninsula receives sediment via longshore drift from the coastal bluffs of the Colwood delta located southwest of the peninsula (Foster. Ed. 1976, pp.164-166). This is supported by rates of erosion at around 60-90 cm per year to the southwest of the peninsula, while the peninsula grew (pp. 164). Another study in 1983 recorded rates of erosion at around 15-30 cm per year in the area indicating continued shoreline erosion (Pickrill, 1983, pp. 201).

1.3 Changes in Sediment Supply

The form of the peninsula is dependent on the amount of sediment input. Beginning in 1909 mining operations at Producer's Pit, a large gravel pit mine located southwest of the peninsula, delivered a large influx of fine-grained sediments to the beach (Seabulk Systems Analysis Inc., 2008, pp. 3). During the early years of the gravel pit's operations, sand was dumped directly onto the foreshore where it was taken by longshore drift and deposited on the peninsula. The practice of dumping sand on the beach as waste stopped in the early 1970's (City of Colwood, 2010). The increased supply of sediments to the peninsula during the period 1909- 1970 caused the beach face to inflate and the peninsula to widen.

Another geomorphic response to sediment supply is the sorting of the sediment. Sedimentology indicates that in longshore drift the sediment deposits further from the source region tend to be better sorted, finer, and the grain size distribution more negatively skewed (McLaren & Bowles, 1985, pp. 458). With this model, sediment on the Coburg Peninsula is expected to show a similar trend due to its constant supply of sediment from the southeast.

1.4 Erosional Issues for Infrastructure and Mitigation

Both anthropogenic and natural processes can influence rates of erosion and deposition. The erosion and deposition of materials elsewhere is inevitable. As human infrastructure has developed in many coastal areas, mitigation methods have been put in place to defer or slow the process while protecting infrastructure from damage (Kusimi & Dika, 2012, pp. 989). A study at Ada Foah in Ghana examined the impacts of erosion on coastal property using DSAS to measure the extent of shoreline change in the area over time (Kusimi & Dika, 2012, pp. 987). Other infrastructural concerns surrounded a road along the coast of Ada

Foah that washed away limiting community access routes (Kusimi & Dika, 2012, pp. 989). This case study was useful to review because of similarities in issues surrounding coastal infrastructure and methods used to analyze shoreline retreat. Damage and overwashing of Ocean Boulevard, the road running the length of the Coburg Peninsula, is one of many concerns with the peninsula's changing shoreline. The road has anchored the peninsula in place through hard structural enforcement. It is a valued access road between the opposite sides of Colwood and offers a shorter commute to Victoria for Colwood residents. This road is at risk of being cut off by erosional processes occurring around the bridge at the northern end of the peninsula, particularly during storm events. The bridge itself was constructed in 1930, replaced in 1968, widened in 1984, and continuously inspected ever since (City of Colwood, 2010). Further repairs occurred in 2003 when the bridge deck was replaced followed by a brief closing in the winter of 2007/08 while the road surface was repaired (City of Colwood, 2010). In 2010 the bridge was closed again for a short period of time because of erosion at the north end of the bridge but reopened later on in the year (City of Colwood, 2010). The 2010 closure was due to concerns that wave action had lowered the beach level to the point of exposing the bottom of the northern bridge abutment to erosion (Stantec, 2010, pp. 1). Concerns grew as side scour caused fine sediment to be eroded from behind the abutment (2010, pp. 2). Stantec, however, was of the opinion that the structure of the pilings was not at risk (2010, pp. 2) and the bridge was reopened. Continuous erosion may cause the bridge to be shut down in the near future due to safety concerns. This decision would increase commute times for people living on the southern side of the Colwood Delta and limit access to Ocean Boulevard. A parking lot also had to be removed from the northern tip of the peninsula due to severe erosion of the sediment lobe that extends off the northwest of the peninsula. This is a good indicator that decreased sediment supply is causing a reduction in the size and stability of Coburg Peninsula.

Rip-rap is an anthropogenic structure constructed in an attempt to mitigate erosion. Rip-rap was put in place on the seaward side of the northern tip of the Peninsula (see Figure 4) to protect the DND Ranger Station from wave action and erosion (Seabulk Systems Inc., 2008, p. 3). The station was removed on Friday September 13, 2013 due to seawater damage and damage from wave-tossed logs (City of Colwood, n.d.).

Sea level is a natural influence on erosion and deposition rates. Sea level rise can increase rates of erosion (Day, 2004, pp. 24) by exposing sediments previously out of reach of the water to wave action (Day, 2004). Sea level in itself does not act to increase erosion but facilitates increased erosion rates during storm events (Day, 2004, pp. 24). The Scientific Committee on Ocean Research (SCOR), in their study of sea level rise and erosion rates, asked the question, "How does a beach change in its morphology when there is a higher water level?" (1991, pp. 896)). The study found that with increased sea level came retreating shorelines (SCOR, 1991, pp. 899). Retreating shorelines can be found all over the world as indicated by Charles Day in his paper on the exacerbating effect of sea level rise on erosion (2004). He discussed how more than 70% of the world's shorelines were retreating (Day, 2004, pp. 24). Future sea level rise on the west coast is imminent. This is important to consider due to climate change and extreme weather events that may influence erosion rates in the future.

