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Lake Winnipeg Erosion and Accretion Processes

A Compendium to the Lake Winnipeg Shoreline Management Handbook

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Lake Winnipeg Erosion and Accretion Processes

Compendium to the Lake Winnipeg Shoreline Management Handbook

Prepared for

Manitoba Clean Environment Commission

Prepared by

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12371.101

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1.0 INTRODUCTION

Section 1.0 of the report provides a general overview of Lake Winnipeg and the scope for this report.

1.1 Overview

Lake Winnipeg is located in the southern half of the Province of Manitoba and is the world's tenth largest freshwater lake by surface area. It features a watershed that drains almost one million square kilometres, including the majority of the agricultural land in the Canadian Prairies and extends into North Dakota and Minnesota in the United States of America (refer to Figure 1.1).

Figure 1.1 Lake Winnipeg and Watershed

The watershed features many large river systems. The two largest, the Saskatchewan which drains much of the Canadian Prairies and the Winnipeg which drains the Lake of the Woods region of Western Ontario, collectively contribute 75% of the inflow to Lake Winnipeg. There are many other smaller rivers that make up the remaining 25% of the inflow, including the Red River that drains north from the USA. The only river that drains Lake Winnipeg is the Nelson in the north.

The outflow from the lake has been regulated by Manitoba Hydro since 1976 at the Jenpeg Generating Station to optimize hydropower generation and mitigate extreme flooding on Lake Winnipeg. The management of the outflow has reduced the historical water level range (highs and lows), with varying degrees of benefits and impacts to the more than 40 communities around the perimeter of the lake.

This report was commissioned by the Manitoba Clean Environment Commission (CEC) to serve as a technical reference for the ongoing public hearing into the licensing of Manitoba Hydro to regulate the water level under the Water Power Act. Much of the material in this document builds from the technical studies completed by Baird & Stantec (2000) for the Lake Winnipeg Shoreline Advisory Group and subsequently republished in the Lake Winnipeg Shoreline Management Handbook (Manitoba Conservation, 2001).

1.2 Scope

The scope of this technical report for the CEC includes:

- Description of erosion and accretion processes on Lake Winnipeg;
- Historical perspective on Lake Winnipeg erosion, including pre- and post-regulation;
- Review select relevant literature on water level regulation and implications for erosion rates for freshwater lakes;
- Outline the requirements for future technical studies to quantify the influence of Lake Winnipeg regulation on erosion and accretion rates; and
- Recommend future actions for the Government of Manitoba, local communities and riparian land owners to manage coastal hazards, promote the sustainable use of the lake ecosystem, and increase the resilience of shoreline communities.

As noted, this report has been prepared as a compendium to the Lake Winnipeg Shoreline Management Handbook. Interested readers are encouraged to review this handbook, as it provides a more thorough overview of shoreline processes. This report focuses on providing additional information on numerical modeling techniques to quantify the potential impacts of water level regulation on erosion and accretion, plus providing recommendations on future technical studies.

2.0 SHORELINE PROCESSES AND WATER LEVEL REGULATION

The key factors and processes influencing the evolution of the Lake Winnipeg shoreline are reviewed, including geology, erosion, sand transport, deposition, and water level regulation.

2.1 Processes Influencing Shoreline Evolution

2.1.1 Geology and Shore Type

The geology of the lake influences the evolution of the shore, including the type of substrate on the lake bottom and exposed at the water's edge, the rate of erosion, the type and volume of material available for transport along the shore by waves and currents, and the location of sand and gravel deposits. The following sections discuss the general geologic conditions in southern Manitoba and the typical shore types found on Lake Winnipeg.

2.1.1.1 Geology of Southern Manitoba

A map of the bedrock geology of Manitoba is provided in Figure 2.1. The eastern shore of Lake Winnipeg is defined by the limit of the old Precambrian bedrock from the Canadian Shield (noted as Archean in Figure 2.1), which is approximately three billion years old. The Precambrian rocks dip below the lake where they are covered by a complex sequence of sedimentary bedrock from the Paleozoic era, roughly 570 to 235 million years ago. The various sequences include limestone, dolomite, shales and sandstone.

For a period of roughly two million years, Manitoba was exposed to multiple advances and retreats of the continental ice sheets. This era is known as the Pleistocene. Below the ice sheets and during the melting process, the province was covered with a complex web of consolidated glacial sediment, such as glacial tills (a mixture of fine sediments such as silt, clay, and rock fragments). During the retreating phase of the glacial periods, large volumes of melt water flowed into the glacial lake leaving large deposits of unconsolidated (loose) sand and gravel.

The last glacial ice sheet migrated north of the modern Lake Winnipeg basin approximately 10,000 years ago. The underlying bedrock and sedimentary rocks in the province were now capped with a variety of glacial tills, lacustrine clays, and sandy outwash deposits. These sediments are often referred to as surficial deposits, as they cover the underlying bedrock in most locations.

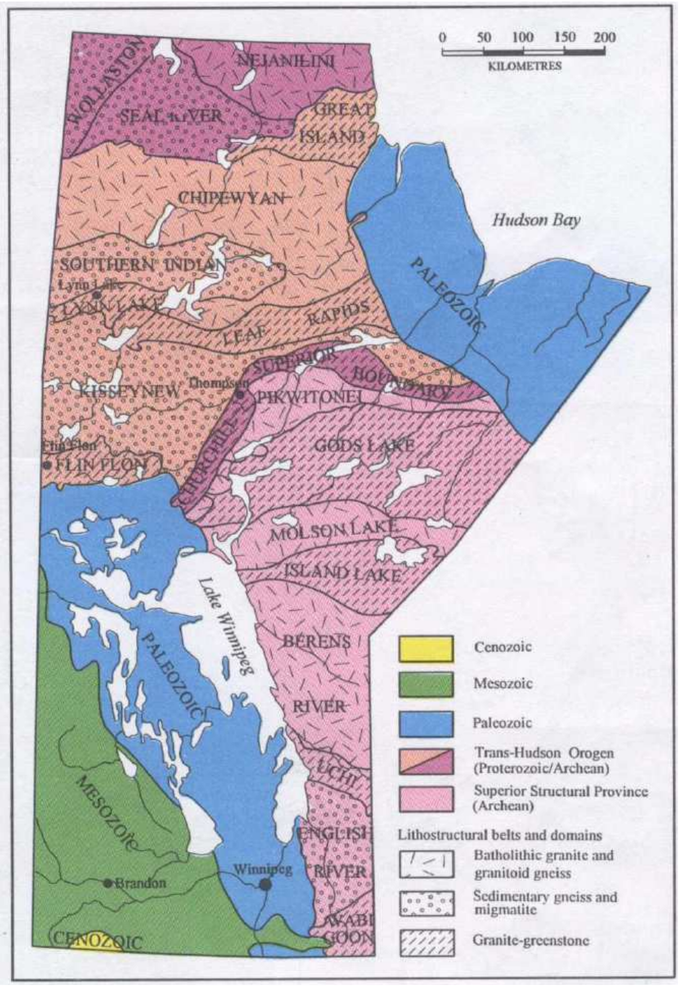


Figure 2.1 Bedrock Geology of Southern Manitoba (courtesy Province of Manitoba)

2.1.1.2 Present Shore Types on Lake Winnipeg

The underlying bedrock and surficial deposits have been subject to wind, waves and ice action at variable water levels resulting in the modern shoreline of Lake Winnipeg. The following general shore types are used to classify the perimeter of the lake for purpose of scientific analysis. The Lake Winnipeg Shoreline Management Handbook (Manitoba Conservation, 2001) provides additional description of these shore types and their distribution around the perimeter of the lake.

Bedrock Shorelines: Bedrock exposures are not common on Lake Winnipeg, as the bedrock is generally covered by thick glacial deposits in most locations. Where present, such as the southwestern tip of Elk Island north of Rural Municipality of Victoria Beach (refer to Figure 2.2), the bedrock exposure has a controlling influence on the shoreline morphology due to its very slow erosion rate. In other words, while erosive processes such as wave attack and physical and chemical weathering do alter the bedrock, the changes generally occur at a very slow rate. Conversely, shorelines comprised of glacial sediments and sand erode at a much faster rate. Given their general resistance to erosion, bedrock shores are not very sensitive to fluctuating water levels.

Figure 2.2 Exposed Sedimentary Bedrock on Elk Island

Cohesive Shorelines: Collectively, the term cohesive shores refers to shorelines comprised of the consolidated glacial sediments commonly found in Lake Winnipeg, including the hard glacial tills and softer lacustrine clays. These shorelines are highly erodible when exposed to wave action. Since the soil matrix often features very little sand, the cohesive material is typically exposed and beaches are often very narrow or not present at all. This is the case for the eroding cohesive shoreline along the western shore of Lake Winnipeg in Figure 2.3.

Figure 2.3 Eroding Cohesive Shoreline with Low Bank

Eroding Sand Deposits: Between 10,000 and 5,000 years ago a large glacial lake, Lake Agassiz, occupied a significant portion of southern Manitoba at an elevation higher than present day Lake Winnipeg. As the Pleistocene ice sheet migrated north, glacial melt water flowed into Lake Agassiz leaving large deposits of sand and sandy outwash (sand with rounded pebbles, cobbles, and boulders). Today, when the elevation of these sand deposits exceed the modern lake level, a wave cut sand cliff forms. Refer to Figure 2.4 for a picture of the Sand Cliffs on the eastern shores of the Rural Municipality of Victoria Beach. These large sand deposits erode in a similar manner as bluffs formed of cohesive sediment. In other words, they maintain a steep slope above the beach and are generally devoid of vegetation. When the slope fails, wave action will eventually erode and transport the slumped sediment at the toe in an alongshore direction leaving the steep sand exposed and the cycle repeats.

