Lake Ontario Shoreline Recession

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By

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Determining Shoreline Recession Rates Using Remote Sensing Techniques for the Ganaraska Region Conservation Authority along the Bluffs of Lake Ontario

(GEOG 4030Y)

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Abstract

The purpose of this project was to assess shoreline recession rates from the bluffs of Lake Ontario within the Ganaraska Region Conservation Authority (GRCA) using a variety of techniques, including ground surveying with a Global Positioning System (GPS) and remote sensing image analysis. We examined and determined the shoreline recession rates from GPS data and aerial photographs using arcGIS. The toe and crest of the bluffs were traced on digitized aerial photographs from 2005 and 2014. The shoreline recession rates were found by using the NEAR_DIST tool in arcGIS which calculates the distance between two points. Overall shoreline recession rates for the toe and crest of the bluffs were attained. The overall recession of the toe was approximately 27 cm yr^{-1} on average and the crest is approximately receding at 23 cm yr^{-1} on average. This method for calculating shoreline recession rates was tested by calculating annual shoreline recession between the 2014 trace line and the 2015 GPS data points using the distance tool for three specific sites. These recession rates resulted in a large amount of uncertainty within all three sites and had weak correlation to the values calculated from the NEAR_DIST tool for both the toe and crest of the bluffs. In addition, we could not compare which form of surveying (GIS and total station) is more accurate for determining shoreline recession rates. However, comparisons were made between modern surveying techniques and traditional surveying practices through qualitative analysis.

Acknowledgments

A true geographer learns through the soles of their feet, and that's what we did. Special acknowledgments goes to Sarah Lidster, Gregory Young, and Trent University faculty members for their consultation during this study. We would also like to thank Mike Smith for his guidance and assistance during property visits; and the GIS department at GRCA for providing us with data and encouraging the development of the project as it unfolded.

Table of Contents

1.0 Introduction

The Ganaraska Region Conservation Authority (GRCA) started in October of 1946 through the Conservation Authorities Act (1946) to protect, manage, and restore wetlands and natural habitat through programs that balance human, environmental, and economic needs in southern Ontario. The GRCA manages a watershed of 935 km^2 from Wilmot Creek in Clarington to east Cobourg and from the south shore of Rice Lake to Lake Ontario. The GRCA upholds provincial legislation and municipal laws within seven municipalities. One of the mandates of the GRCA is to monitor shoreline recession of the bluffs located along Lake Ontario within their spatial boundaries through watershed management actions. Watershed management is vital to protect the quality and quantity of surface and ground water as well as aquatic and land based resources. Watershed management includes tools and programs related to protecting people and property. A component of watershed management is assessing and “predicting” natural hazards. Shoreline recession can be assessed as a natural hazard because of the potential impacts it can leave on people and property. Therefore, by understanding the geographical factors and geomorphological processes that affect shoreline recession, and by comparing modern and historical methods for determining shoreline recession rates, conservation authorities such as the GRCA can manage and assess shorelines within their jurisdiction to balance human, environmental, and economic needs.

The purpose of this study was to determine shoreline recession rates along the shoreline in the Durham region of the GRCA and to contribute to the four part GRCA shoreline management plan (Natural Hazard Section) to explain the advantages and disadvantages of GIS software, GPS and total station methodologies for identifying shoreline recession rates.

Using geographical information systems (GIS) and remote sensing, we determined the recession rates of bluffs along the north shore of Lake Ontario. We compared data from previous years with the data we collect to determine if using remote sensing is accurate. The key questions were: What are the recession rates at various locations? How does the use of modern techniques (both GPS and Remote Sensing) improve our ability to measure and understand shoreline recession? and why are recession rates different at specific locations along the bluffs?

Figure 1: A Map of the Ganaraska Region Conservation Authority Jurisdiction Boundaries and Study Areas

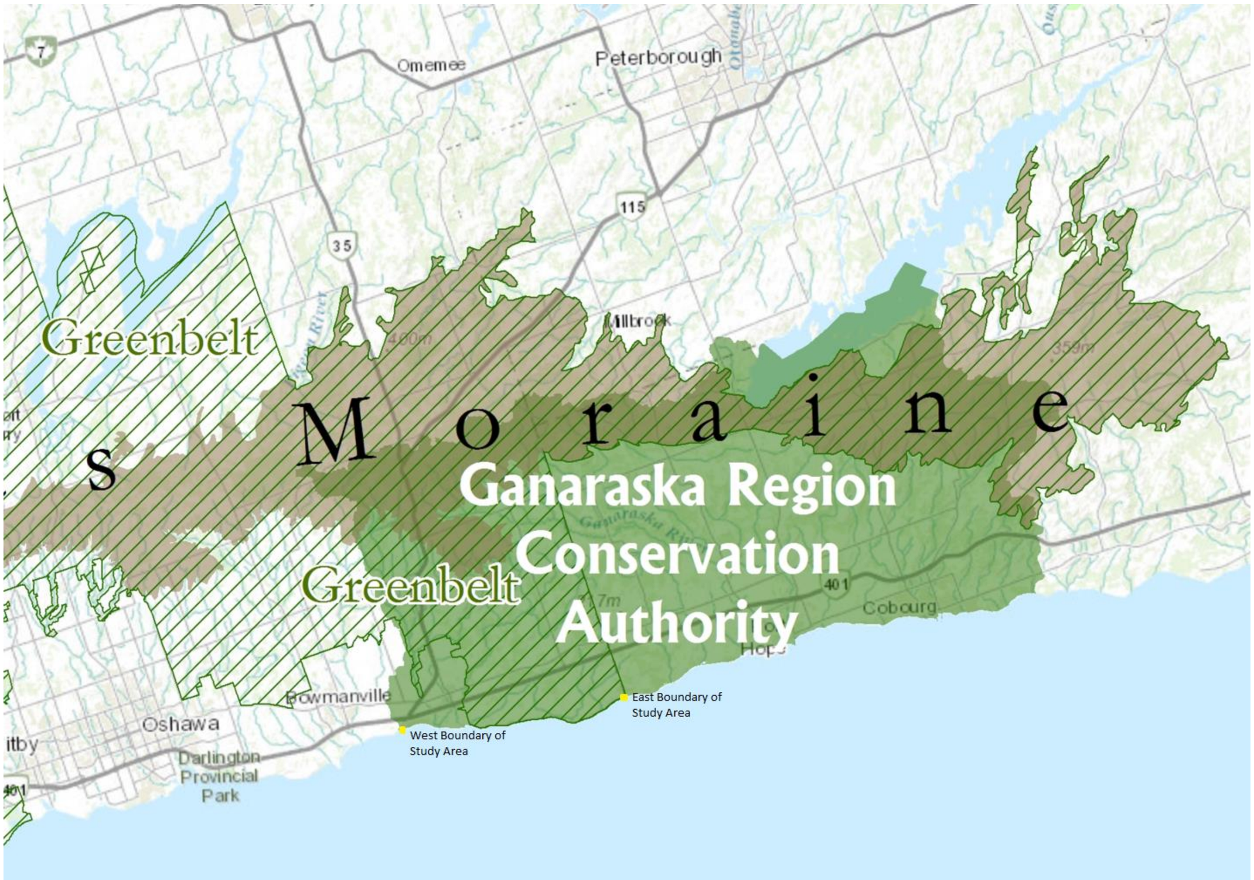


Figure 1 is a map that represents the geographical region that the GRCA regulates (green). This region is approximately 935 km^2 in area in which seven municipalities are located. The project will focuses on areas in Durham Region along the Lake Ontario shoreline, which was predetermined by the GRCA (yellow).

2.0 Past Studies

Shoreline recession has a major influence on the formation of bluffs along the shoreline of the lower Great Lakes. Research has been conducted to measure the recession of many shorelines in the southern Great Lakes region in past decades. There are different methods and approaches that look at various geographical influences on shoreline recession. Methods such as using pegs and pins, remote sensing techniques and statistical formulas are examples of the methods used in academic studies to estimate shoreline recession rates. The geomorphological processes that occur along the southern Great Lakes shorelines are the reason for the recession of these shorelines. Studies conducted on shoreline recession of bluffs in the southern Great Lakes region consist of research on different sections of the bluff profile. The following is a brief review of past research on Great Lakes shoreline recession and methodologies to estimate shoreline recession rates.

Amin and Davidson-Arnott (1995) researched toe erosion on glacial till bluffs along the south shore of Lake Erie. The study focused on how wave energy has a major influence on toe erosion rates. The researchers' methodology consisted of using peg lines as markers to measure for toe erosion rates. By placing peg lines consisting of pins that were 0.25m intervals apart and with steel rods driven vertically throughout the shoreline and at the base of the toe, the researchers measured the rates of recession at the base of the toe. "Three peg lines were established at each site, with care being taken-to ensure that uniformity in bluff and beach characteristics was maintained within the area containing the lines" (Amin and Davidson-Arnott 1995). Shorelines were monitored in two week intervals from April to December 1986. The horizontal shoreline recession rate was measured by observing pins and their increased exposure length from previous measurements by recording rising and falling water levels through observations every two weeks. Moisture content of the soil was measured in a laboratory to test the cohesion of bluff till material. The shoreline along the bluffs was approximately 5 m wide and became narrow at some locations along the shoreline. Four sites were analyzed and all sites had erosion at the toe of the bluff. The bluffs were approximately 5-17 m in elevation and were bare of vegetation. The majority of the winds come from the west, and therefore cause waves to form from west to east. The results of this study showed that all sites experienced shoreline recession of 2 to 6 cm yr^{-1}.