2. Study Site

Observations and data for this project were taken at the Coburg Peninsula, located at 48°25'33.16"N and 123°28'3.84"W just west of Victoria, British Columbia in the Capital Regional District (Figure 1 and 2). This is a popular recreational area for many people to relax at the beach and enjoy the migratory bird sanctuary (Figure 3). The peninsula serves not only as a local attraction but it is also an emergency evacuation route. The Coburg Peninsula encapsulates the well-known Esquimalt Lagoon and when looking into the future, erosional impacts on the Peninsula have large implications for the lagoon as well (Graham, 2006). The lagoon is a Migratory Bird Sanctuary and must be protected under the Migratory Birds Convention Act.

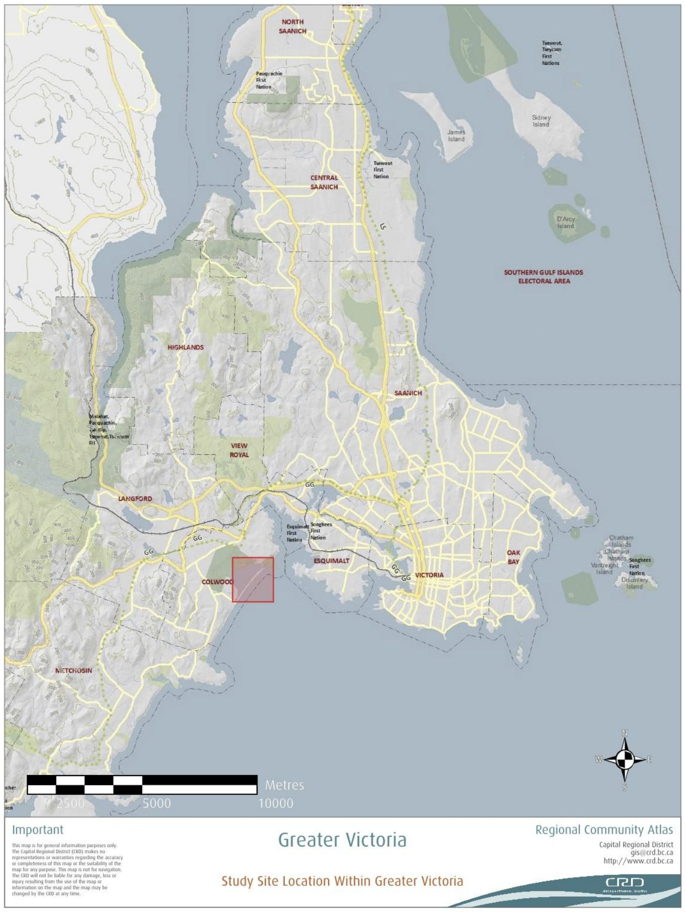

Figure 2. The Coburg Peninsula, highlighted in red, located to the West of Greater Victoria. (CRD Atlas, 2013)

Figure 3. The Coburg Peninsula at the Esquimalt Lagoon. Source (CRD Atlas, 2014)

Figure 4. The Coburg Peninsula is a popular recreational area for beach goers and bird watchers

Figure 5. Rip-rap added to the northern end of the peninsula as a mitigation method

Data and Methods

2.1 Digital Shoreline Analysis System

DSAS was used to investigate shoreline change over time. It involves creating shapefiles of shoreline positions using air photos and importing them into ArcGIS. Transects running perpendicular to the shoreline were cast from a baseline (Ocean Boulevard in this case) and shoreline change rates were calculated by DSAS for each transect. Air photos were obtained from the Capital Regional District (CRD) and the map library at the University of Victoria to create a time series from 1954 to 2013. All the photos were georeferenced and the shorelines were digitized in QGIS and then put into the DSAS Version 4 ArcGis extension. DSAS was run on 2 different 10 year time series, the first from 1992 to 2002, and the second from 2003 to 2013. DSAS was also undertaken on the tidal flats south of Fort Rodd Hill from 1979 until 2013 to analyze the large deposition of sediment in front of the bluffs. The 2013 air photos from the CRD were used as the base map in all of the DSAS figures seen below. The 59 year time-scale helped to determine how the peninsula responds to changes in sediment supply over a long-term timeframe. This extended time-series helped to avoid seasonal changes that could falsely influence the results. Lag-effects of sediment supply changes were identified as adequate time was given for the system to re-orient itself after significant erosion.