Figure 2.4 Erosion at the Sand Cliffs

Depositional Beaches: Sand and gravel that is transported along the shore will accumulate in depositional beaches where there is a natural barrier such as a headland to disrupt the flow of sand, or a significant change in the shoreline orientation (potentially influenced by the underlying bedrock). Along the southeast shore of Lake Winnipeg, Grand Beach is an example of large depositional beach. Landward of the beach, sand dunes typically form when sediment is blown landward by the wind. Refer to Figure 2.5 for an aerial view of Grand Beach and the large headland feature that traps the sand moving in a southerly direction.

Figure 2.5 Grand Beach Adjacent to a Rocky Headland

Muddy Shorelines: In locations sheltered from waves on the open lake, fine sediments such as silt and clay will accumulate in depositional environments forming muddy shorelines. They can also be influenced by river or creek inflow, which transports additional fine sediment for deposition on the lake bottom. These shorelines often feature submerged and emergent vegetation, such as cattails. The embayment's along the southern perimeter of the lake are muddy shorelines (refer to Figure 2.6).

Figure 2.6 Southern Shoreline of Lake Winnipeg

2.1.2 Erosion Processes

Erosion is a natural process. On a water body such as Lake Winnipeg, the natural rate of shoreline erosion is related to the shoreline geology or the resisting properties of the shore materials and the primary driving force of erosion, namely waves and currents. When the weather is stormy and the energy associated with currents and breaking waves exceeds the resisting properties of the lake bottom and/or shoreline sediment, erosion occurs. When the weather and the waves are small, the shoreline is generally stable and no erosion occurs.

For bedrock exposures and sedimentary rocks, the rate of shore erosion is very slow and generally not measureable over the duration of years to decades. Therefore, for management purposes, shorelines consisting of bedrock are often considered stable. They are not sensitive to water level fluctuations or different water level regulation regimes.

When the shoreline consists of cohesive sediments, such as glacial tills and lacustrine clays, erosion occurs on the lake bottom (below the lake surface) and at the shore, as shown graphically in Figure 2.7. On the lake bottom, currents and turbulence generated from breaking waves leads to the permanent erosion and removal of the cohesive sediment. This process is referred to as lakebed downcutting and is irreversible. In other words, once the consolidated cohesive sediment is eroded, it cannot reconstitute itself (be put back together). During storm events, the greatest amount of downcutting occurs close to shore and decreases in an offshore direction.

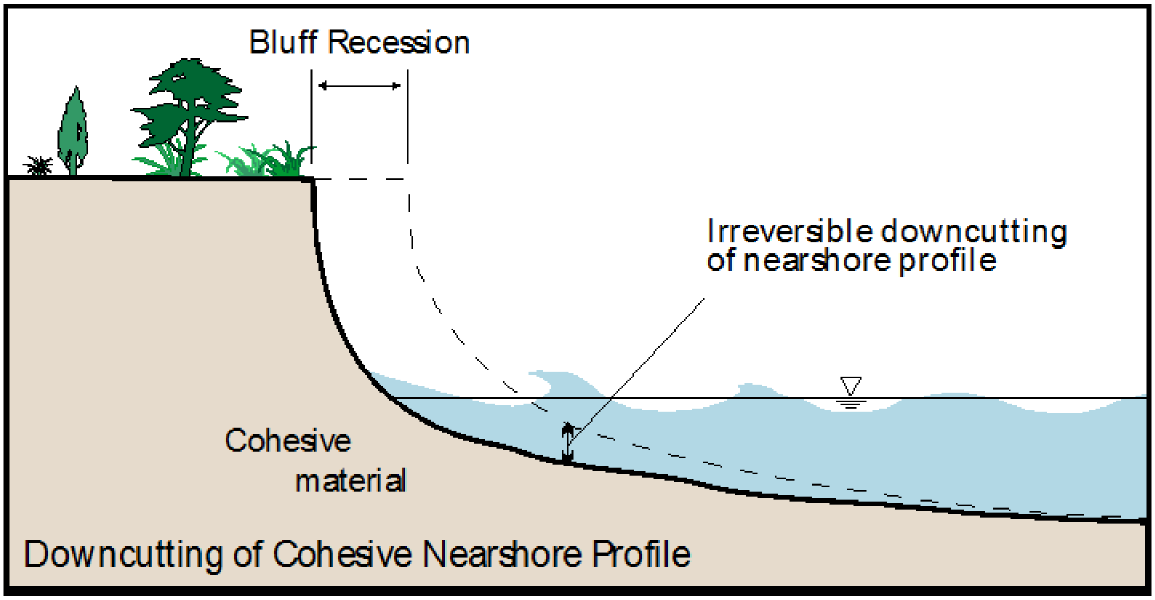


Figure 2.7 Conceptual Sketch of Erosion for a Cohesive Shoreline

At the shore, storm waves attack the cohesive bank or bluff and remove the consolidated material. Regular storm activity keeps the bluff in a near vertical condition as it migrates inland. The bluffs can fail in shallow slides or larger rotational failures. The rate of bluff retreat at a given site on Lake

Winnipeg is a product of the annual wave climate (which varies around the lake based on the wind climate and open water distance, known as fetch) and the resisting properties of the glacial tills and weaker lacustrine clays. When the rate of bluff recession is averaged over many years, the rates are typically between 0.3 to 0.6 m/yr (Handbook, 2001). However, the rate of erosion is not a linear process and in many cases the majority of bluff recession that occurs in a given decade can be attributed to one or two very large storms. In between storm events, the bluffs and beach do not erode.

2.1.3 Sand Transport Along the Shore

When sand and gravel are eroded from the shoreline, some of the sediment will be transported along the shoreline based on the orientation of the lake and the dominant direction of the wave climate. Refer to Figure 2.8 for a conceptual diagram showing wave crests approaching the shore at an angle, which generates longshore currents that in turn transport sediment along the shoreline. While individual storms can move sediment in different directions (e.g., northerly storms move sediment southward along the east shore of the lake), most locations feature a dominant direction of sediment transport based on the dominant wave direction. Over time the majority of the sediment is transported in this dominant direction.

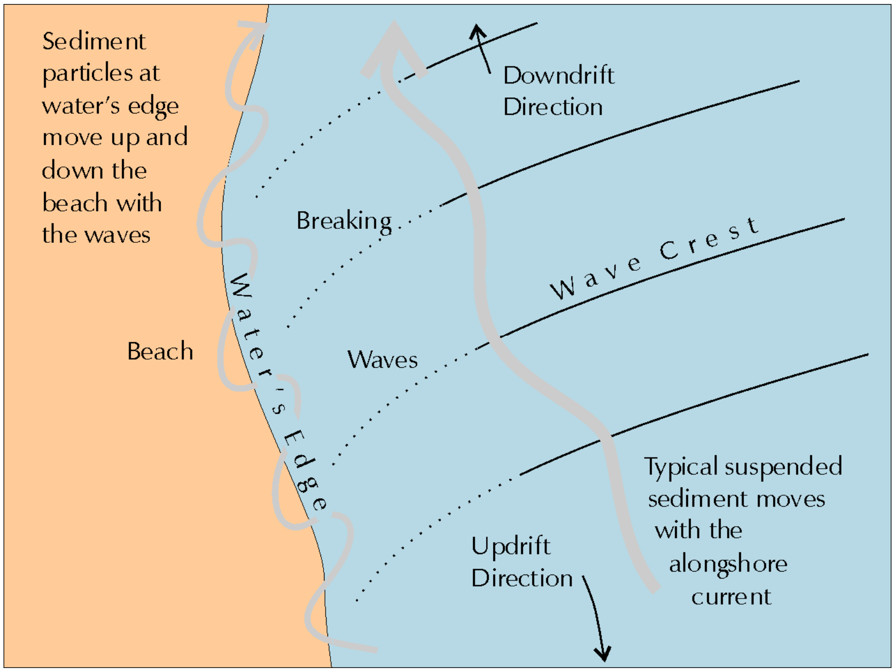


Figure 2.8 Conceptual Diagram of Alongshore Transport of Sediment

Sand and gravel are transported along the shoreline until there is a change in shoreline orientation or a natural barrier (e.g., a headland) or an artificial obstruction that blocks the flow of sediment (e.g., a marina). Over time the sand will accumulate in beach deposits against these obstructions, such as at Grand Beach (see Figure 2.5). If the supply of sediment is continuous, large dunes will form at the back of the beach, as seen in Figure 2.9.

Figure 2.9 Sand Dunes at Grand Beach

2.1.4 Isostatic Rebound

Isostatic rebound refers to the uplift of the underlying bedrock over time. For the Lake Winnipeg Basin, the northern limits are rebounding at a faster rate than the southern shoreline since they were covered in glacial ice longer. As a result of this slow process, the southern shoreline of the lake is slowly sinking relative to the lake surface and migrating southward due to wave overtopping of the beaches during storms. A thorough review of isostatic rebound and potential implications for Lake Winnipeg is provided by Thorleifson (2015).