The reason for these recession rates in the toe comes from a variety of factors. High magnitude wave energy events produced by storms resulted in erosion higher up the face of the bluff, while lower wave magnitudes had greater toe erosion rates (Amin and Davidson-Arnott 1995). Another factor is climate. Meteorological data were obtained from the nearest weather station to track wind velocity. Climate plays a key role due to the changes in water level throughout the seasons. Rotational slumps at the crest occurred during spring and summer due to freeze and thaw cycles, and saturated soils produced runoff resulting in sediment at the base of the toe. However, toe recession, beach thickness and width resulted from swash bores, wave breakage, waves reaching the toe and reflection of unbroken waves (Amin and Davidson-Arnott 1995). In addition, the lowermost pins received higher erosion rates than pins placed higher on the face of the bluff (Amin and Davidson-Arnott 1995).

This study is relevant to the GRCA shoreline recession study because it focuses on the geomorphological processes that occur to produce the recession of the south shoreline in Lake Erie. "As a result, erosion resulted from a wide range of processes, including compression, tension, cavitation, direct wave turbulence, and abrasion due to entrained sediment" (Amin and Davidson-Arnott 1995). The significance of wave energy and the influence it has on shoreline recession rates is influenced by other factors such as climate, soil structure and texture along with moisture content. These factors and soil properties occur along the bluffs in all of the sites located along the Lake Ontario shoreline in the GRCA.

Although Meadows et al. (1997) designed a study on determining the relationship of wave energy and water levels on the southern Great Lakes, the results are significant because it focused on periods of high lake water levels, storm events and their effects on shorelines on the Great Lakes. The methods for collecting data were aerial photography, as well as wave and lake water level data to determine the effect that storm events have on shorelines. Meadows et al. (1997) clearly defined the difference between erosion and recession: "Waves and wave-driven longshore currents, superimposed on a higher lake level, usually cause a landward translation of the shoreline profile that, if there is no loss of material, is referred to as recession. Alternatively, there is a net loss of material from the profile, the process is referred to as erosion. Therefore, shoreline erosion damage is dependent upon the relationship between lake level and the incident wave energy at the shore." (Meadows et al. 1997). A series of gauges were used to collect wave energy and water levels from the lakes, while aerial photography was only used to determine the amount or effect of wave energy and water levels on the shoreline.

Two time periods were studied, the years of 1967-1975 and the years of 1984-1985. Within the first time frame studied, the researchers found that there was a rapid increase in wave energy and lake water levels within the first year (1967) and the largest amount of shoreline damage occurred within the time frame of 1972-1973 (Meadows et al. 1997). In contrast, the second time frame had more property damage than in the previous year (Meadows et al. 1997). Although the highest peak in lake water levels was not until the following year (1986), there were no records of property loss (Meadows et al. 1997). The reason for the absence of these records is because previously there has been a large loss of material from the shoreline and it was stable for that year. It could also have been from a shorter amount of time in comparison to the two time frames that had been studied.

Another relevant study on shoreline recession was at Point Pelee National Park (PPNP) along the northern Lake Erie shoreline. This study focused on the impact of ice cover on shoreline recession on the west side of the park. The study found that high recession rates were produced from low ice cover conditions due to the increase of wave turbulence against the shoreline (BaMasoud and Byrne 2012). Ice cover during the winter provides protection for the shoreline against wave energy. Therefore, by having less ice cover waves can remove sediment from the shoreline. Less ice cover due to warmer conditions results in greater freeze and thaw cycles within sediment which increases weathering in soil. Ice broken off by waves can transfer sediment offshore. This physical weathering enabled sediment to easily be transferred by geomorphological processes that influence shoreline recession rates. "In the Great Lakes, various factors may contribute to shoreline erosion such as storm and wind climate resulting in wave attack and sediment removal, rising lake levels resulting in submergence of the beach area and enhanced wave reach, and anthropogenic factors such as human-made coastal structures resulting in interruption of sediment supplies in the littoral cell." (BaMasoud and Byrne 2012).

The methods for calculating shoreline recession rates in the bluffs of PPNP were based upon using aerial photography of the study area and using arcGIS to trace and digitize the photographs. 314 transects were created approximately in 30 meter intervals and placed perpendicular to the baseline from data obtained in 1985 (BaMasoud and Byrne 2012). These transects were divided based on similar shoreline changes. To estimate shoreline changes, the end-point rate was used to compare past recession rates with the new transects created. "Shoreline change rates [measured in m/y] were estimated using the end-point rate (EPR) method (as described by Dolan et al., 1991). Positive rates correspond to accretion and negative rates correspond to recession. End-point rates are then compared to rates from the period 1959–2004" (BaMasoud and Byrne 2012). Wind data from Environment Canada, average lake water level data (NOAA Great Lakes Environmental Research Laboratory (GLERL)) and ice cover data (United States National Ice Center) were obtained to compare shoreline changes from years past. The results of this study showed that shoreline recession has increased from past studies conducted in the study area. “Shoreline changes in the period 2004–2006 in western PPNP are different from those observed in the period 1959–2004. End-point rates for the period 2004–2006 show that the western PPNP shore exhibited recession (− 0.97 m/y) along most of PPNP's shore” (BaMasoud and Byrne 2012). Meteorological forcing was the major indicator for shoreline recession in this study. Mid latitude pressure systems move west to east and their position depends on the polar front, jet stream and upper westerlies (BaMasoud and Byrne 2012). Therefore, western facing shorelines often show higher recession rates than those facing eastern because of the path of low pressure systems.

Low ice cover on Lake Erie resulted in stronger storm systems due to fluctuations in temperature. “Low ice cover in the western basin during the 2006 winter may have enhanced wind speed. According to Angel (1996), winter cyclones intensify under strong temperature contrasts between cold air and the ice-free water surface” (BaMasoud and Byrne, 2012). An increase in lake water level changes shoreline recession rates; however, human induced changes can also raise shoreline recession rates. For example, shoreline protection structures can obstruct sediment flow and can cause recession in other areas along the shoreline. Furthermore, ice cover related shoreline recession in the Great Lakes is affected and induced by a variety of geographic variables such as climate, wind, human development and rising lake water level.

A study conducted in 2013 focused on determining which method of calculating shoreline recession rate is more accurate in PPNP on Lake Erie (BaMasoud and Byrne 2013). Three methods of determining shoreline recession were used; these methods included the use of aerial photographs of the bluffs. The methods were end point rate (EPR), linear regression (LR) and lake level predictor (LLP). Aerial photographs from 1931 to 2008 were obtained by the Essex Region Conservation Authority (ERCA) and photographs with poor image quality were discarded from the analysis. Identifiable benchmarks were selected in the form of fixed human made structures. Aerial photographs were then digitized and shorelines were traced using ArcGIS. The shorelines were detected by using a wet/dry boundary mark (BaMasoud and Byrne 2013) and monthly average lake water levels were obtained from GLERL. Shoreline recession distance was measured by transects that were normal to the baseline. “Shoreline displacements are described by the distance calculated along transects between the two shorelines in reference. A positive value of shoreline displacement indicates a shoreline advance in relation to the older shoreline and vice versa. Shoreline change rates were estimated using the end-point rate (EPR) and linear regression (LR) methods as described by Dolan et al. (1991). In summary, the EPR is obtained by dividing the net shoreline displacement between the earliest and latest shorelines by the years between the two shorelines" (BaMasoud and Byrne 2013). Linear regression rates were obtained by utilizing the least squares method and a line of best fit of shoreline position, which means that the linear equation produced by the line of best fit is the rate of recession (BaMasoud and Byrne 2013). The LLP method uses a linear equation to predict shoreline position. This method in particular assumes that lake level changes directly affect the shoreline position. Therefore, the accuracy of the LLP method is based upon the response of average lake levels and shoreline position (BaMasoud and Byrne 2013). Even though aerial photographs were analyzed from 1931-2008, the amount of uncertainty was too high to use the majority of acquired photographs. Therefore, shorelines from time scale 1990-2008 were traced instead. All methods were used on every aspect of the shoreline; however, not one method was the most accurate for predicting shoreline recession on all sides of the bluffs (BaMasoud and Byrne 2013). The end point rate method was the best method for predicting shoreline recession on the western bluffs of Point Pelee, while linear regression had the strongest uncertainty in their data (BaMasoud and Byrne 2013). Uncertainty was measured using root mean square error and mean absolute error statistical methods in the calculated shoreline recession rates (BaMasoud and Byrne 2013).