2.2 GRADISTAT

GRADISTAT is a free particle size analysis software (Blott, S. 2010). It was used to examine the sediment sorting at four different sites along the peninsula. All four samples were gathered at the most recent high tide mark on March 16, 2014 (Figure 1), and dried in ovens for 24 hours at 110^{o} Fahrenheit. After this time the samples were sorted using a splitter until samples were near 100g (Sample 1:101.5g, Sample 2: 114.0g, Sample 3: 137.8g, and Sample 4: 113.2g). Following this each sample was put through five sieves at 1mm, 710μm, 500μm, 255μm, and 250μm which were then placed within a laboratory sieve shaker for 15 minutes per sample. Upon completion sediments remaining in each sieve were carefully weighed and input into GRADISTAT to analyze each sample's sorting. The program compared the percentage of the sample contained within each sieve with the initial weight of the sample. From the analysis of each sample, tables were created classifying the samples by sorting and providing a breakdown on the makeup and distribution of particle size within the sample. The tables and figures in the Results section show the GRADISTAT results. All other meta data for the analysis are available upon request.

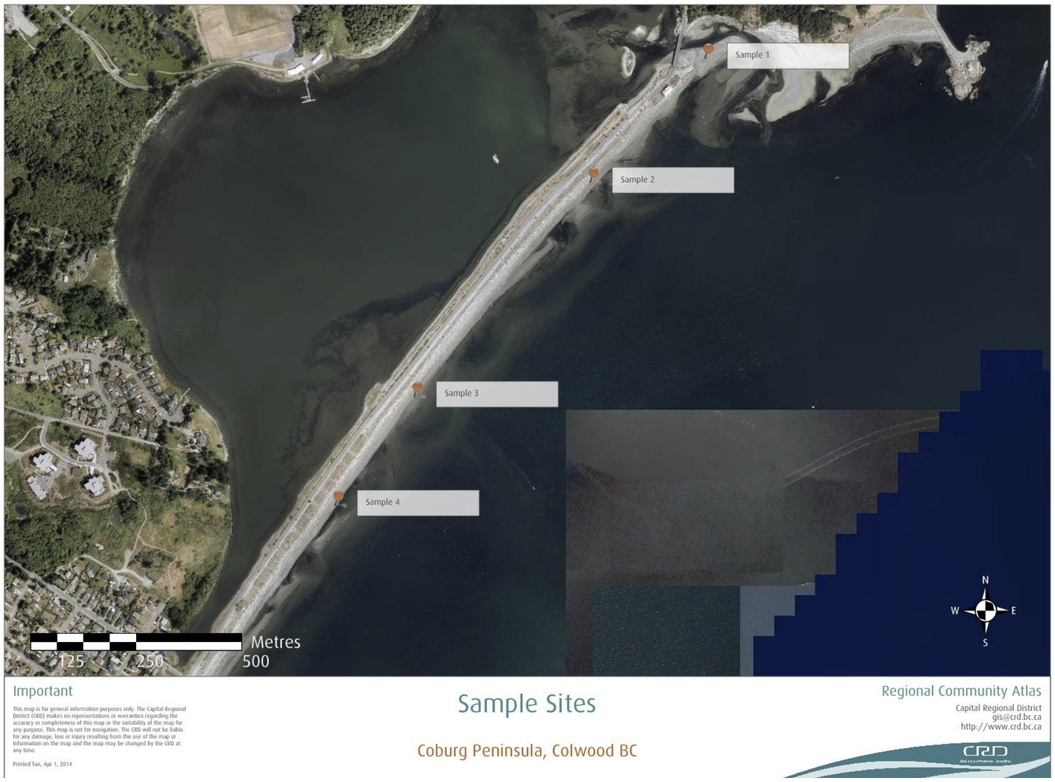

Figure 1. Sample site location along the length of Coburg Peninsula. (CRD Atlas, 2014)

4. Results:

4.1 DSAS Results

Rates of shoreline movement are shown in Net Shoreline Movement (NSM), which gives the distance a shoreline has moved over the time series. An End Point Rate (EPR) is also given to show the yearly rate of shoreline movement surrounding the rip-rap on the northern tip of the peninsula between 2003 and 2013 (Figure 8). Linear Regression Rates (LRR) are provided to give an underestimated shoreline movement rate during the two time series. Averaged rates of shoreline movement in NSM, EPR and LRR can be found in Table 1 below. DSAS confirmed our predictions formed from research into the study site. The shoreline is eroding at varying rates along the peninsula, most notably erosion rates are high at the northern tip where the tidal stream moves in and out of the lagoon. All DSAS statistics are available upon request.

Table 1. Average Shoreline Change Rates (meters) for DSAS Statistics by Time-series and Location

	1992-2002 (Coburg Peninsula)	2003-2013 (Coburg Peninsula)	1979-2013 (Fort Rodd Hill Bluffs)
EPR (m)	-0.446	-0.410	0.485
NSM (m)	-4.459	-4.105	16.516
LRR (m)	-0.174	-0.335	0.271