2.1.5 Anthropogenic Impacts on Shoreline Erosion

When physical assets, such as buildings, are constructed too close to an eroding shoreline, a common response is the construction of shoreline protection structures. If properly constructed, shore parallel structures, such as revetments, can provide short-term relief from shoreline erosion. However, revetments do not stop the lakebed downcutting process at the toe of the structure, as described in Figure 2.10, and eventually these structures will require costly maintenance or fail.

When shore parallel protection structures are constructed along eroding beaches, they eliminate the supply of new sediment from bluff erosion, which is an important contributing source. Since a continual supply of new sediment is required to maintain the local beaches on Lake Winnipeg, the construction of shoreline protection structures without artificial beach nourishment will eventually result in the loss of the beach.

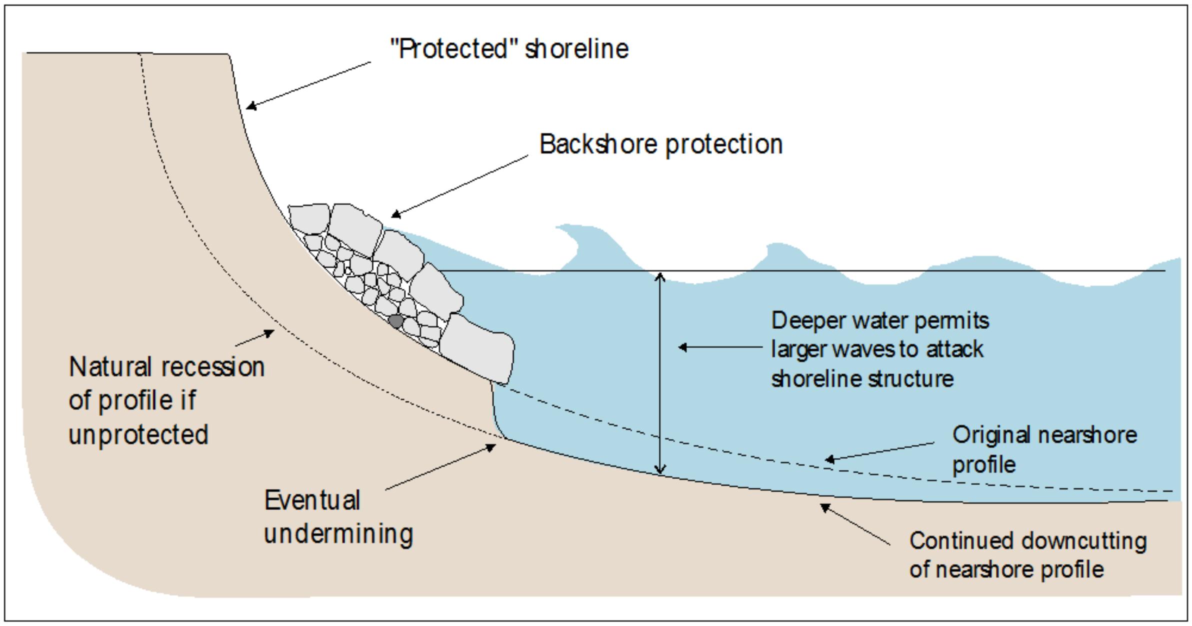


Figure 2.10 Influence of Lakebed Downcutting on Toe Erosion and Structure Failure

2.2 Lake Winnipeg Water Level History

2.2.1 Natural Water Level Fluctuations

The water level of Lake Winnipeg fluctuates naturally due to long term and seasonal variations in precipitation, evaporation, inflow rates, and outflow rates. Storm surge due to wind setup can affect the water level in the short term. Figure 2.11 shows the natural fluctuations of the monthly mean lake level from 1913 to 1975, prior to regulation.

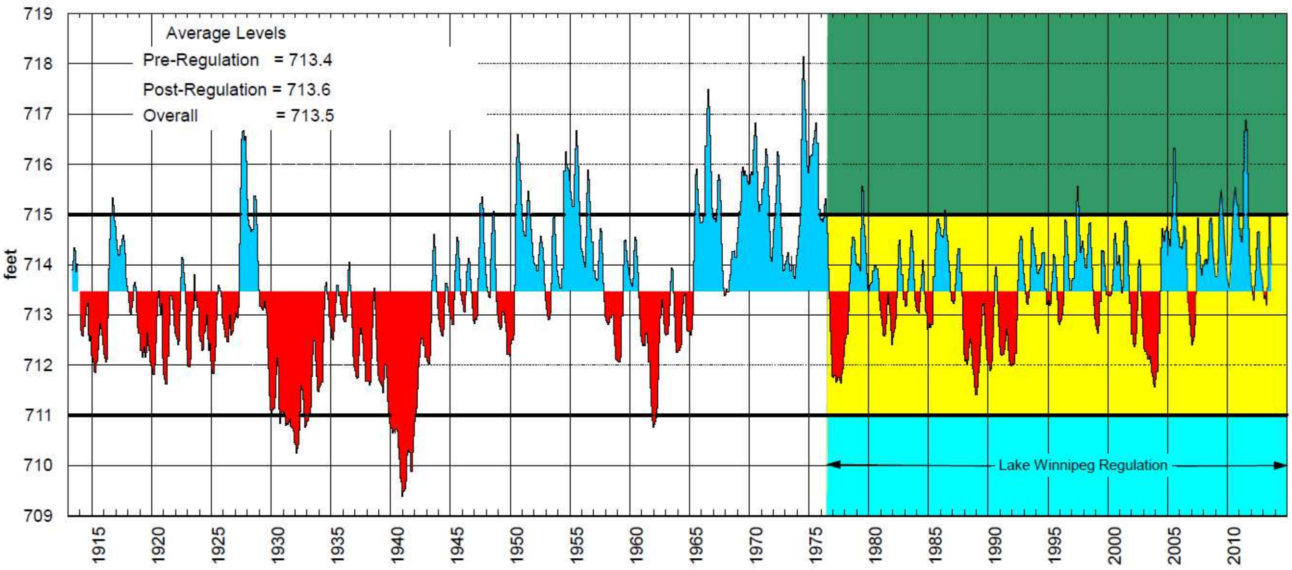


Figure 2.11 Pre- and Post-regulation Water Levels on Lake Winnipeg

2.2.2 Lake Winnipeg Water Level Regulation

The regulation of Lake Winnipeg water levels by Manitoba Hydro began in 1976 and is licensed by the Manitoba Water Power Act. The operating range for the lake is 711 to 715 feet. According to the operating license, the outflows from Lake Winnipeg are governed by the elevation of the lake surface as follows:

- When the lake level is between 711 and 715 feet, the outflows are adjusted as required for power production on the Nelson River;
- When the lake level is above 715 feet, the Jenpeg flow control structure is operated at maximum discharge; and
- When the lake level is below the lower operating range of 711 feet, the Minister responsible for the Water Power Act establishes the outflow requirement.

Refer to Figure 2.11 for a plot of the Lake Winnipeg monthly mean water levels pre- and post-regulation, courtesy of Manitoba Hydro. The upper (715 feet) and lower (711 feet) operating targets are plotted as horizontal black lines. As documented on Manitoba Hydro's website (http://www.hydro.mb.ca/corporate/water_regimes/lake_wpg_status.shtml), the mean lake level prior to 1976 was 713.4 ft. It has increased slightly to 713.6 ft for the post-regulation era. While the mean lake level has not changed substantially for the post-regulation era, the overall range of the monthly mean lake levels has decreased. Prior to 1976, the lake level fluctuated naturally and featured a range of approximately 8.5 feet. Since regulation, the range has been substantially reduced to approximately 5.5 feet.

If the Jenpeg control structure was not built, the water levels on Lake Winnipeg would have fluctuated naturally as they did prior to 1976 (see Figure 2.11) based on inflow from the lake's tributaries, precipitation, evaporation, and the outflow to the Nelson River. Using rating curves calibrated for the historical pre-regulation period, Hesslein (2015) estimated the hypothetical Lake Winnipeg water level conditions for the period 1976 to 2011 if no regulation structure was in place. Refer to Figure 2.12. During the years of high water supplies, the estimated lake level would have been higher (e.g. lake 1990s to present). Conversely, during very dry years, more water was retained in the lake and the water levels didn't drop as far as they would have under a natural system (e.g., decade of the 1980s).