The results of the study were as follows. "For western PPNP, the EPR method performed best compared to other methods, with a RMSE value of 9.9 m. For eastern PPNP, the method ranked second after LR, with RMSE value of 33.2 m. The median value of prediction was very close to the actual eastern positions in 2008 (− 74.5 m vs. − 74.4 m). However, the RMSE value was high at 33.2 m, when compared to the western side at 9.9 m (Table 4 in BaMasoud and Byrne 2013). For eastern PPNP, the LR method provided the best predictions among the three methods with a RMSE of 26.3 m (Table 4 in BaMasoud and Byrne 2013). For western PPNP the method provided the least accurate predictions with a RMSE of 12.8 m. The LLP method resulted in the highest RMSE value among the three methods for eastern PPNP predictions, 60.8 m. In contrast, the LLP method ranked second in western PPNP with a RMSE of 11.5 m" (BaMasoud and Byrne 2013). BaMasoud and Bryrne's theory for the recession of the shorelines at Point Pelee was due to low ice cover, climate patterns, low pressure system intensities, lake water levels, wave energy, and soil characteristics from glacial till (BaMasoud and Byrne 2013).

In PPNP, the strongest storms occurred during the fall and spring months and the eastern bluffs of the point received the strongest wave energy. Geographically, there is an open water fetch on the east side that promotes stronger waves which increases erosion on the eastern bluffs. "Surface wave action on the eastern side is typically higher than that on the western side, a result of the longer open-water fetch east of the park, resulting in larger and stronger waves. Although the region's wind regime is dominated by SW to W winds, severe NE to E storms occur especially during fall and spring (Coakley, 1977). These winds are aligned along the greatest fetch distance in Lake Erie, generating the highest waves around the park, causing erosion of the east shore. Lower ice cover in winter due to deeper waters and larger waves results in more exposure to winter storms and hence more erosion" (BaMasoud and Byrne 2013). The east side was the most vulnerable due to the cohesive nature of the sediment in the bluff profile.

In an article about spatial modeling and analysis for shoreline change detection and coastal erosion monitoring written about Lake Erie, Rongxing et al. (2001) focused on different models that can be applied to determine changes in the shoreline. Methods that were used in this study were the following: high-resolution imagery, spatial modeling, a digital water level model, coastal terrain model and bathymetric data. High-resolution imagery was used to monitor shoreline erosion and the causes of the erosion. The digital water level model, coastal terrain model and bathymetric model were all used together to further understand how all these different factors connect with each other (Rongxing et al. 2001). The coastal terrain model showed elevations of the terrain and this worked in conjunction with the digital water level model and bathymetric model to determine when water levels were elevated and if the coastal terrain would decrease. If this were the case there would be a direct correlation which would allow for the modeling of storms and their effect on shoreline erosion.

Factors affecting erosion on Lake Erie are waves, littoral transport and sand supply, lake level change and the geomorphology of the region (Rongxing et al. 2001). Wave energy is a primary cause of shoreline erosion because of the force and duration that can be associated with large storm events. Storm events not only increase wind speed which in turn creates larger wave energy that accelerates erosion but storm events can also raise water levels. The geomorphology of Lake Erie is of glacial origin and sediments are glacial till and lacustrine sediments (Rongxing et al. 2001). The sediments that were present such as the glacial till allow for the recession because of their ability to be transported. The researchers divided lake level changes into three categories: short term, seasonal and long term. Short term is defined as storm events and wind stresses, seasonal is considered periods of runoff from spring melts, and long term is considered to be changes over long periods of time.

In this study, the highest shoreline recession rates varied between 1158-1706 cm yr^{-1} in Sheldon Marsh, Ohio. These rates appeared in the unprotected sandy barrier area. The end barriers connecting to the studied shoreline (Sheldon Marsh to Vermilion, Ohio) were considered relatively stable (Rongxing et al. 2001). This was primarily because of the shoreline conditions in these areas. For instance, some of these areas had man-made protection against the erosive power of the waves. Areas that experience the largest amount of erosion were areas that have an unprotected sandy barrier. The areas of approximately 305 cm yr^{-1} are two till areas that would be easily eroded (Rongxing et al. 2001). Another area was located at the end of the barrier that is connected to the shore. This area experienced erosion of a few cm yr^{-1} as recorded in this study (Rongxing et al. 2001). Lastly, an area of clay shoreline was considered to be relatively stable in comparison to the other shorelines studied here and had little to no erosion. This was due to the porosity of clay and its ability to retain any water within its particles.

Bukata and Haras (1976) examined methods for recording Great Lakes shoreline changes using historical aerial photography. The location that they studied was Lake Erie from the township of Essex to the Niagara region. They used province-wide aerial photography (photogrammetry) that was flown in the years of 1952-1955 (Bukata and Haras 1976). This type of data enabled them to examine the changes along the shoreline using the same type of data set. They recorded points every 1.6 km that allowed for easy identification of locations along the large shoreline. Having benchmark locations for different maps/photography would be useful and these locations measured would be easily identifiable.

Bukata and Haras (1976) showed the shoreline recession rates on a map of the area with shaded colours for areas that have recessed at higher rates. The range of erosion rates were less than 0.5 m yr^{-1} to greater than 2.0 m yr^{-1}. The map displays the areas of Essex, Kent, Elgin and a small portion of Haldimand-Norfolk are being eroded more than 2.0 m yr^{-1} (Bukata and Haras 1976). The areas that had been eroded less than 0.5 m yr^{-1} were areas that were protected within a bay area. The areas with higher erosion rates had exposed shorelines that were not protected by a bay.

The reason for the difference in erosion rates would be because the areas of high erosion rates are more open to the lake and the lake's erosive measures such as wind and wave action. A benefit noted in this study was that during the time frame that these photographs were taken it was a period of high water level. This would indicate that these erosion rates would be some of the largest to expect for Lake Erie and would increase in the spring due to thaw/snow melt.

Throughout these published articles aerial photography was used heavily as a tool for determining shoreline recession rates. Therefore, aerial photography may prove to be a good historical data set. In studies such as BaMasound and Byrne's (2013), the researchers were able to digitize the area using aerial photography. Moreover, Rongxing et al. (2001) focused on spatial modeling and aerial photography for shoreline change. The use of aerial photography gives the researcher the ability to determine shoreline recession rates using GIS software. Using such programs gives the researcher the ability to avoid bias that could result from using other methods for calculating shoreline recession. It also allows for a complete view of the recession for different areas. There were other methods of determining recession rates, but they all seemed to have a drawback. In the study by Amin and Davidson-Arnott (1995) the use of peg lines and steel rods required the researchers' to make many site visits to visually inspect where the lake water levels met the indicators on the peg and steel rods. In a sense, this is a type of method that is based on that fact that increased exposure meant increase of erosion.

These past studies focused on assessing shoreline recession and were used to compare methodological similarities and differences to our study. Throughout our research, we could not find any published research articles that used the same methodology that we have produced. However, the use of survey-grade GPS in our study was helpful in ground-truthing the current position of shoreline features that were also measured using the GIS method. In the future it would be best if these surveys were carried out at the same time as the aerial photos are taken.

3.0 Methodology

This study entailed gathering of the years of aerial photography from the GRCA in order to measure the shoreline recession rates. We chose the aerial photographs of 2005 and 2014 for this study. Although there were many years we could have chosen from, we decided to only use the above years because of time constraints for this study and because there was no aerial photographs taken for 2015. Using a 9 year difference would allow for a larger change at the sites along the shoreline. Historical ground survey data from traditional survey methods were not obtained from the GRCA, and therefore total station data cannot be compared to data obtained from GPS surveying and shoreline recession calculations. Using this information we examined and determined the shoreline recession rates using modern techniques and analyzed which form of surveying is the most accurate for determining shoreline recession rates.

On October 27, 2015 we went with a representative of the Ganaraska Region Conservation Authority to locate current/up to date shorelines for three different locations/sites that had a variation of recession that affected each site. These three specific sites along the shoreline which are regulated by the GRCA were used to determine an overall shoreline recession rate and to provide accurate locations of the shoreline for 2015. These three sites gave our research a variation of recessional rates.

Three specific sites along the shoreline were used to determine an overall shoreline recession rate and to provide accurate locations of the shoreline. In addition, site notes (Appendix D) were taken at each site to understand the geographical factors and characteristics that would explain shoreline recession rates. At each site the following measurements were made.

Soil texture describes the relative amounts of different sized particles (clay, loam, or sand) in the soil. The soil texture analysis was done by feel because a reasonable determination can be achieved by texture feel rather than an absolute determination in a laboratory. This was done by taking a walnut sized sample of each mineral horizon on the palm of the hand and moistening the soil with water. By rubbing fingers together to break down soil structure, the soil can be classified. For instance, clay can contain more water in its micro pores and therefore feels very fine but when wet can form a long thin flexible “ribbon” when pressed between the thumb and forefinger. The soil properties of sand feel rather gritty and the particle sizes can be seen with the naked eye. It does not form a “ribbon” when wet and will break its structure when pressed with the thumb and forefinger. In contrast, silt has properties in-between clay and sand.

Individual particles cannot be seen with the eye in the field and it can be moulded when wet but will not smear when pressed with the thumb and forefinger. A flow chart for determining soil texture by feel was used and is provided in the initial assessment procedures (Appendix F). The following sections contain descriptions of each measurement site.