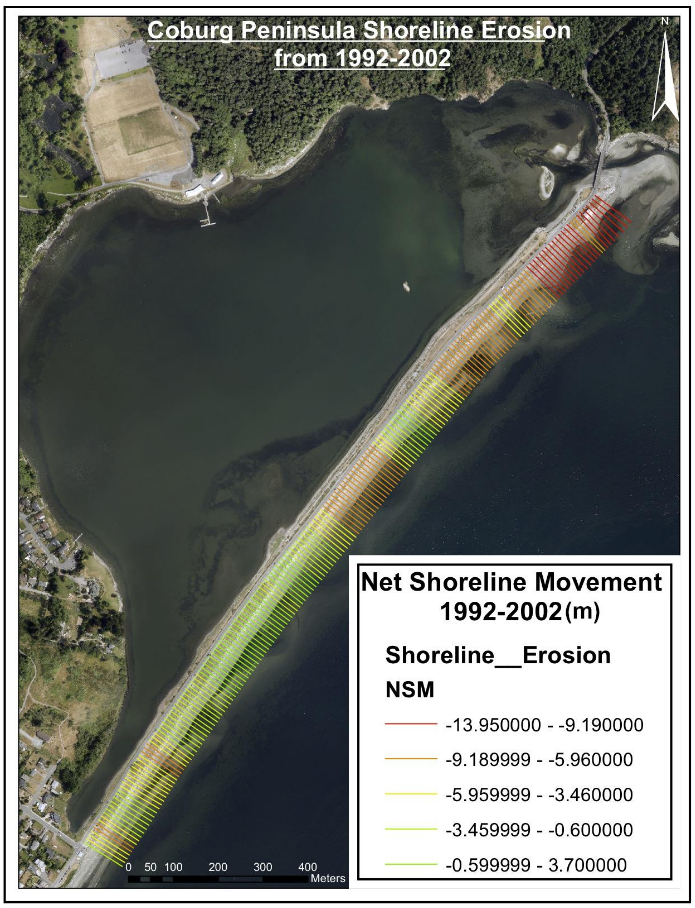

Figure 6. Digital shoreline analysis from 1992 until 2002.

In Figure 6 shoreline change rates for the time series 1992-2002 are shown. The transects near the northern tip of the peninsula show accelerated erosion during the 10 year period.

This shows that the peninsula is starved for sediment. Lack of sediment supply affected the most dynamic feature (the northern tip), which is also the farthest feature from the sediment source. The figure shows the southern extent of the peninsula as being more stable, suggesting sediment movement is still strong from the source to this area. As sediment is deposited on the southern end of the peninsula less is available to be transported to the northern tip where rapid erosion is occurring.

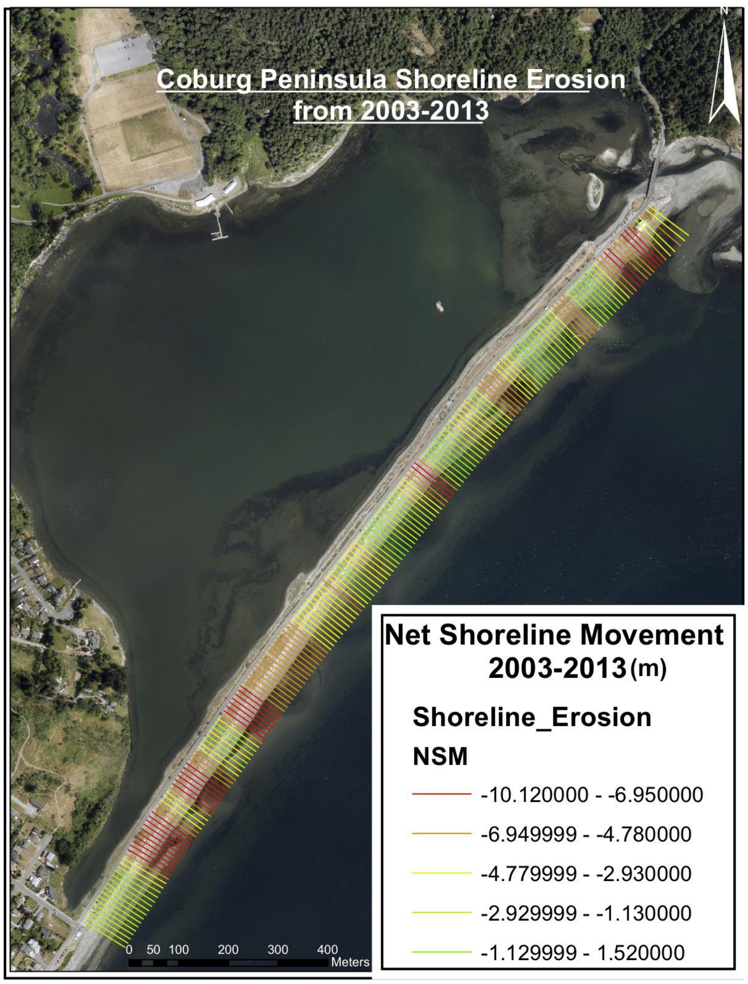

Figure 7. Digital Shoreline Analysis from 2003 to 2013.

In Figure 7 Net Shoreline Movement at the southern end of the peninsula has decreased and caused higher erosion rates. A significant change during 2003 to 2013 from 1992 to 2002 is the concentration of erosion around the rip-rap at the northern end of the peninsula. Rip-rap can cause side-scour and beach steepening which is the main reason for increased erosion.