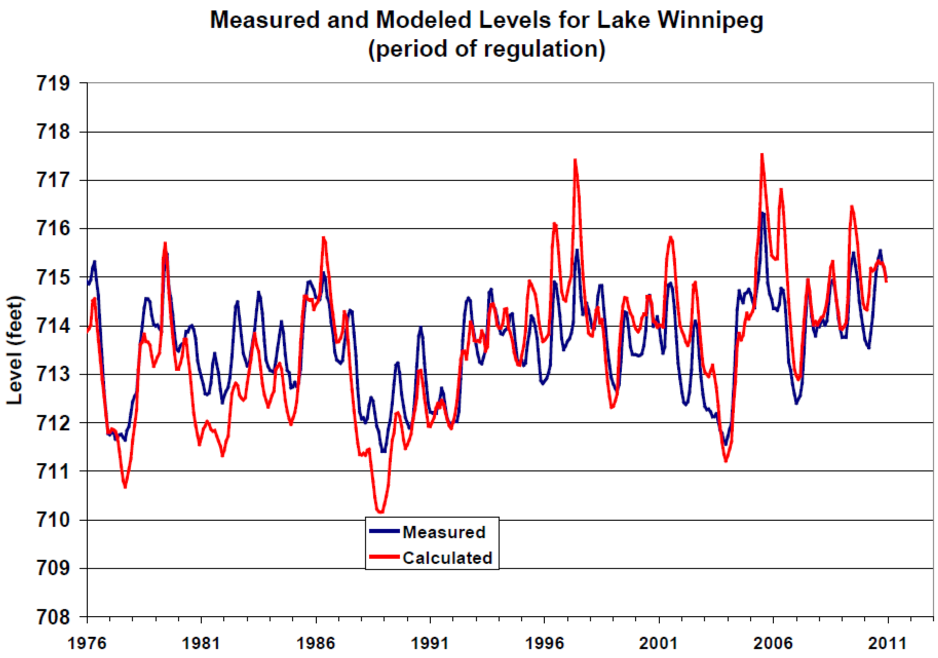


Figure 2.12 Estimated Lake Winnipeg Water Levels without Regulation from 1976 to 2011 (Hesslein, 2015)

The actual measured lake levels did exceed 715 feet between the late 1990s and present, however, without the modifications to the discharge potential of the lake and the flow control structures at Jenpeg, the lake levels would have been even higher. For example, 716 feet would have been exceeded during five years and 717 feet would have been exceeded on two occasions.

2.2.3 Lake Level Impacts on Erosion and Accretion

The impact of Lake Winnipeg regulation on shoreline erosion and accretion processes is complex and would require comprehensive technical studies to quantify. Such work is beyond the context of this report. However, general comments are provided based on the typical shoreline types found around the lake and other technical studies (see Section 3.0).

Bedrock shorelines, such as exposures of the Canadian Shield along the channel between the north and south basin (refer to Figure 2.13) or the younger sedimentary rocks (see Figure 2.2), erode very slowly and the rate is not sensitive to water level fluctuations.

Figure 2.13 Bedrock Shoreline on Lake Winnipeg

For cohesive shorelines, lake level fluctuations don't determine if a shoreline will erode, rather they determine where on the profile the erosion will occur. If wave energy exceeds the resisting properties of the cohesive sediment during a storm, the sediment will erode. The water levels during the storm determine if the erosion will be focused on the nearshore (i.e., during low lake levels), on the beach (average lake levels), or at the bluff toe (during high lake levels).

The only technically defensible way to determine if the present water level regulation plan has changed long-term erosion rates is the application of numerical modeling tools. For example, an engineering model must be capable of simulating erosion processes on the nearshore and bluff over time for varying water levels. One such tool, the COSMOS model (Nairn and Southgate, 1993; Southgate and Nairn, 1993), has been applied on Lake Winnipeg previously (Baird & Stantec, 2000), on other prairie lakes and reservoirs (Mollard and Baird, 2003; Baird, 2007), and throughout the Great Lakes region of Canada and the United States (Baird, 2003; Baird 2006). The application and functionality of the COSMOS model is described further in Section 3.0 of this report.

The evolution of sandy and muddy shorelines, including long-term erosion and accretion rates, can also be influenced by water level regulation. The quantification of impacts requires a comprehensive technical investigation that looks at framework geology, wave and current regime, lake levels, rate of sediment supply, sediment transport, and ultimately sediment sinks (accretion). Further discussion of such a technical study is provided in Section 4.0.

3.0 EROSION AND WATER LEVEL REGULATION CASE STUDIES

Select relevant literature on erosion response to water level regulation is reviewed in the following sections.

3.1 Lake Winnipeg Shoreline Erosion Study (2000)

The Lake Winnipeg Shoreline Erosion Study was completed by Baird & Stantec (2000) for the Lake Winnipeg Shoreline Erosion Advisory Group. The primary goal of the study was the review of erosion processes for the southern basin of the lake and identification of appropriate shoreline management options. Key findings from this technical investigation were subsequently transferred into the Lake Winnipeg Shoreline Management Handbook (Manitoba Conservation, 2001).

Of particular interest to this report is a series of beach profile data at Site 8031, located along the western shore of the southern basin. The 1971 and 1994 profiles are plotted in Figure 3.1 and document both the downcutting of the nearshore (between 30 to 100 metres on the x-axis) and the horizontal retreat of the eroding bluff face (between 30 and 10 metres on the x-axis).

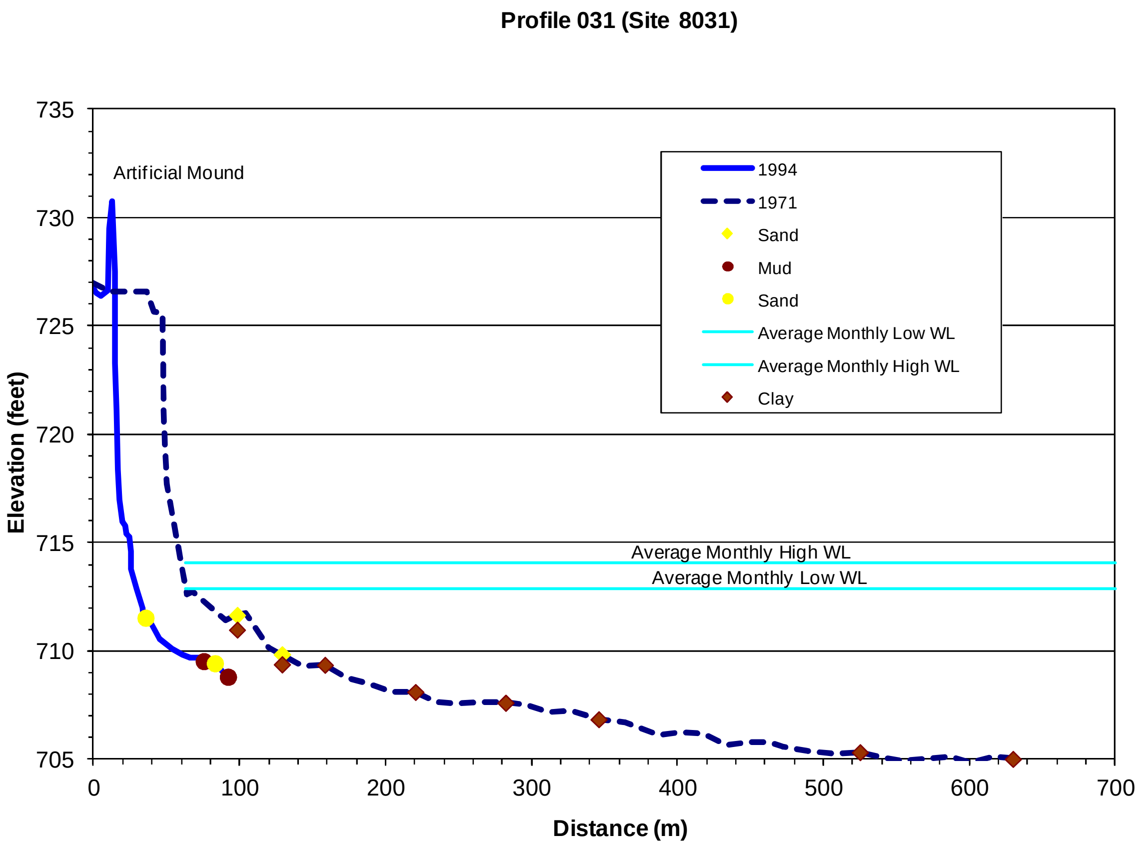


Figure 3.1 Beach Profile Data at Site 8031

The COSMOS erosion model was used and calibrated against the measured erosion from 1971 to 1994, as shown in Figure 3.2. The downcutting predicted with the model (black line in Figure 3.2 labelled 'depc-depin') matches closely with target downcutting that occurred between 1971 and 1994. The model predicted 31 metres of bluff retreat, while the actual amount was 33 metres.