3.1 Site 1

Figure 2: A Visual Perspective of Site 1 (Google Maps) 

The first site we visited was a bluff located along a natural park (Fig 2). As we started to take measurements along the bluff we noticed an outlook point where there is a pavilion for people visiting to look out on Lake Ontario. In front of the pavilion the grass was cut similar to someone’s house lawn and as you approach the bluff you can notice that there is more recession taking place within the area of the grass that has been cut. Standing at the crest of the bluff looking down you could visually see rotational slumps where the recession was occurring. This slope failure could be explained because surface runoff would be greater on the area that has been cut because there is less vegetation slowing the runoff and absorbing the water which is evidence of overland flow. Soil texture analysis indicated that there was more silt than sand and clay located along the toe and throughout the bluff profile at site 1. Field notes on site 1 are located in Appendix D.

Figure 3: Photographs of Site 1

Figure 3 (October 27, 2015) shows how surface runoff and discharging ground water are influencing the recession rates at site 1 and can be visually noticed by the rills that occur from the crest to the toe of the bluff. Vegetation grows at the toe of the bluff which indicates that the soil at the toe of the bluff is more saturated than the crest. Site 1 was rather difficult to gather satellite signals for the GPS due to the positioning of the satellites and signal blockage because of trees and shrubbery (viewing left from the bottom picture).

3.1 Site 2

Figure 4: A Visual Overview of Site 2 (Google Maps) 

The bluff at site 2 was not as large as the bluffs at site 1. This site was located adjacent to a new housing development. This site has a cut lawn up to the bluff which shows how surface runoff and discharging ground water are influencing the recession rates at site 2. There was not a significant buffer zone of vegetation here which could explain some of the recession occurring. There was drainage piping from surrounding tile beds from agriculture fields. The second and third site both had drainage piping that could cause higher erosion and increase recession rates. These pipes at one point were completely covered but as time progressed and the recession continued these pipes became exposed. The piping would only increase the amount of recession occurring on the bluffs because of the water that would be coming out of them during high rain storm events when the bluffs would already be prone to receding. Soil texture analysis indicated different soil classes for the east and west sides of the bluff. The analysis revealed that sand was predominant on both the east and west sides; however, we found that there was more of a mixture of clay and sand to the east, while on the west side there is more silt and sand. Field notes on site 2 are found in Appendix D.

Figure 5: Photographs of Site 2

Figure 5 (October 27, 2015) shows how hydrologic factors such as surface runoff and discharging ground water have eroded the bluff face as it flows into Lake Ontario at site 2. Vegetation was predominantly grown in areas where the landscape is relatively flat. Often these areas are in places where sediments are deposited onto the shoreline/toe. However, saturation from storm events and spring freeze/thaw can cause large amounts of sediment to be displaced onto the middle of the bluff profile. In result, the angle of repose is high and the slope is less which results in more vegetation growth.



3.2 Site 3

Figure 6: A Visual Overview of Site 3 (Google Maps)

The final site we visited was the largest of the bluffs, which were approximately 18-27 m in elevation. Site 3 represents had overhanging or vertical cliffs depending on spatial orientation. This site was very interesting because of its large horns, rotational slumps and slides. This is the only site we visited with housing adjacent to the bluffs. The housing will be and is in danger because of higher recession rates due to its location and geomorphological processes operating on this site. The major contributing factor to shoreline recession at site 3 is the spring season and high precipitation events with freeze/thaw weathering (Appendix D). In addition, Site 3 is receding because of sporadic slab failure due to high amounts of water in the vertical joints

(Buttle and von Bulow 1986). Super saturation, overland flow, and undercutting at the shoreline causes rotational slumps and horns at the crest of the bluff. In addition, there were tile drainage pipes from across the road which accelerate erosion rates. Furthermore, there were saturated layers located along the bottom of the bluff and middle layers in between the bluff profile. This is an indication of ground water discharge and seepage (Buttle and von Bulow 1986). As a result, high angle shallow slumps form due to the hydraulic gradient in different till layers when soil moisture content is high (Buttle and von Bulow 1986). The soil texture analysis indicates that there was a predominant mixture of sand and silt along the toe of the bluff with large deposits of sand and silt located along the shoreline, while clay was located along the middle and bottom of the bluff profile. In addition, there was vegetation overhang about a meter thick along the crest of the bluff. Note: Using total station transect surveying methods would be difficult due to the position variability of the bluff. The bluffs can be difficult to access because of the steepness of the bluff features and lack of access points. Also using total station you cannot replicate the same exact transect line from previous site visits because of the recession occurring. Field notes on site 3 can be found in Appendix D.

Figure 7: Photographs of Site 3

Figure 7 (October 27, 2015) shows visual results of how recession rates can vary along the bluff which are receding at large rates. Unfortunately, residents that live on site 3 are losing their property because of the magnitude of geomorphological processes which are influenced by factors in climate. These large rotational slumps and horns are the result of these processes and factors.



At each site, the GPS unit (ProMark 800) was used to deliver precise location of coordinates of the crest and toe of the bluff. The GPS unit is especially useful for the last site we visited because it was lightweight and easy to carry up and down the bluffs. We were instructed to look for the availability of satellites which could be seen on the screen of the GPS unit. There had to be a minimum of 3 satellites before we were able to take the point. This required some moving around to be able to pick up the satellites. We tried to stay away from obstacles such as trees that could block the unit from seeing the satellites. We tried to be as close to the edge of the bluff as possible when trying to attain satellites and taking the point. When we were surveying, we would take points about every 10 m unless there was a feature we wanted to capture such as the rotational slumps (we mentioned earlier at site 3). If we wanted to capture a feature we would take as many points as necessary to be able to show the feature within arcMAP. We surveyed both the crest and toe of the bluff so that when comparing the values we could get an average recession rate for both the crest and toe of the bluff. This process could be considered dangerous because of the height of the bluffs, therefore it should be noted that we were equipped with a harness that was tied off to another person. This was the safety protocol that we followed in the case of someone falling over the edge of the bluffs. The other members that did not have a harness were instructed to stay back from the edge to avoid any falling hazards.

Once we had completed the surveying for all three sites we then returned to the GRCA office where we gave the GPS unit back for the retrieval of the data points. These data points were gathered and downloaded onto an aerial photograph of the area for 2014. Staff from the GRCA then uploaded onto an external drive all the data necessary for us to continue our project. On the drive were photographs from the lake of the bluffs and the features present, orthoimagery, and the aerial photography that was needed for this project. In addition, the 2005 and 2014 maps were provided by the GRCA. The 2005 and 2014 map data were used to outline the crest and toe of the bluffs using arcMAP. In order to have an increase in measurement accuracy, we decided to cut out unidentifiable bluff locations. We considered unidentifiable bluffs as areas where there was beach, concrete barriers around piers and armoured roadways. In addition, line segments were spatially connected through the select feature class to give us an accurate reading of the amount of recession these bluffs are experiencing. Once this was complete, we then overlaid the two outlines of the toe and crest of the bluff. This would then allow us to calculate a recession rate for both the toe and crest of the bluff.

A tool in arcMAP called the "NEAR_DIS tool" can calculate the distance between two points but it uses the closest point. When we initially started to use this tool it gave us an overall shoreline recession of 200 m over the span of 9 years and when divided it gave us over 20m yr^{-1}. This value was much too high for a recession rate. We determined that the problem was that there are sections on the aerial photos where the traced lines of the bluffs are discontinued/segmented. There are these segmented lines because there are sections of the shoreline line that were not clear indications of bluffs. The NEAR_DIS tool connected vertices from 2005 to 2014 trace segments from other bluff segments in different locations on the orthoimagery which resulted in the large recession rate. Once we determined that this was the cause of the large recession rate, we then measured what we believed to be the farthest distance between the 2005 and 2014 lines. We were able to adjust the maximum distance that the near tool would be able to measure, which is the farthest point between the 2005 and 2014 lines. This maximum distance that we found was 10 m. This maximum distance is smaller than the breaks along the shoreline. This adjustment allowed us to try the near tool again which gave us a more reasonable measurement of the recession rate. Appendix C shows the trace lines for each site and GPS data points for both years and the toe and crest of the bluff.

To approximate the shoreline recession rate for 2014 to 2015 we used the measure tool in arcMAP to measure the distance between the 2015 GPS data points and the nearest 2014 crest line points (vertex). The measure tool allows the user to identify the distance between features. By using this tool, we can calculate shoreline recession rates on an annual basis.

4.0 Results

Using the method in Appendix A for calculating the recession rates for the entire lake Ontario shoreline with the GRCA, we found that the shorelines we measured are receding at an average rate of approximately 27.44 cm yr^{-1} for the toe and 22.78 cm yr^{-1} for the crest. Figures 5 and 6 show statistics and frequencies between 2005 and 2014 trace distances. Note, an example of the attributes table for each year's point feature class is in Appendix B.