Figure 8. Northern tip of Coburg Peninsula.

Figure 8 highlights the increased erosion around the rip-rap during 2003 to 2013. The rip-rap was installed to protect the Ranger DND station; however, this strategy was unsuccessful as the station was removed after being damaged by wave action. Hard structures used to protect shorelines often concentrate erosion on other portions of the shoreline. Observation of the beach face during the winter of 2014 showed a steep, thin beach with waves often running right into the rip-rap. This suggests rip-rap has accelerated the process of beach thinning and caused increased erosion.

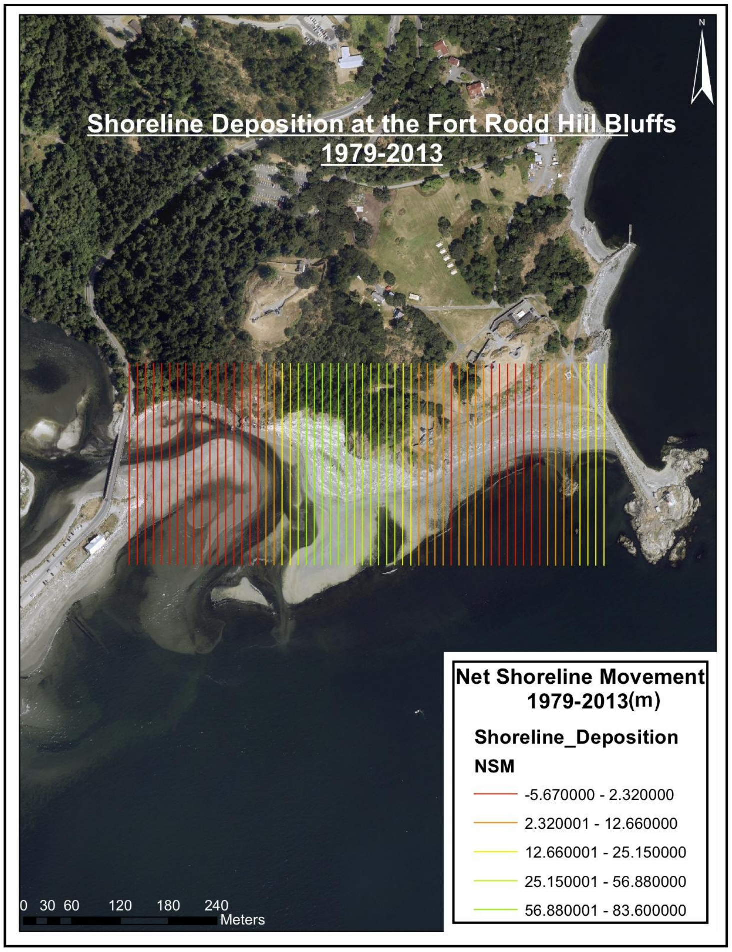

Figure 9. Digital Shoreline Analysis from 1979 to 2013 at the Fort Rodd Hill.

Figure 9 shows the redistribution of sediments eroded from the peninsula in front of Fort Rodd Hill and Rodd Point. Sediment lost from the peninsula due to erosion is deposited inside the lagoon on the flood tidal delta, or on the tidal flats between the northern tip of the peninsula and Fisgard Lighthouse (Seabulk Systems Analysis Inc., 2008, pp. 4). A significant amount of the tidal flats have been raised above the high water line in the past 34 years. Air photo observations show that the tidal flats exposed above the high water level are stabilized by large woody debris. This stabilization has caused increased deposition in the past 10 years by retaining sediment and allowing accretion under strong tidal flows. Green transects show accretion rates of 1.67m/year to 2.46m/year. This extremely high deposition rate, especially in the time series 2009 to 2013 has implications for infrastructure management. We also theorize the possible creation of a dune system on the tidal flats. A surplus of fine-grained sediments and strong winds create the perfect situation for a stable dune system to grow.

4.2 GRADISTAT Results

After running the GRADISTAT analysis, the program output grain size distribution charts for each site based on the quantities of sediment remaining in each of the sieves. The program used the sample statistics to classify each sample in terms of how well sorted it was and what type of distribution the sample had. These are shown below in Table 1.

Table 1. Sediment name and sample type for four samples collected at the recent high tide mark of the seaward side of the Coburg Peninsula on March 16, 2014

Site	Sample Type	Sediment Name
1	Unimodal, Poorly Sorted	Very Coarse Silty Medium Sand
2	Bimodal, Poorly Sorted	Poorly Sorted Medium Sand
3	Bimodal, Moderately Sorted	Moderately Sorted Very Coarse Sand
4	Unimodal, Moderately Well Sorted	Moderately Well Sorted Medium Sand

The distribution of grain size for each site indicate which grain sizes were most abundant in the sample and which were less so. These distributions are shown in Figures 10 to 13.