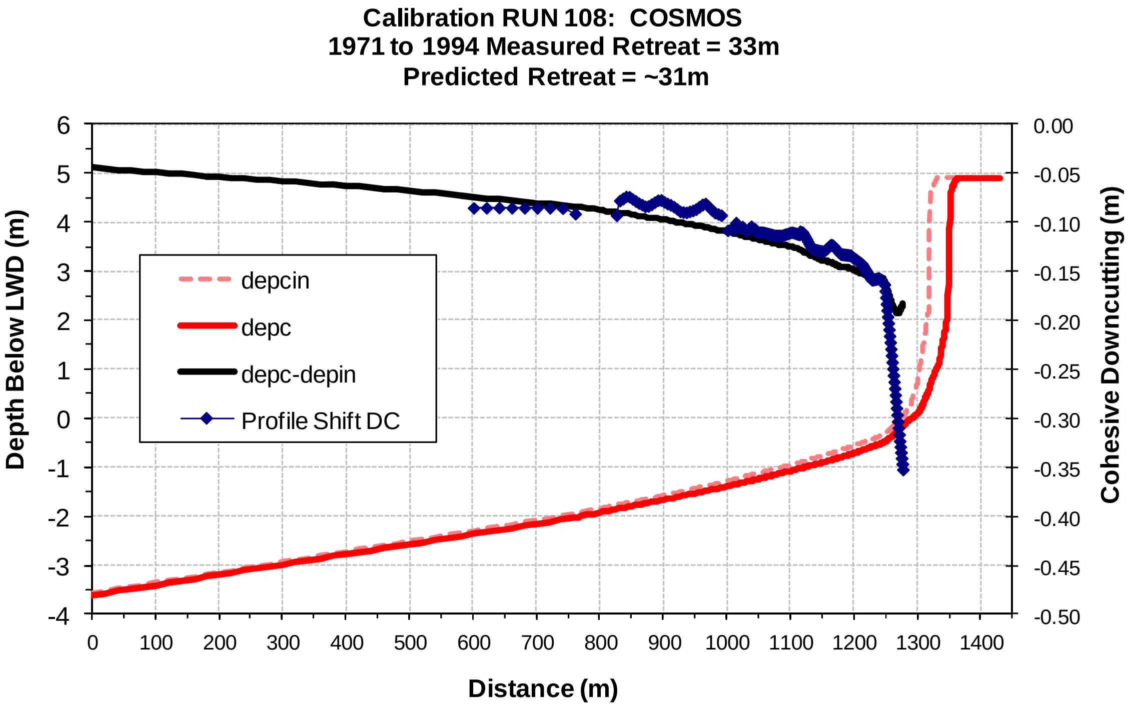


Figure 3.2 Calibration of the COSMOS Model at Site 8031 from 1971 to 1994

A close-up view of the erosion estimate with COSMOS using actual water levels and predicted historical wave heights from the 1971 to 1994 is provided in Figure 3.3, as represented by the red line. To investigation the sensitivity of erosion to lake level, the entire lake level hydrograph from 1971 to 1994 was lowered by 1 ft (0.3 m) and 2 ft (0.6 m). Using the same waves, the erosion simulation was completed again with the model. The corresponding erosion estimates are also plotted in Figure 3.3 and show a reduction in the amount of bluff erosion. However, as shown in Figure 3.4, the amount of lakebed downcutting follows the opposite trend of the bluff recession. When the entire lake level sequence is hypothetically lowered by 2 ft, the bluff erosion rate decreases substantially but the downcutting of the nearshore actually increases. This finding is consistent with the discussion in Section 2.2.1. Shoreline erosion wouldn't stop on Lake Winnipeg if the lake level was dropped uniformly by 2 ft, the erosion would just occur at a lower elevation (e.g., on the nearshore profile).

It is important to note that general conclusions about the role of water level regulation on Lake Winnipeg erosion rates cannot be drawn from this single model simulation. In addition, the two hypothetical scenarios of a 1 ft and 2 ft drop in the lake level are not something under consideration by government, Manitoba Hydro, or recommended by Baird. The model simulations are presented simply to highlight the predictive capability of the COSMOS model and the sensitivity of shoreline erosion to water level fluctuations.

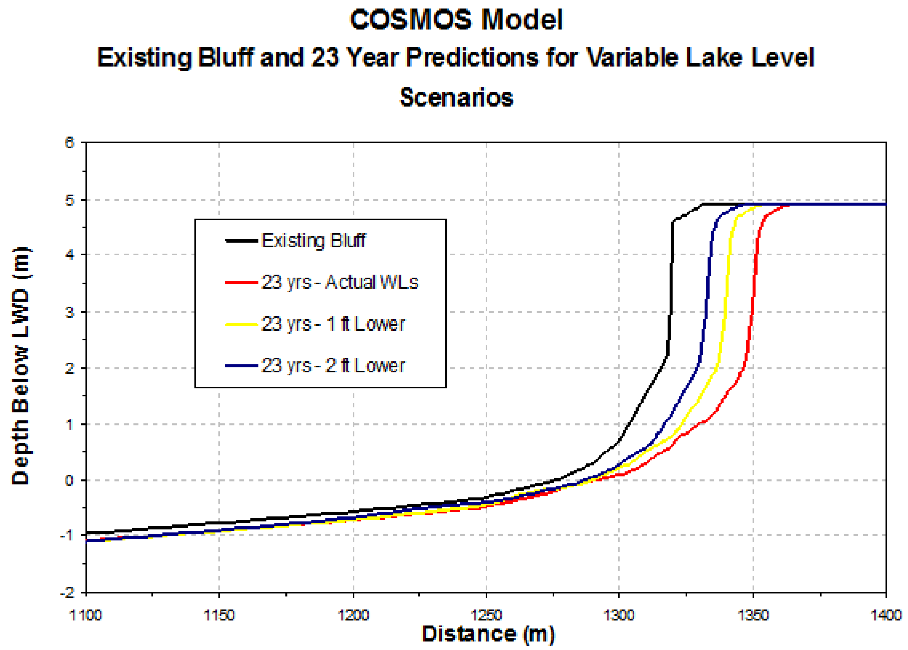


Figure 3.3 Two Hypothetical Water Level Scenarios Simulated with COSMOS

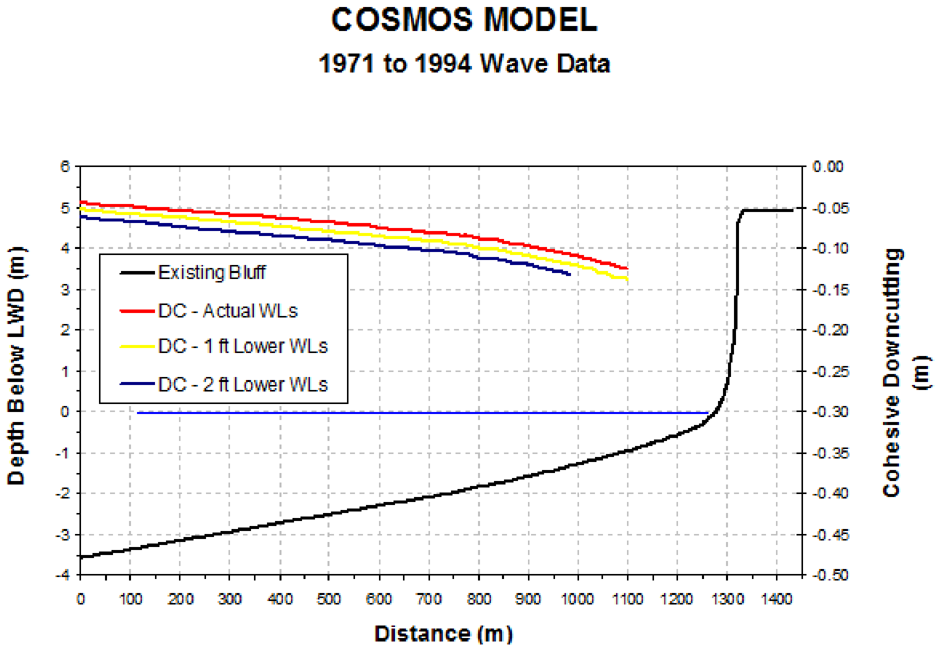


Figure 3.4 Lakebed Downcutting Estimates from the COSMOS Model

3.2 Lake Diefenbaker Erosion Modeling (2003)

J.D. Mollard and Associates and W.F. Baird & Associates (2003) completed an erosion modeling investigation at Elbow Harbour, Lake Diefenbaker. Lake Diefenbaker is located in the South Saskatchewan River Valley, approximately150 km northwest of Regina, Saskatchewan. Refer to Figure 3.5, which also references the location of Elbow Harbour, the site of the numerical modeling. A picture of a typical eroding bank in cohesive sediment is provided in Figure 3.6.

The work was completed for Environment Canada and Alberta Public Works, Supply and Services. The primary objectives of the study included calibrating and verifying the predictive functionality of the COSMOS erosion model, and commenting on the functionality of the model to predict future erosion in prairie lakes and reservoirs. The relevant model findings are summarized below, along with comments on the relevance for future Lake Winnipeg investigations.

The Lake Diefenbaker reservoir was created in 1966 and features an operating range of more than nine metres. For reference, the time series reservoir levels from 1977 to 2000 are also plotted in Figure 3.7. Measured 1977, 1984 and 2000 shore profiles at Elbow Harbour are also plotted in Figure 3.7. The COSMOS erosion model was successfully calibrated and verified against the measure profile data in Figure 3.7.

Of particular interest to Lake Winnipeg relicensing is the plot of cumulative bluff recession on Lake Diefenbaker in Figure 3.8. The years of greatest recession (1976, 1981, 1993 and 1995) all correspond to years when the reservoir was at or near the full supply level. In years when the reservoir peaked at levels below the full supply level, erosion was focused on the nearshore profile and the bluff was not eroding.

With the model coefficients fully calibrated, COSMOS was re-run for the period 1977 to 1984 with a full supply level artificially raised by one metre (refer to Figure 3.9). For this scenario, the wave cut terrace at Elbow Harbour is out of equilibrium with the storm waves. In other words, the majority of the wave energy reaches the bluff toe and is not dissipated on the nearshore profile. Consequently, the predicted recession between 1977 and 1984 increased by 50%.