Figure 5: Statistics and Frequency Chart for the Crest of the 2005 Point Feature Class When Measured to the 2014 Crest Line Feature Class (Meters)

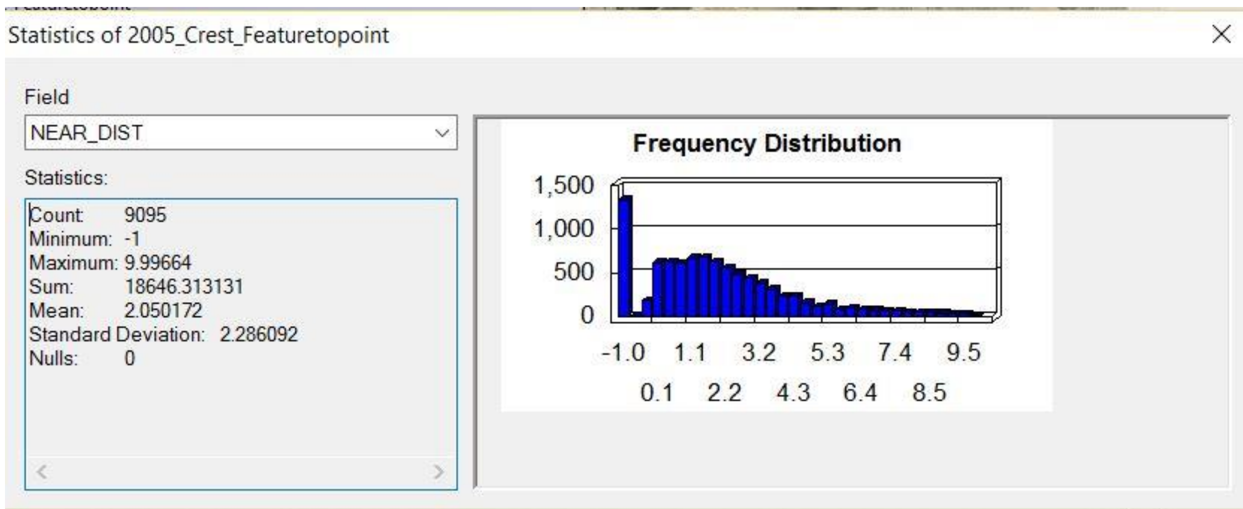
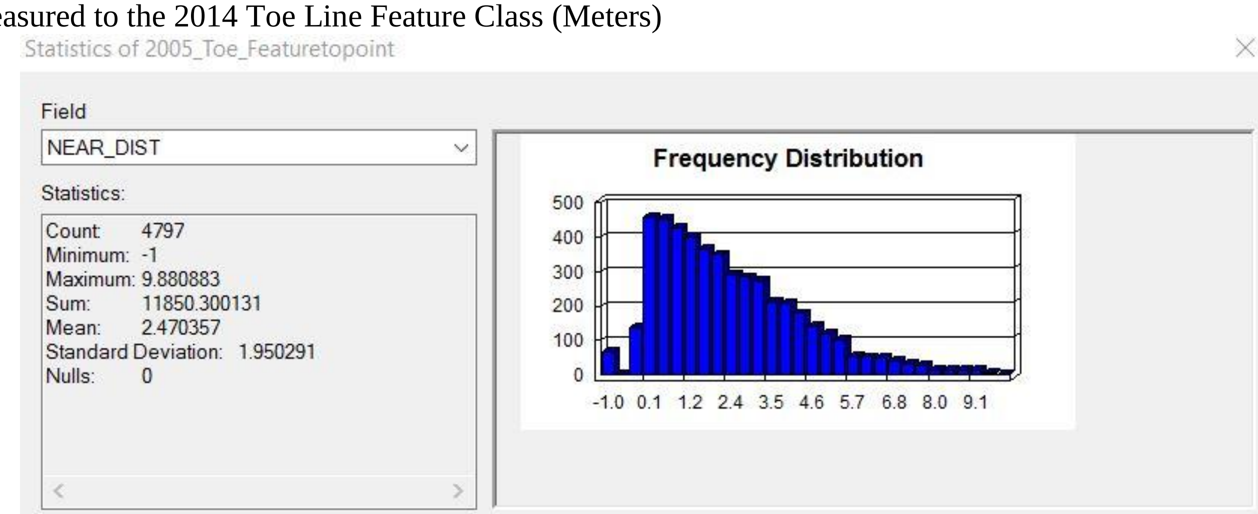


Figure 6: Statistics and Frequency Chart for the Toe of 2005 Point Feature Class When Measured to the 2014 Toe Line Feature Class (Meters)



By observing the statistical summary of all the NEAR_DIST values in each of the year's attribute tables, we identified the mean average distance in meters. However, this is the mean distance for nine years. Therefore, in order to get an annual recession rate, we divided that number by nine. Calculations of these recession rates are represented below.

Toe: 2.47 m/9 yr

=27.44 cm yr^{-1}

Crest: 2.05 m/9 yr

$$=22.78\ \text{cm yr}^{-1}$$

As noted above, we calculated an average shoreline recession rate for both the toe and the crest. Based on past studies and the constant fluvial and coastal processes, the toe is expected to erode at a rate faster than the crest. The geographical attributes of Point Pelee are different but there are key similarities between the bluffs of Lake Ontario within the GRCA and the bluffs in PPNP, Lake Erie. For instance, the climate for both of these regions is relatively similar and with an increase in average winter temperatures, there is less ice cover for protecting these shorelines which means that waves can transport sediment away from the shoreline and promote undercutting of the bluffs. The parent material in each region is mostly sedimentary rock with fragments of igneous and metamorphic rocks due to glacial till which was produced by glaciers that occurred 12,000 years ago and formed the Great Lakes. The study by BaMasoud and Byrne (2013) focuses on the accuracy of using remote sensing as a method for estimating shoreline recession rates: "the EPR, widely used for shoreline change rate estimation, can give the best performance in areas where the two points used to estimate the rate happen to be along or close enough to the long-term trend line as was the case for the west side of PPNP" (BaMasoud and Byrne 2013). Also, there is no standard way for determining shoreline recession rates because of differences in the geographic attributes of each location of interest and how that area interacts with its local environment. Therefore, advantages and disadvantages of each method vary depending on these geographical attributes and parameters set by the researcher.

4.1 Comparing NEAR_DIST to the Measure Tool in arcMap

In order to determine which form of surveying (GPS and total station) is the most accurate for determining shoreline recession rates we must have viable ground survey (total station) data which unfortunately were not available. However, we could compare GPS surveying data from 2015 to the remote sensing techniques used to calculate the entire Lake Ontario shoreline for 2014 (trace lines).

To verify if our method is valid for calculating annual shoreline recession rates the measure tool in arcGIS was applied to calculate annual recession rates for the three specific areas. In result, the NEAR_DIST tool used to calculate the overall shoreline recession for the bluffs within the GRCA on Lake Ontario is not an accurate representation of the annual recession rates for the three specific sites when compared. This means that the GPS surveying data gave a more accurate representation of where the shoreline is at that instant in time.

Table 1: Measure Tool Distance Measurements & Calculations for Site 1

Toe (left-right) Meters	Crest (right-left) Meters
0	0
1.20	0
1.35	0
0.753	0
0.961	0
1.49	0
1.91	0
1.16	0
0	0
0	0
0	0
0	0
0.559	0
0.820	0
1.12	0
	0
	0
	0.655
	0
	0
	0
	0.990
Average Meters	Average Meters
0.754	0.075

Average Centimeters	Average Centimeters
75.4	7.49

Table 2: Measure Tool Distance Measurements & Calculations for Site 2

Toe (left-right) Meters	Crest (right-left) Meters
0.56	0.05
0	0.52
0	0.12
0	0.31
1.58	0.34
3.51	0.47
4.02	0.17
3.54	0
3.26	0
2.83	0
2.65	0
0	0
0	0
0	
0	
0	
Average Meters	Average Meters
1.37	0.15
Average Centimeters	Average Centimeters
137	15.0

Table 3: Measure Tool Distance Measurements & Calculations for Site 3

Toe (left to right) Meters	Crest (right to left) Meters
2.95	0
2.76	0
2.45	0
2.56	0
3.56	0
3.64	0
4.19	0
1.27	0
3.27	1.41
3.71	0.75
2.30	1.29
1.80	1.67
5.01	3.08
4.46	0
2.88	0
0.94	0
0	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	1.41

	1.51
	0
	0
	0
	0
	0
	2.74
	0
	1.80
Average Meters	Average Meters
2.81	0.43
Average Centimeters	Average Centimeters
281.1	43.5

For Tables 1, 2, and 3 measurements of zero meters are the sections where the traced line is located in the same spot as the GPS point. This measurement of zero would indicate that no recession had taken place between the time the aerial photos were taken (2014) and the GPS surveys (2015). The blank spaces within the Tables are a result of inconsistent or missing GPS data points. In some areas there were more GPS points at the crest than at the toe. This is because features are usually more prominent at the crest than at the toe. The number of GPS data points depended on the length of the bluff and whether there were significant features. The toe of all the bluffs that we visited were all fairly straight lines which is why there were more GPS points at the crest than at the toe. Unfortunately, when tracing in proximity to the GPS data points, arcMAP automatically connects vertices to GPS data points regardless of the scale. Therefore, there is a considerable amount of error within the values represented in Tables 1, 2, and 3. Furthermore, depending on the magnitude of certain geomorphological processes and geographical factors, certain locations along the bluff will recede at minuscule values or zero meters throughout the year while others may erode at higher rates. By observing and comparing these aerial photographs at specific locations, there is change between bluff features in time. So if a specific location of the bluff did not recede for that year, in the span of nine years, the overall bluff will recede along with accumulation of aggregate deposits on the toe, and or recession in the crest. The values are represented by the recession in the crest, toe and accumulation of aggregates on the toe. Even though the overall shoreline recedes over many years, certain areas along the bluff deposit aggregates to its toe that have fallen from the crest due to the force of gravity, and coastal processes can transport aggregates and deposit them to other regions in Lake Ontario. It may be perceived on aerial photography that the toe in certain locations along the bluff is accreting material, however, that increase can be attributed to the loss of soil from the crest of the bluff.