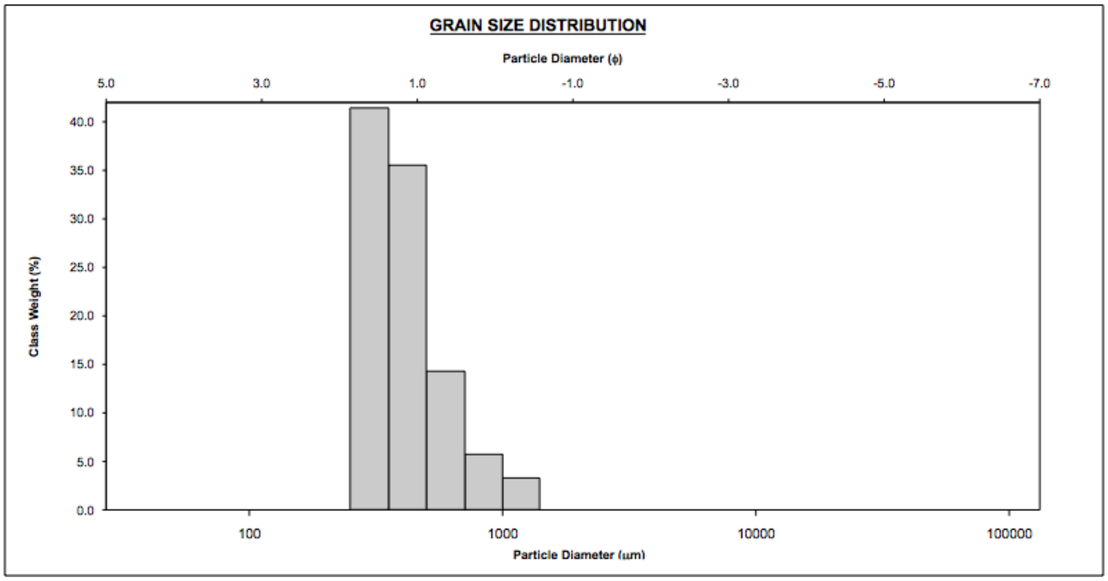

Figure 10. Grain Size Distribution at Site 1.

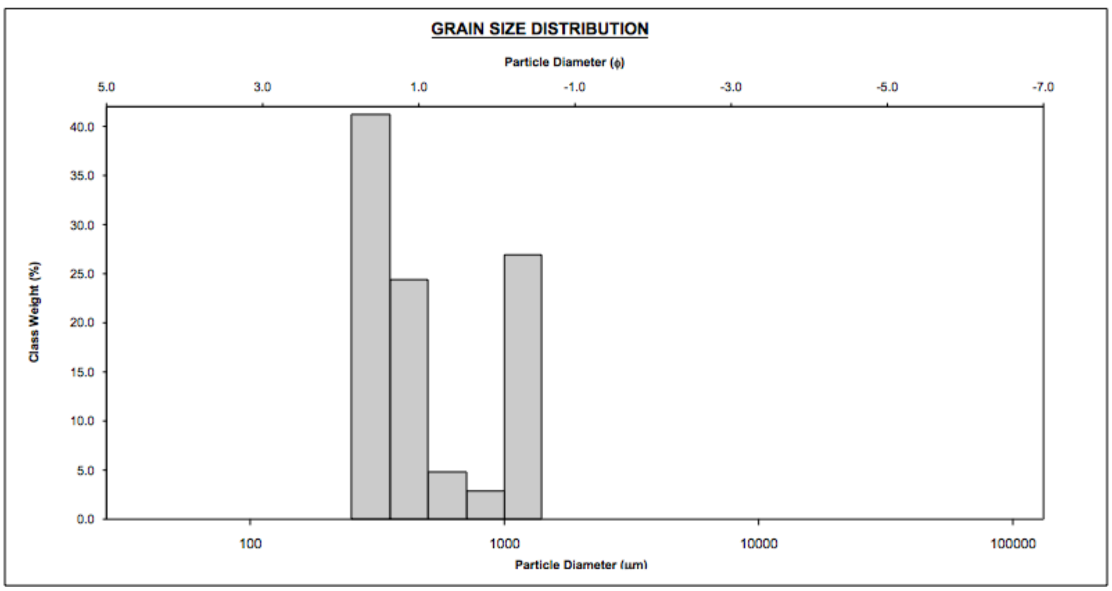

Figure 11. Grain Size Distribution at Site 2.