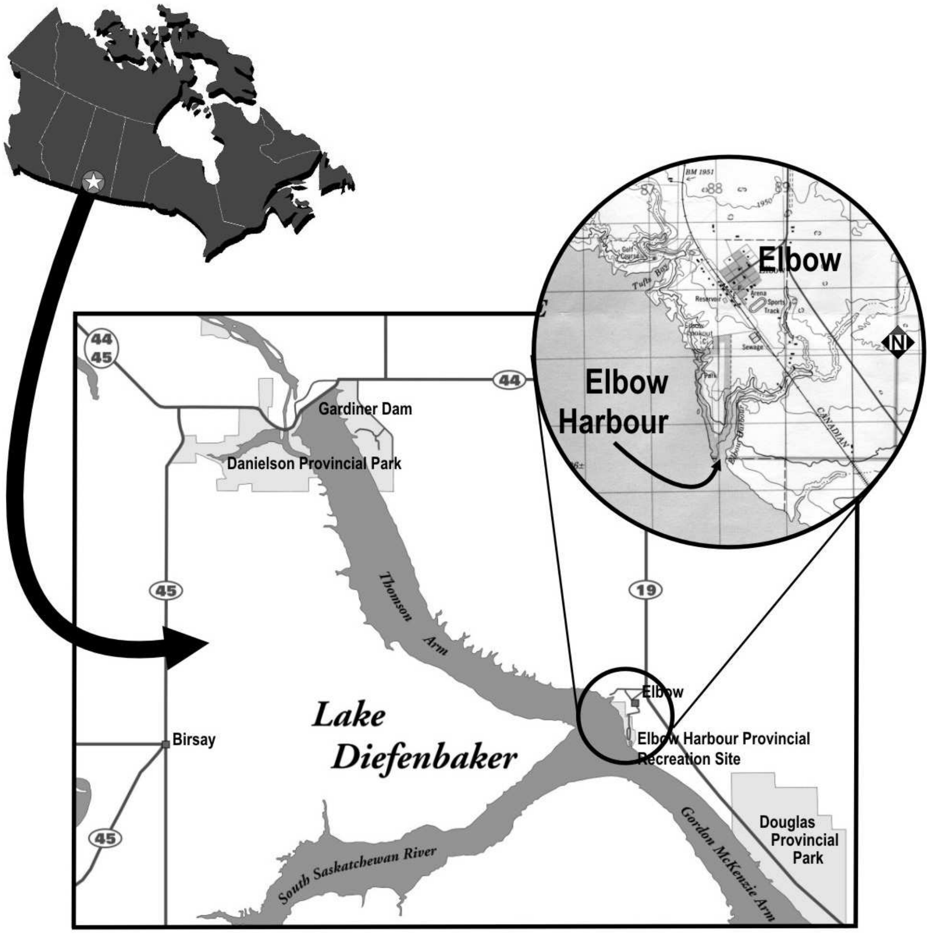


Figure 3.5 Location Map of Lake Diefenbaker and Elbow Harbour

Figure 3.6 Typical Eroding Bank in Cohesive Sediment at Elbow Harbour

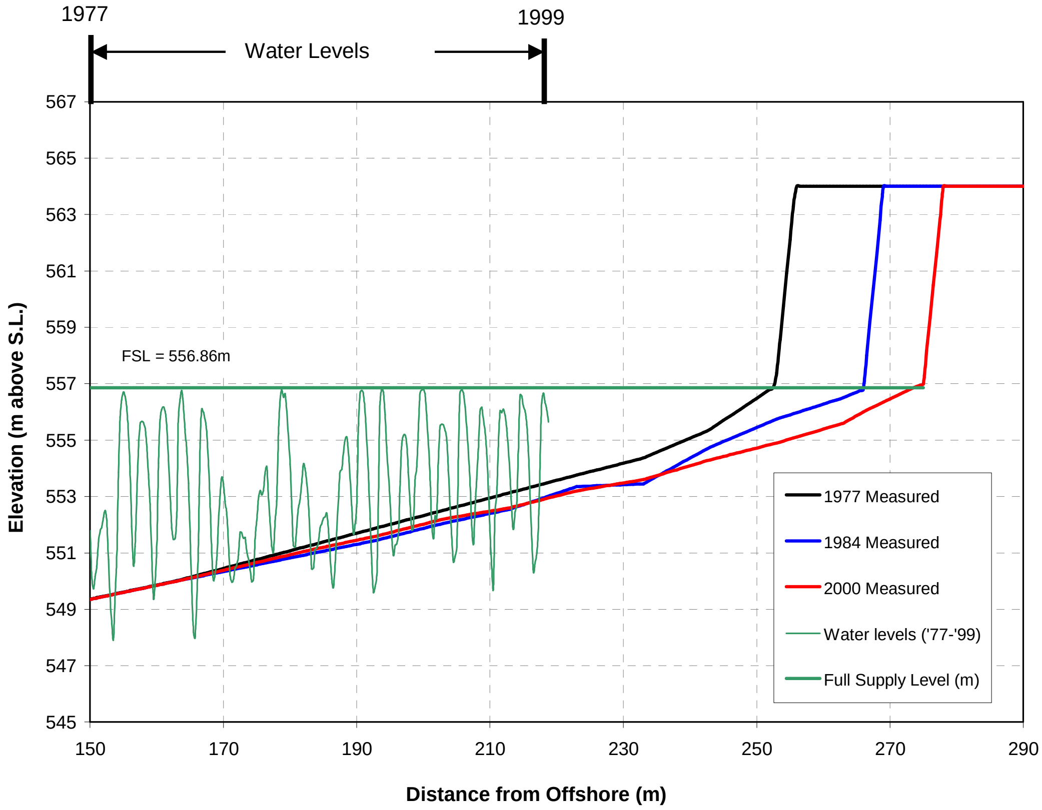


Figure 3.7 Measured Profile Data and Historical Water Level (1977 to 1999), Elbow Harbour

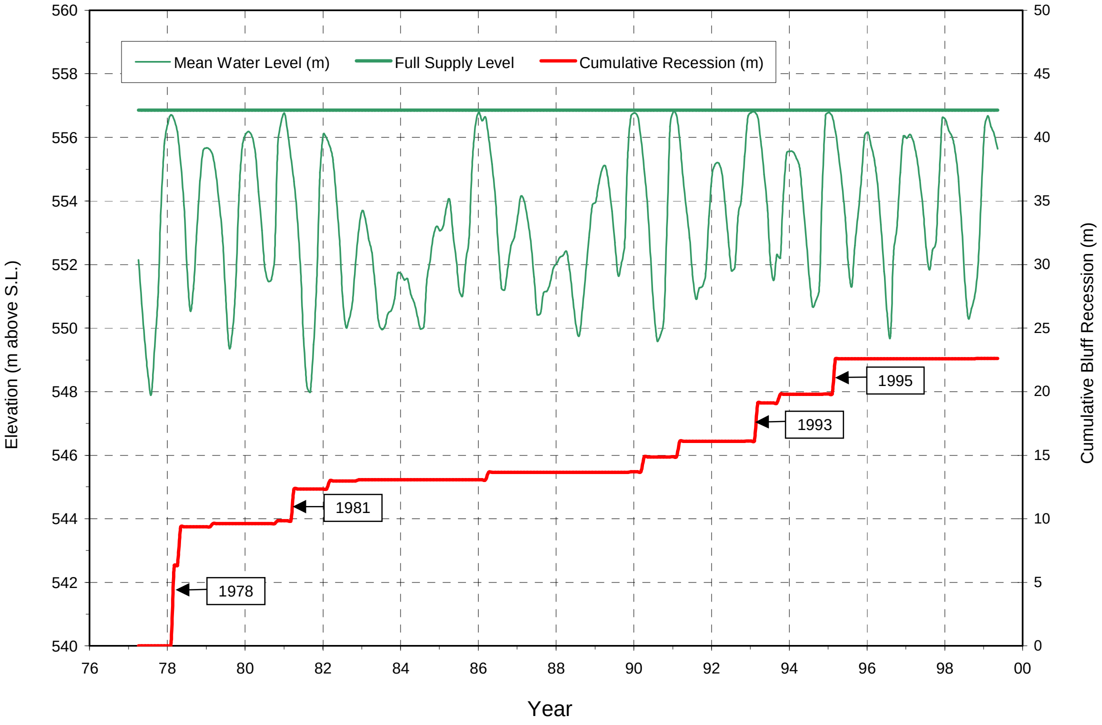


Figure 3.8 Cumulative Bluff Recession Estimates from the COSMOS Model (1977 to 1999), Elbow Harbour