5.0 Discussion

Remote sensing techniques have their limitations. The limitations we faced were within the method itself, aerial photographs, and lack of comparable data. In the method applied in this study, the values of difference are geared toward how the vertices along the trace lines match to the nodes/points along the adjacent line. There is uncertainty within the data because the measurements between the vertices and nodes were not perpendicular to each other because the near feature tool in arcGIS takes measurements from vertices that are closest to the points. Therefore, distances that are measured between points and vertices may perhaps be on an angle, which means that Pythagoras' theorem would need to be applied. The result is that it creates inaccurate data and further developments need to be made in order to integrate this uncertainty into the calculation. Another limitation with the method is limiting the radius in which the NEAR_DIST tool will measure. For instance, for calculating the recession rates using remote sensing, we measured the farthest distance between the 2014 vertices and 2015 GPS data points. Using this distance, which was 10 m, we used the NEAR_DIS tool to search for the nearest points using a 10 m radius.

Furthermore, there is uncertainty in using the measure tool for approximating shoreline recession rates when comparing the 2014 trace line and the 2015 GPS data points. This uncertainty is based on how these distances were measured. The measure tool measures distance (m) in a straight line; however, when connecting the vertices to the GPS data points, the measurement should be taken with vertices that are as close to being perpendicular as possible because arcGIS lacks the capability of calculating missed spatial distances between the vertices and the GPS data point(s). This means that trigonometry formulas must be used in order to acquire accurate recession rates when using the measure tool. This may be the reason for some discrepancy in the data from Tables 2, 3, and 4.

There are many limitations and uncertainties when using aerial photographs in arcGIS. For instance, the largest limitation was tracing the bluffs. Aerial photographs lack quality when the scale is small especially for the older aerial photography. The 2005 aerial photography was blurry in places which made it difficult to trace the toe and crest of the bluffs. The 2014 photograph was clearer and this could be because of the advancement in technology since 2005. It could also be because of the angle at which the photograph was taken. If there was any rotation when the plane was taking the photograph, it could have caused the image to be blurry. In order to have an accurate trace of the bluffs and shoreline recession rates, the traces must match the crest and toe of the bluff. The average scale at which we traced the bluffs is 1:500 meters. However, depending on the year, there were blurred areas of the bluff that were undefinable. To counter this discrepancy, we used bluffs that were easily identifiable between both the 2005 and 2014 aerial photographs. Hence, any bluff features that were not identifiable were not used in this report. Tracing the bluffs that had thick vegetation created a challenge for identifying the bluffs' geographical features and where the crest or toe change direction. The aerial photographs for 2005 are excellent for identifying where the crest and toe are located without vegetation blocking the crest. However, for the 2014 aerial photograph vegetation in some areas made it difficult to determine the direction of the toe and crest because of shading due to the angle at which the photo was taken. This is one of the best reasons for having physical GPS coordinates at certain sites because global positioning systems are able to give a more accurate reading of the location of the bluff's features depending on whether if the geographic referencing in arcGIS is correct. The physical tracing of these bluff features caused limitations on this method which are based on human and computational error. The human error comes from identifying the crest or toe lines, and the computational error is based on arcGIS auto connecting to certain vertices or data points that are close in proximity. For example, as a person is tracing the shoreline, arcGIS may connect vertices to other data points: Thus, when tracing the 2014 bluff with 2015 data points on the 2014 aerial photograph, arcGIS may auto connect the 2014 line feature classes with the 2015 data GPS points when they are very close to each other. Digitized site aerial imagery with trace lines is given in Appendix C.

Unfortunately, the GRCA did not have transect survey data for 2005 and 2014. However, the issue with transect survey data in general is that it takes a long time to measure the data points and there needs to be a constant benchmark. Benchmarks change because of human and physical geographic factors such as an object that has been moved due to aerial and fluvial geomorphological processes or an object moved by a person. In addition, measurements could not be taken on land that has a steep incline/descent such as the slope on the bluff faces at site 3. Ultimately, GPS data are the most accurate source for determining the location of the bluffs. However, by using the methods presented in the study, approximate estimations can be made on the rate at which these shorelines are receding as a whole. For specific locations that are eroding faster than others, GPS data can be made perpendicular to previous GPS coordinates using the measure tool in arcMAP. The only limitations for using GPS technology are that it needs satellites to capture the coordinates of its location and GPS units need batteries. The GPS does not work well under tree canopy because it cannot get a straight line of sight to the satellites. These limitations can be viewed on arcGIS when these data points are overlaid onto the orthoimagery. The issue is that the person using the GPS needs to be connected to multiple satellites (a minimum of 3) in order to obtain data. For this reason, the precise location of the crest and toe varies based on the retrieval of satellite information. Therefore, on the digitized images, data points may be perceived as a quarter of the distance between the toe and the crest (Appendix C). Many things can obstruct information coming from satellites such as vegetation, satellite position, telemetry connections between the GPS, satellites, and the GCRA base station receiver.

The advantages between modern techniques and historical methods for collecting shoreline recession rates have been represented through their limitations based on past studies and the process of traditional surveying techniques and modern techniques. Remote sensing techniques require less physical labour, but require greater network management due to the lack of physical data, and can be done with one individual. Total Station data require initial physical materials and equipment is larger and heavier to use and set up; however, total station data can be converted digitally. Total station surveying is more labour intensive, and requires two people to survey the landscape. Overall each method has its own limitations and benefits; however, the modern remote sensing methods can give an accurate representation for determining shoreline recession rates based upon the research found in this study.

Shoreline recession rates depend widely on the geographical processes acting within temporal and spatial dimensions. The main factors that past studies have found for causing shoreline recession within all sites and for the overall shoreline are: waves (wave energy), geomorphology, lake level change, littoral transport and sand supply as well as hydrologic functions (e.g. surface runoff and groundwater seepage). The water level and wave energy are the driving factors for removing sediments from the shoreline at the toe of a bluff. In the published articles, it has been shown that higher water levels and larger amounts of wave energy result in large recessional changes within the shoreline. While soil characteristics of the shoreline test the resistance of the removal of the sediments, such areas that have clay deposits have been found to be less likely to recede and therefore be more stable than areas of other sediment such as sand or silt. Soil characteristics must be taken into account to better understand a shoreline's ability to resist erosion. Many of the studies had similar reasoning for the recession of shorelines within the southern Great Lakes. Geomorphological processes and the geographical attributes of the shorelines is the cause of these recessions in the shorelines that are managed by the GRCA. Geographical factors such as climate, wave energy, lake water level, ice cover and soil characteristics were used to give causation for the estimated shoreline recessions within all of the published articles.

6.0 Recommendations

The recommendation that we would make based on the data that we attained and were provided by GRCA is to integrate the GPS technology and arcGIS to calculate these shoreline recession rates. GPS data allow for a more accurate location of where bluff features are located. This allows for any bluffs that are thick with vegetation to be identifiable with annual GPS coordinates. By using remote sensing techniques such as the method in Appendix A or using the measure tool, recession rates can be measured annually through aerial photographs. The integration of the GPS technology and using ArcGIS would allow for an accurate recession rate measurement.

In addition, we recommend that comparisons could be made by determining how much of the shoreline receded. We can do this comparison by giving positive or negative shoreline recession values that correlate to whether the shoreline is receding (negative) or advancing (positive) due to the accumulation of aggregates on the toe. By putting signs on these recession rates, there can be a definitive recession rate for both the toe and crest of these bluffs. This could be represented through a "bar graph that shows latitudinal differences between the two measurement sources where each bar represents an equal increment of longitude. Such a plot would provide not only the direction and magnitude of the departure but more importantly the spatial context" (McKenna-Neuman 2016).

The last recommendation we would make is to have yearly monitoring done at sites where recession rates are high (e.g. Site 3). This monitoring should be done either in early spring before the leaves grow on the trees or in the fall after the leaves have fallen off, and before the snow arrives. Collecting the GPS points when there are no leaves on the trees allows for a clear line of sight for the GPS unit. It should also be noted that the data collection should be done every year at the same time of year as well as the continued collection of aerial photography from the Durham region. Having a better data set could/will result in a more direct conclusion of whether one method is better than another and will give a better representative of the yearly recession rate.

7.0 Conclusion

In this study, we found that for the period of 2005 to 2014 the overall shoreline recession rates are approximately 27 cm yr^{-1} for the toe of the bluffs and 23 cm yr^{-1} for the crest. When comparing the remote sensing technique found in Appendix A to the measure tool in arcMAP for calculating annual shoreline recessions for 2015, we found that there was a high amount of uncertainty in the data and that more research needs to be conducted on using this method as a viable method for calculating shoreline recession rates.