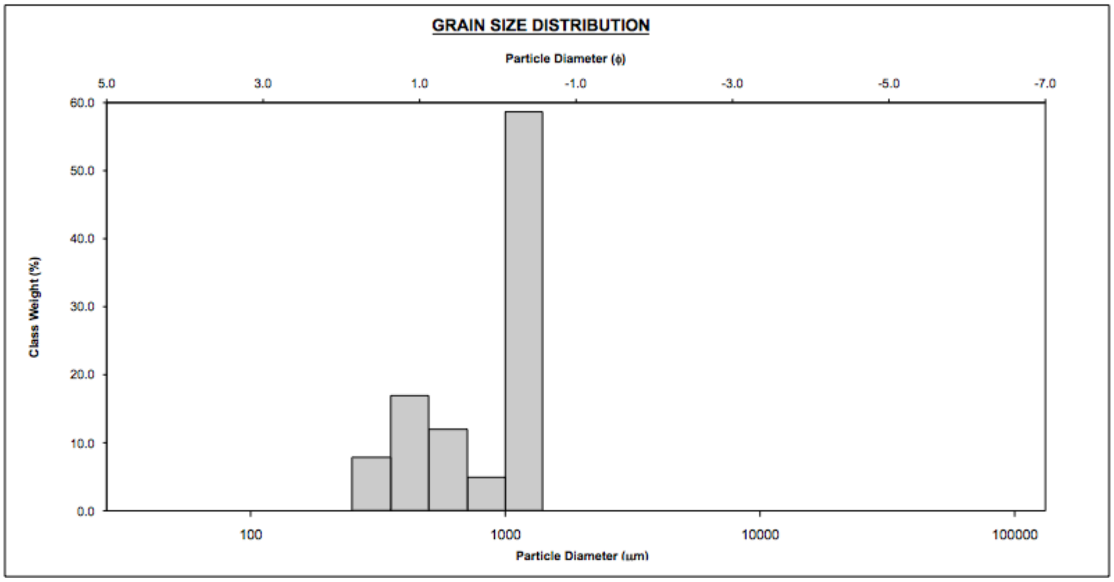

Figure 12. Grain Size Distribution at Site 3.

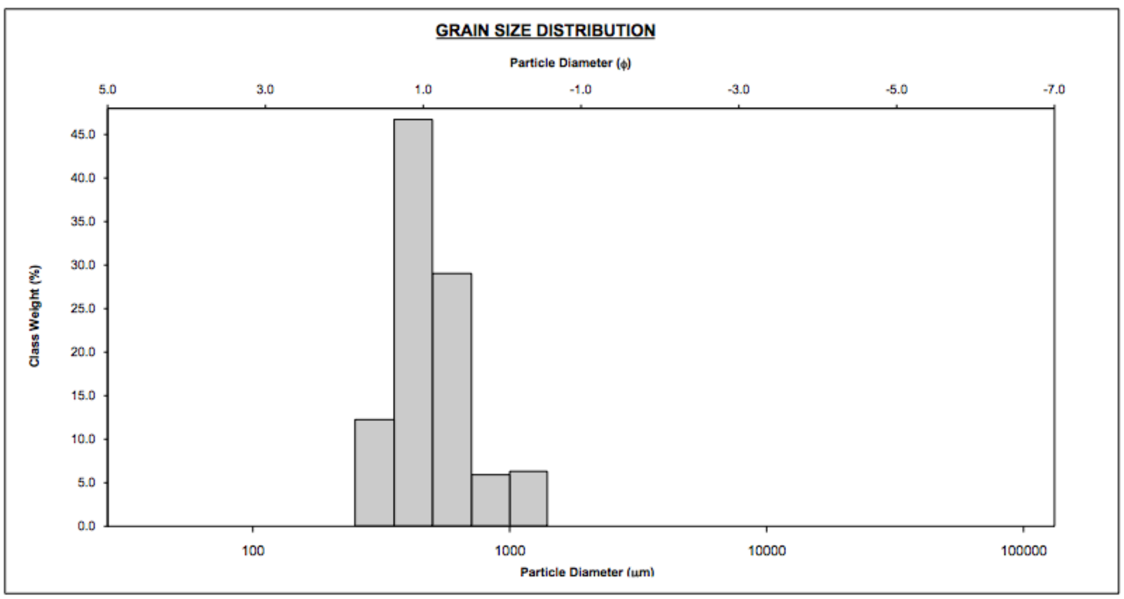

Figure 13. Grain Size Distribution at Site 4.

Table 2. GRADISTAT breakdown of sample makeup for each site

Site	1	2	3	4
Very Coarse	0.0%	0.0%	0.0%	0.0%

Gravel				
Coarse Gravel	0.0%	0.0%	0.0%	0.0%
Medium Gravel	0.0%	0.0%	0.0%	0.0%
Fine Gravel	0.0%	0.0%	0.0%	0.0%
Very Fine Gravel	0.0%	0.0%	0.0%	0.0%
Very Coarse Sand	2.7%	23.8%	57.5%	6.0%
Coarse Sand	17.1%	7.0%	17.1%	34.4%
Medium Sand	65.5%	60.0%	24.9%	57.3%
Fine Sand	0.0%	0.0%	0.0%	0.0%
Very Fine Sand	0.0%	0.0%	0.0%	0.0%
Very Coarse Silt	2.5%	1.5%	0.0%	0.4%
Coarse Silt	2.5%	1.5%	0.0%	0.4%
Medium Silt	2.5%	1.5%	0.0%	0.4%
Fine Silt	2.5%	1.5%	0.0%	0.4%
Very Fine Silt	2.5%	1.5%	0.0%	0.4%
Clay	2.5%	1.5%	0.0%	0.4%

5. Discussion

Digital Shoreline Analysis has provided insight into the rate of erosion on specific points in time and space along the Coburg Peninsula. The past 59 years have shown a deflation of the beach face and a redistribution of sediments. Sediments eroded from the beach have moved via longshore drift and been redistributed by the tidal flow that keeps the spit from entirely enclosing the lagoon. Sediment is pulled into the lagoon during a rising tide and becomes part of the flood tidal delta. During an ebb tide sediment is pushed towards Fisgard Lighthouse and deposited in front of Rodd Point or in the offshore benthic environment (Seabulk Systems Analysis Inc., 2008, pp. 4). Figure 9 shows the tidal flats south of Fort Rodd Hill are the most significant area of deposition.