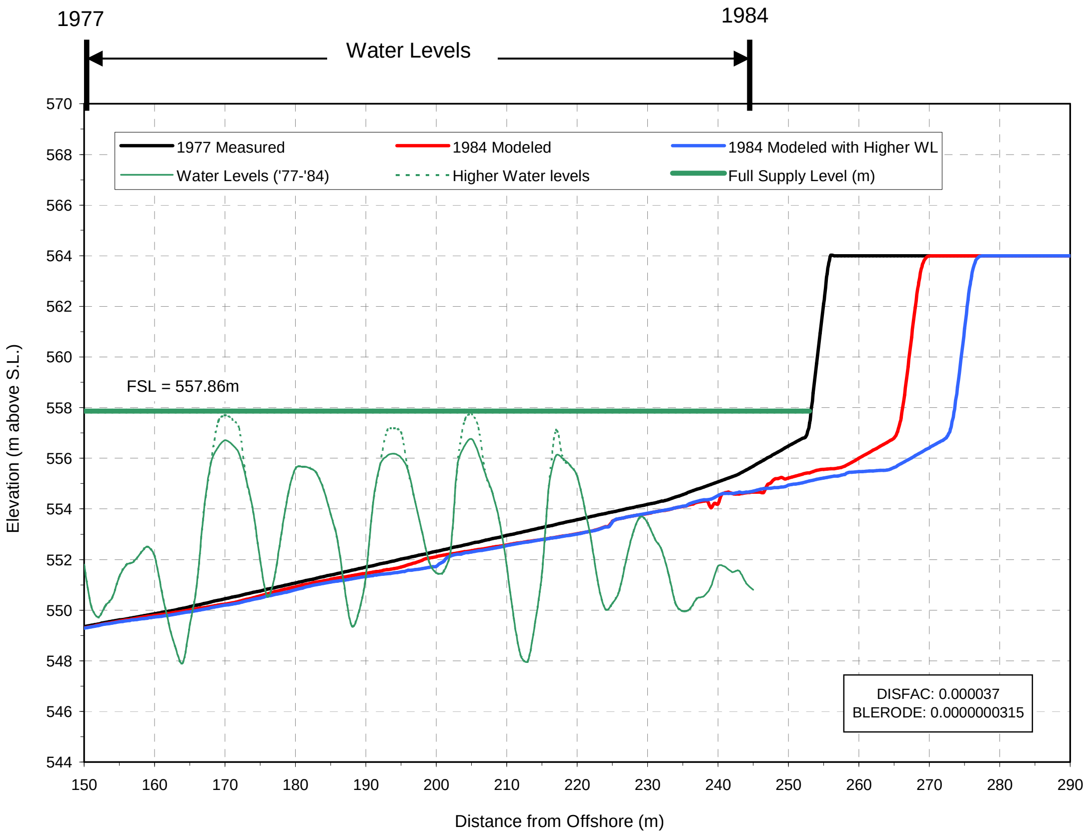


Figure 3.9 Predicted Bluff Recession with a 1 m Increase in the Full Supply Level, Elbow Harbour

The key relevant findings from this technical investigation for Lake Winnipeg include:

- A physics-based deterministic erosion model was successfully calibrated and verified for a prairie reservoir with fluctuating water levels.
- For reservoirs or regulated lakes, the majority of the bank or bluff erosion is attributed to severe storm events during high lake level periods.
- When severe storms correspond to lake level periods above the full supply level or upper limits of the operating range, the corresponding erosion rate will significantly exceed the natural long-term background rate. This is consistent with the measured results from the October 2010 weather bomb on Lake Winnipeg (Baird, 2014).

3.3 IJC Lake Ontario Water Level Regulation Study (2006)

Lake Ontario regulation began in 1960 with the construction and operation of the Moses-Saunders Power Dam in Cornwall, Ontario. After more than 40 years of operation with the initial regulation plan, the International Joint Commission (IJC) completed an investigation to optimize benefits for all stakeholders, including commercial shipping, hydro electric power generation, recreational boating, ecosystems, and riparian land owners. The erosion and flooding investigation is summarized in a report for the detailed study sites (Baird, 2006).

The monthly mean water levels on Lake Ontario, from 1920 to the early 2000s are presented in Figure 3.10. Prior to 1960, water levels fluctuated naturally due to variability in key components of the water balance, including inflow and outflow rates, precipitation and evaporation. The fluctuations in the monthly mean were approximately 2 m during the pre-regulation era. For the post-regulation era, the operational procedures for the dam have focused on keeping Lake Ontario water levels within a narrower 1.2 metre range, between 74.2 m to 75.4 m. With the exception of a few years of very high supply conditions in the mid- 1970s and early 1990s, the water levels have been constrained within this artificial range. These post-regulation changes in the hydrograph on Lake Ontario are similar to the post-regulation changes in the hydrograph on Lake Winnipeg, which commenced in 1976 (refer to the plot in Figure 2.11).

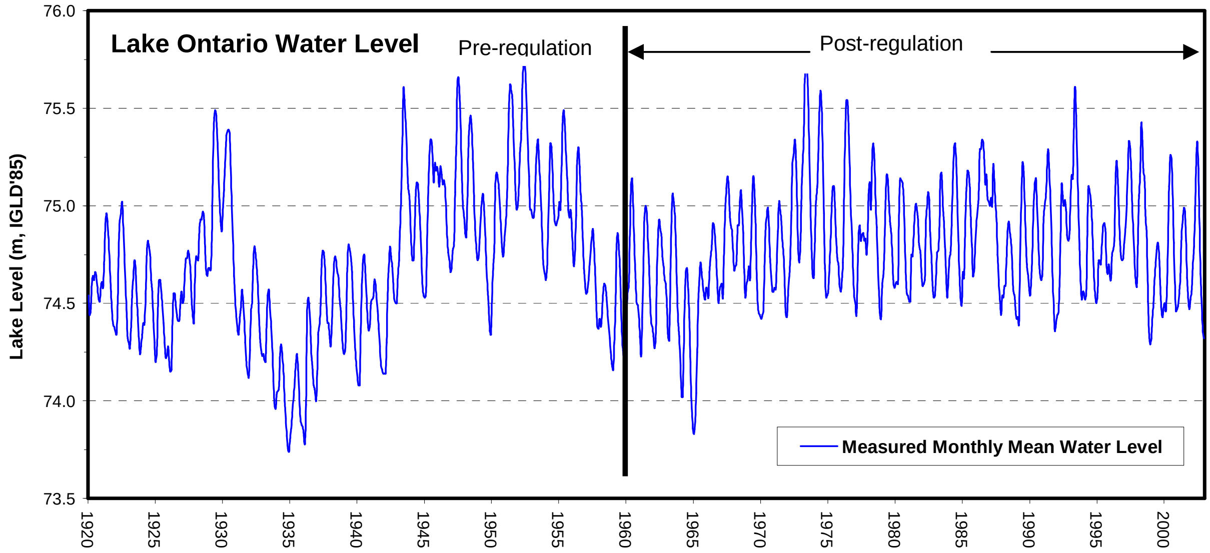


Figure 3.10 Lake Ontario Water Levels from 1920 to 2000 (pre- and post-regulation)

Study Site 8 is located on the south shore of Lake Ontario, in Wayne County, New York. Refer to Figure 3.11 for a plan view map of the site and Figure 3.12 for an oblique photograph of the eroding bluffs. Given the very narrow beach conditions at the site, bluff erosion is very sensitive to periods of high lake levels. The COSMOS numerical model was utilized to investigate the rate of anticipated erosion for a series of alternative regulation plans and climate scenarios using the historical net basin supplies from 1960 to 2000. Figure 3.13 provides a time series plot for the following key hydrographs:

- 1958DD with Historic (red): This is the actual historical water levels from 1960 to 2000 based on regulation plan 1958D with deviations.
- 1958D with Historic (blue): Hypothetical water levels (simulated with a routing model) from 1960 to 2000 using the historical operation rules (1958D) without any deviations to address extremely high supplies; note the very high spikes in water levels in the mid-1970s and late 1980s.

- 1998 with Historic (green): Hydrograph associated with a new regulation plan under consideration (1999) produced very similar conditions to the actual plan and measured water levels.
- Pre-Project with Historic (pink): This is the hypothetical water level conditions on Lake Ontario if the hydro electric dam wasn`t constructed and the water levels were still fluctuating naturally.
- Horizontal Lines for 74.2 and 75.4 are the lower and upper targets for the operating range.

The erosion estimates from the COSMOS model are plotted in Figure 3.14 for the four hydrographs plotted in Figure 3.13 plus three Climate Change scenarios which feature lower water levels. The largest amount of horizontal bluff recession was associated with the Pre-Project hydrograph (pink line in Figure 3.13). The second highest rate of bluff retreat was for 1958D without deviations, followed by 1958D with deviations (the actual plan).

The cumulative bluff recession from 1960 to 2000 for the same model simulations is plotted in Figure 3.15. The amount of estimated bluff recession for the Pre-Project hydrograph (the "what if" scenario had the dam not been constructed) is almost twice as great as the actual amount of recession.

The key findings relevant for the Lake Winnipeg regulation review include:

- The COSMOS model was successfully applied at Site 8 to investigate the impacts of various alternative regulation plans under consideration by the IJC and compare the results to the actual post-regulation conditions from 1960 to 2000 and the hypothetical conditions if the dam wasn't constructed.
- The regulation plan 1958D with deviations reduced the natural range of Lake Ontario from approximately 2.0 to 1.2 metres. This reduction in the range of lake levels in turn reduced the long-term erosion rates on Lake Ontario by approximately 50%.
- The functionality demonstrated at Site 8 was encapsulated into a lakewide tool, the Flood and Erosion Prediction System, which simulated shoreline erosion, flooding hazards and shoreline protection maintenance with automated tools for 22,000 individual property parcels. This lakewide assessment, including economic damage calculations, provided a comprehensive evaluation of regulation plan impacts on riparian interests.