There are many advantages and disadvantages when comparing past and modern technology. Using the data and information available from GRCA we were not able to draw a clear conclusion about which method is best to use for measuring shoreline recession rates. Therefore, as previously stated above we would need more data about the years we are comparing before we would be able to conclude that one method is definitively more accurate than another. However, with only the information we were given, we have concluded that GPS technology is more accurate. Using remote sensing techniques such as the method in Appendix A and integrating GPS technology, we can accurately locate and determine the recession rates of shorelines.

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9.0 Appendices

9.1 Appendix A

Steps Used in arcGIS to Determine Shoreline Recession Rates

1. Open your ArcMap document.
2. In ArcMap, open the Search panel (Ctrl+F)
3. Search for and open the "Feature Vertices to Points" tool.
4. For "Input Features" select one of the shoreline layers.
5. For "Output Feature Class" specify the name and location of the output file.
6. Leave "Point Type" set to "ALL" and click OK to run the tool. The resultant layer should automatically be added to the map when the tool finishes running.
7. Back in the Search panel, search for and open the "Near" tool (the name of the tool in the result list will be "Near (Analysis)".
8. For "Input Features", select the layer you created in Step 6.
9. For "Near Features", select the other shoreline layer.
10. Click OK to run the tool.
11. Open the attribute table of the layer created in Step 6. There should be a new field called "NEAR_DIST".
12. Right-click the field header and select "Statistics" from the context menu.
13. In the statistics window, you should now be able to see your mean (Average) distance between the shoreline feature classes.

9.2 Appendix B

Example of Attribute Tables Listed Per Year & Bluff Feature

Table 5: Attribute Table of Point Feature Class for 2005 Crest

FID	Id	Year	Source	Note	ORIG_FID	NEAR_FID	NEAR_DIS (m)
0	0	2005	clarington_20_2005_revised.sid	T	0	11	0.56
1	0	2005	clarington_20_2005_revised.sid	T	0	11	0.99
2	0	2005	clarington_20_2005_revised.sid	T	0	11	1.43
3	0	2005	clarington_20_2005_revised.sid	T	0	11	1.21
4	0	2005	clarington_20_2005_revised.sid	T	0	11	0.62
5	0	2005	clarington_20_2005_revised.sid	T	0	11	1.77

Table 6: Attribute Table of Point Feature Class for 2005 Toe

FID	Id	Year	Source	Note	ORIG_FID	NEAR_FID	NEAR_DIS (m)
0	0	2005	clarington_20_2005_revised.sid	B	0	4	5.07
1	0	2005	clarington_20_2005_revised.sid	B	0	4	5.26
2	0	2005	clarington_20_2005_revised.sid	B	0	4	3.94
3	0	2005	clarington_20_2005_revised.sid	B	0	4	3.82
4	0	2005	clarington_20_2005_revised.sid	B	0	4	4.52

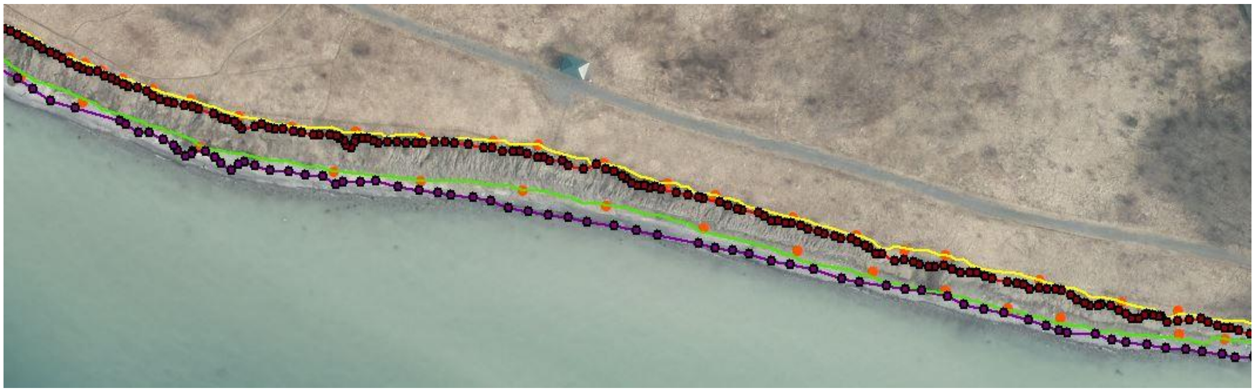
5	0	2005	clarington_20_2005_revised.sid	B	0	4	5.28

9.3 Appendix C

Digitized Site Aerial Images

Note:
- All orange circles are the GPS point locations
- The Purple is the 2005 toe trace line
- The Green is the 2014 toe trace line
- The Maroon is the 2005 crest trace line
- The Yellow is the 2014 crest trace line

Site 1



Site 1 has a scale of 1:1715 with a width of 342m and a length of 158m.

Site 2

Site 2 has a scale of 1:1900 with a width of 439m and a length of 156m.

Site 3

Site 3 has a scale of 1:2000 with a width of 455m and 244m long (arcMAP – measure tool)

9.4 Appendix D

Site Note Scans & Information

Site # 1. (top of bluff).

- Open field at the top of the bluff. w heavy veg.
- Over cast w clouds
- Lake calm, little wave movement.
- Surveyed along the edge (every 10 meters taken point).

Note:

. grass cut infront of pavillion, seems to be a cutting into the bluff from runoff. (channelized cutting). (pictures)

(bottom) Toe.

- 6-7 m bluff. (start point).
- over hanging tree's about to fall into the beach / water / Lake)
- granite boulders within the bluff.
- Very little veg. on the bluff.
- moving along the bluff (west) the bluff becomes larger
- ~~[illegible]~~ Stony beach, some fallen trees.

Site #2: - open field (5m approx) Grassland w̄ development grassland behind.

More vegetation on bluff ↑ → west clay/sand

Clay more east / siltier more west

- over cast w̄ clouds - 20 km/h Gusts
- lake calm w̄ little wave movement
- Vegetation less dense on the bluff
- crest & vegetation meet as well
- runoff carves in the bluff from crest
- Surveyed roughly every 10 m
- ~~Sandy~~ more clay present/loam Bluff w̄ cobble stones on the shore line.
- crest: vegetation less -> closer to condo

The Bluff: Grass, shrubs mixed with open spaces of dirt

- poorly drained, higher moisture content
- event type / episodic slumps
- Boulders & stone along bottoms
- Rotational slumps.
- possible drainage system ?
- cusps along beach

Bonheart Bluffs

Site # 3: - looks silty ⇒ like site 1

- lake lvl at 260 m from sea level
- 90 - 60ft bluffs

Crest:
- rotational slide ↳ ridges in scallops

- Round slumps
- Grassland vegetation - flat slope
- Tile drainage Pipe from acGross the road which accelerates erosion rates
- you can see the top layers of
- Total station transect survey doesn't work unless your accurate due to the position variability of the bluff

- Spring events ⇒ Super Saturation from run off
- Water lvls at its highest.
- Vegetation overhang ⇒ top soil a meter thick.
- Trees growing on the sides of the bank where slope is less, with grass & weeds in between.
- Sediment very bright, on beach constant supply of sediment

Toe: - narrow shoreline
- stones & boulders
- layers of sand & silt - very fine

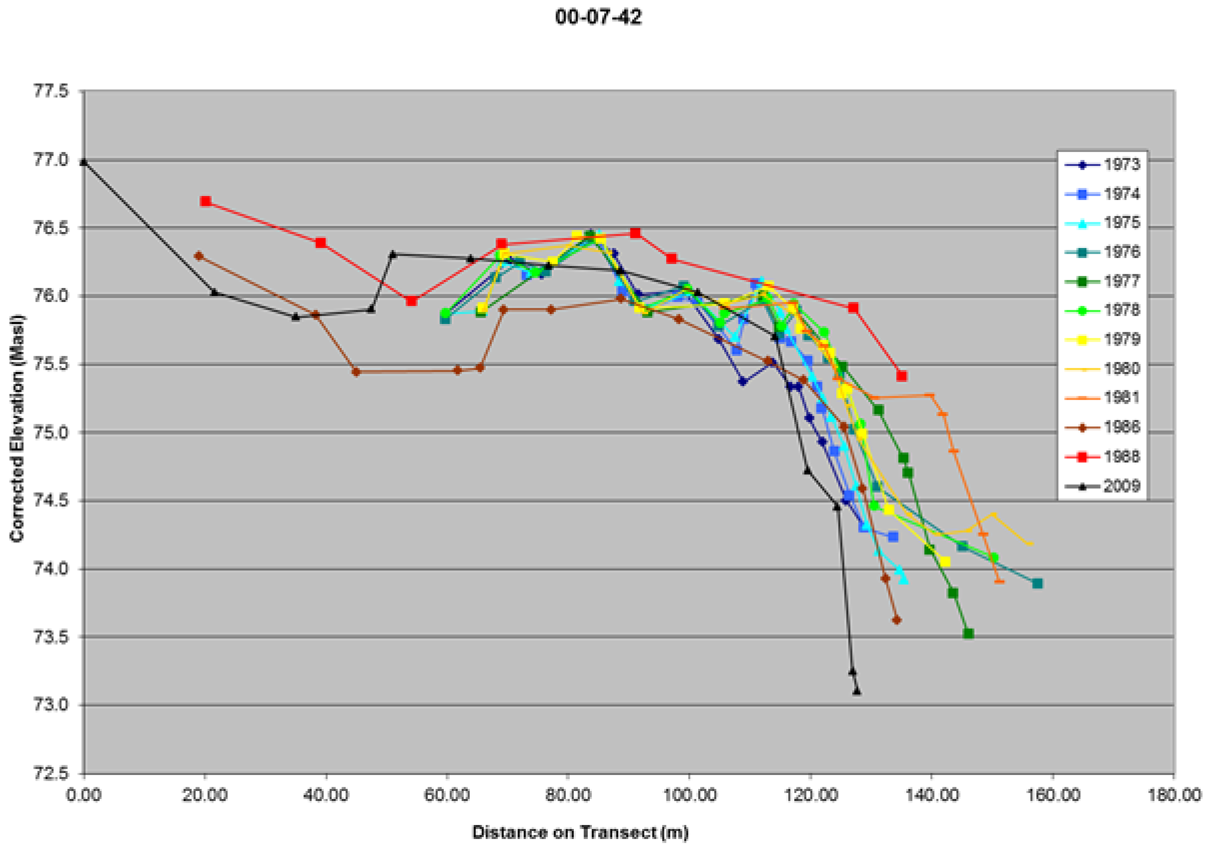
Crest: - erodes mostly from saturation at top, then runoff