When Producer's Pit ceased to dump sand onto the foreshore in the 1970's (City of Colwood, 2010), erosion of the beach accelerated and the inflated beachfront began to recede. This caused major problems for infrastructure as most of the structures on Ocean Boulevard were built while the beach was in its inflated state (Seabulk Systems Analysis Inc., 2008, pp. 2). This is why the parking lot was removed and rip-rap was placed at the base of the lot near the tip of the peninsula to protect it. The rip-rap has facilitated higher erosion rates by causing side scour around the edges of the lot and a significant loss of the beach face in front of the lot (this can be seen in Figure 8). The prominent rip-rap now stands out from the beach face and is causing more concentrated erosion around its edges. Sand from Producer's Pit drastically changed the sediment sorting along the peninsula as most of the natural sediment was coarser grained, originating from the surrounding Colwood Delta. Some areas of the spit have become more vulnerable to breaching and overwash during storm events as a result of sediment redistribution. The southern extent of the peninsula becomes more vulnerable to overwashing as the peninsula thins. The tidal flats on the northern extent decrease wave action moving north, however thinner beach faces can render the northern extent equally as vulnerable. The reduction of beach face on the tip of the spit caused the bridge to be vulnerable during the high water event and storm in 2008 that led to Ocean Boulevard needing to be shut down for repairs (Seabulk Systems Analysis Inc., 2008, pp.6).

Longshore drift processes acting on the peninsula suggest that sediment sorting should be most well sorted at the tip of the peninsula and most poorly sorted at the southern end of the peninsula. Findings from the GRADISTAT software indicated the opposite. Instead the most well sorted sample was furthest updrift while the poorest sorting occurred at the tip of the peninsula. When looking instead at the sediment makeup for each sample patterns emerge showing greater percent makeup of smaller grain sized materials for site 1 such as medium sand and silt with the greatest percent makeup of larger grain sized coarse sand and medium sand found at site 4. One irregularity in the data occurred at site 3 where the grain sizes were significantly larger than the other samples. This is believed to have been due to a berm located at the same point as the most recent high tide mark for site 3. This analysis helps to show that though the sorting of each sample was not as expected, sediment size did trend from coarser and larger material to finer material downdrift.

Reasons for the discrepancy between what sedimentology models predict in terms of longshore drift, sediment size, sorting and the irregular sorting patterns observed at the site are that human interference with the system has altered some geomorphic patterns. The rip-rap installed on the peninsula to mitigate erosional processes alters the natural process by which erosion and deposition occur. Changes in sediment supply to the peninsula result from the discharge of waste sand onto the foreshore from Producer's Pit.

6. Conclusion

A recent decrease in sediment supply during the time series of our data has led to observed erosion and thinning of the Coburg Peninsula. Redistribution of eroded sediments either into the flood tidal delta inside the lagoon, offshore, or onto the Rodd Point Bluffs has caused significant changes in spit form. The main cause of geomorphic change has been anthropogenic interference in natural sediment supply to the peninsula. These changes have had large implications for the City of Colwood as a parking lot has had to be removed, the bridge rebuilt, the road repaired multiple times, and the DND Ranger Station removed. Hard structures like rip-rap have been shown to cause higher erosional stress, and the rip-rap in place on the peninsula has done this causing heightened erosion around the armoured area. In contrast to the inflated beach face caused by mining practices at Producer's Pit, the spit is now eroding due to decreased sediment supply. This human modification of the natural environment has caused the sediment grain size and sorting distribution to be altered from the expected natural trend. Development of the nearshore zone southwest of the peninsula will cause further reduction in supply of natural sediments from the Colwood delta.

In order to maintain infrastructure and current spit form beach replenishment would have to be undertaken; however, this would be very expensive, cause damage to the offshore benthic environment through dredging for sediment, and have to be periodically maintained. This would likely further alter the distribution of sediment sorting and size along the length of the spit. The prograding tidal flats and flood delta would also have to be managed in this scenario and replenishment would only serve to enhance deposition in these areas. Sediment erosion and redistribution is a difficult scenario for engineers or developers to deal with, and the best course of action would be to leave this dynamic landform to restore itself to a natural state of equilibrium. However this is unlikely because of the popularity of the study site and because Ocean Boulevard provides Colwood residents with a shorter commute to Victoria. It is hoped that the insights into sediment redistribution may help future management decisions.

7. Acknowledgments

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