Toe: Rocks size goes from big to small
↳ sand & silt deposits on shoreline bed.

Bluffs: moist along bottom & in between layers.

9.5 Appendix E

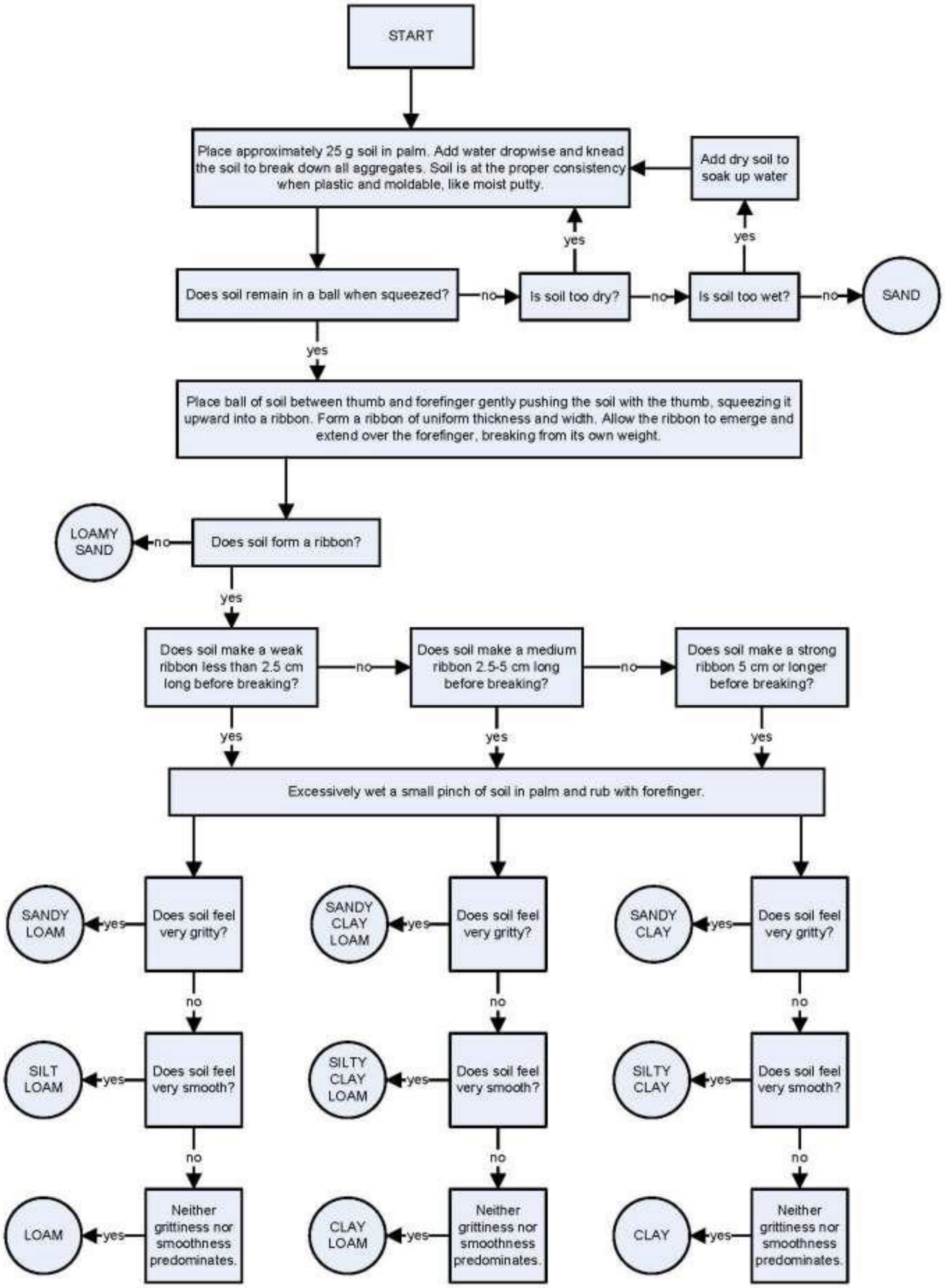
Total Station Data by GRCA



These total station data were not used in our report because we could not compare this total station data to the corresponding years of the orthoimagery (2005, 2015).

9.6 Appendix F

Soil Texture Analysis by Feel


START
Place approximately 25 g soil in palm. Add water dropwise and knead the soil to break down all aggregates. Soil is at the proper consistency when plastic and moldable, like moist putty.
Add dry soil to soak up water
yes
yes
Does soil remain in a ball when squeezed?
no
Is soil too dry?
no
Is soil too wet?
no
SAND
yes
Place ball of soil between thumb and forefinger gently pushing the soil with the thumb, squeezing it upward into a ribbon. Form a ribbon of uniform thickness and width. Allow the ribbon to emerge and extend over the forefinger, breaking from its own weight.
LOAMY SAND
no
Does soil form a ribbon?
yes
Does soil make a weak ribbon less than 2.5 cm long before breaking?
no
Does soil make a medium ribbon 2.5-5 cm long before breaking?
no
Does soil make a strong ribbon 5 cm or longer before breaking?
yes
yes
yes
Excessively wet a small pinch of soil in palm and rub with forefinger.
SANDY LOAM
yes
Does soil feel very gritty?
SANDY CLAY LOAM
yes
Does soil feel very gritty?
SANDY CLAY
yes
Does soil feel very gritty?
no
no
no
SILT LOAM
yes
Does soil feel very smooth?
SILTY CLAY LOAM
yes
Does soil feel very smooth?
SILTY CLAY
yes
Does soil feel very smooth?
no
no
no
LOAM
yes
Neither grittiness nor smoothness predominates.
CLAY LOAM
yes
Neither grittiness nor smoothness predominates.
CLAY
yes
Neither grittiness nor smoothness predominates.

9.7 Appendix G

Key Research Terms:

- GRCA: Ganaraska Region Conservation Authority
- Natural Hazard zones: Part of a four part management plan of the GRCA, the natural hazard zone portion of the management plan is about flooding and erosion
- Shoreline Recession: The shoreline recedes further main land from a previous position that is now engulfed in water.
- Erosion: The action of removing soil and rock from one location on the Earth's crust, then transport it to another location where it is deposited.
- Recession Rates: Is the spatial and temporal aspect of erosion. The amount of soil that is removed per unit of time
- Bluff: A steep cliff or wall made up of rock or soil.
- Weathering: The chemical or mechanical process by which objects are worn or broken down (example: erosion, freeze thaw cycle).
- Toe: The base of a cliff, slope or embankment
- Crest: The top of a cliff, slope or embankment
- GIS (Geographical Information System): A system designed to capture, store, manage, analyze and present all types of spatial or geographical data
- ArcGIS: ArcGIS is a world class, integrated collection of GIS software products that provides a standards-based platform for spatial analysis, data management and mapping.
- Total Station: Is an electronic theodolite (transit) integrated with an electronic distance meter (EDM) to read slope distances from the instrument to a particular point.
- Overlaying: The geometric intersection of multiple datasets to combine, erase, modify, or update features in a new output dataset
- Remote Sensing: The scanning of the earth by satellite or high-flying aircraft in order to obtain information about it.
- GIS Layering: A reference to a data source, such as a shapefile, coverage, geodatabase feature class, or raster that defines how the data should be symbolized on a map. Layers can also define additional properties, such as which features from the data source are included. Layers can be stored in map documents (.mxd) or saved individually as layer files (.lyr)
- Vertex: One of a set of ordered x, y coordinate pairs that defines the shape of a line or polygon feature