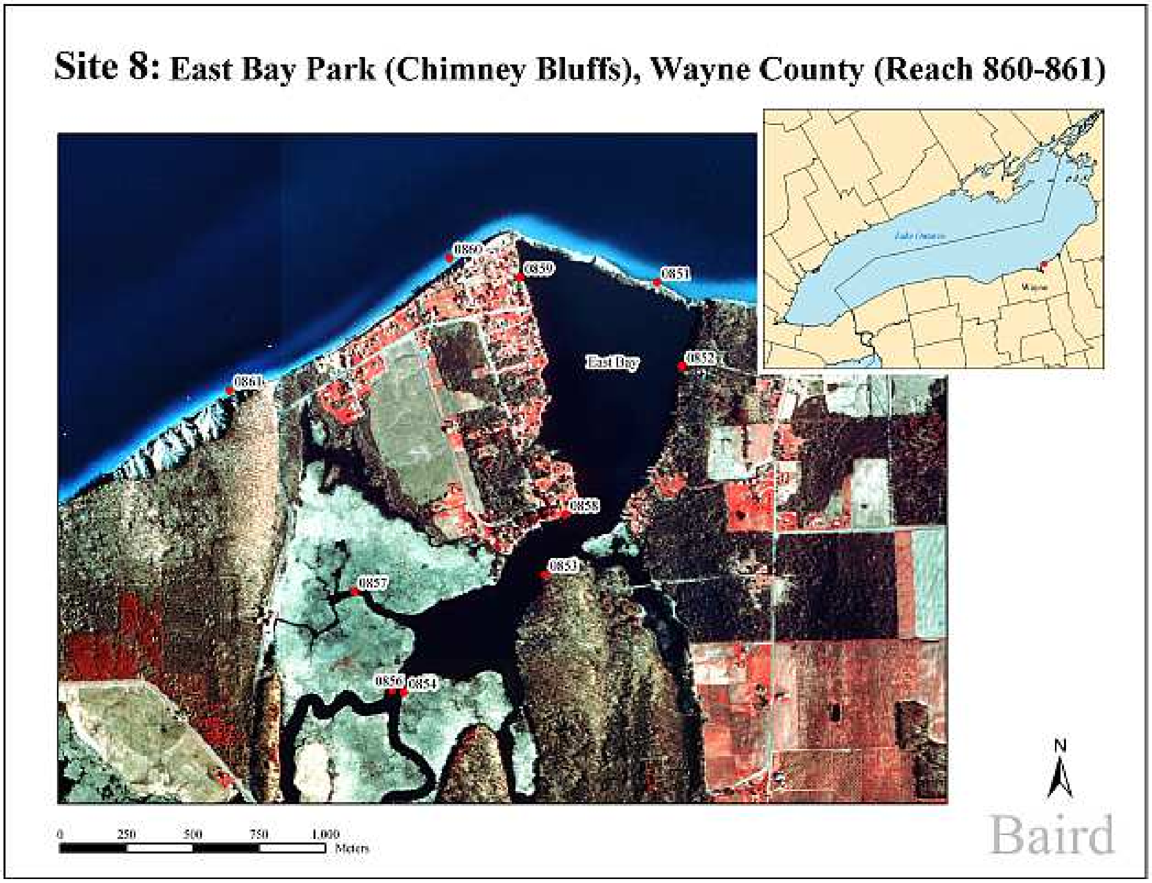


Figure 3.11 Study Site 8 Chimney Bluffs, Wayne County, New York

Figure 3.12 Oblique Photograph of Eroding Bluffs at Site 8, Wayne County, New York

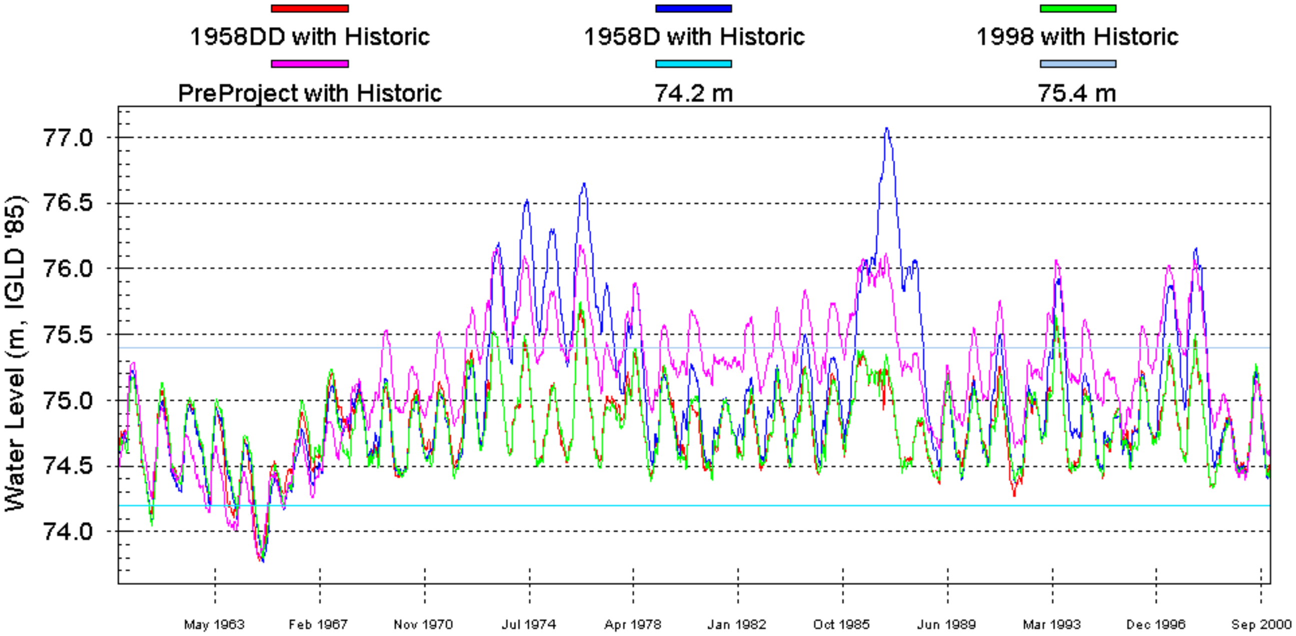


Figure 3.13 Four Water Level Hydrographs used for Erosion Modeling with COSMOS, plus Upper and Lower Target Operation Range (75.4 and 74.2 m)

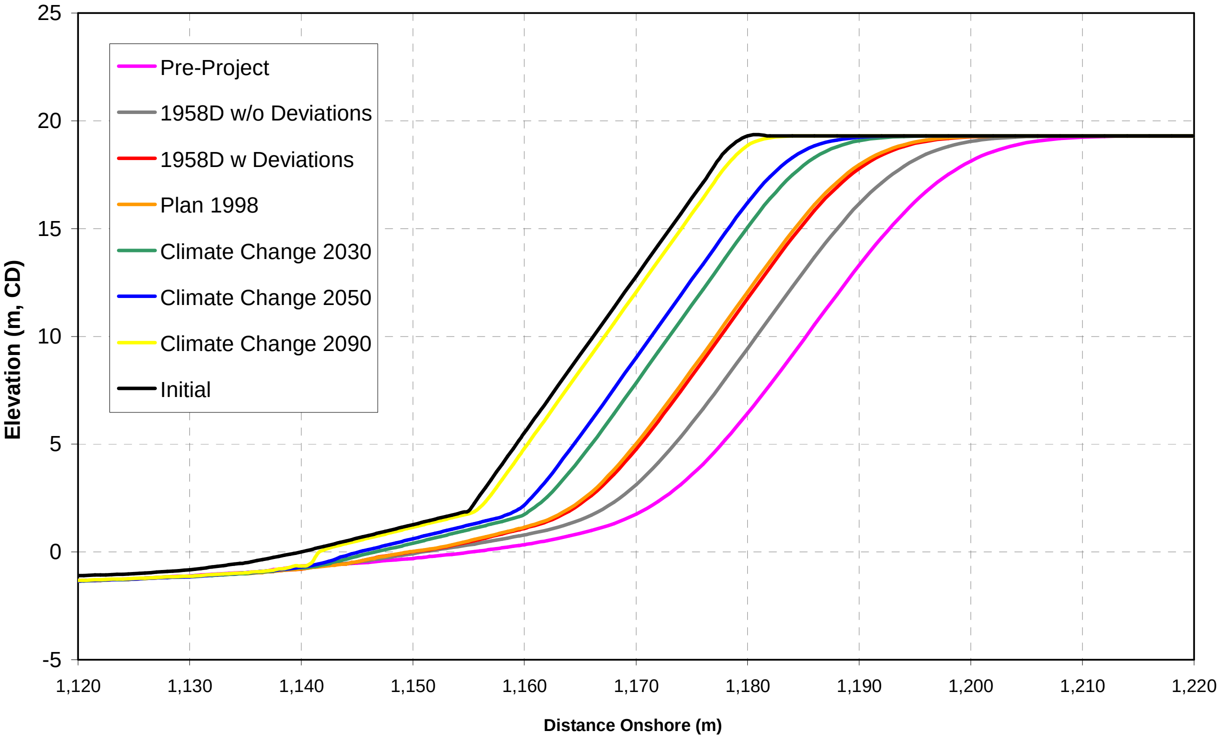


Figure 3.14 Erosion Estimates from the COSMOS Model Presented in Cross-section View. Regulation Plans Listed in Legend from Greatest to Least Recession

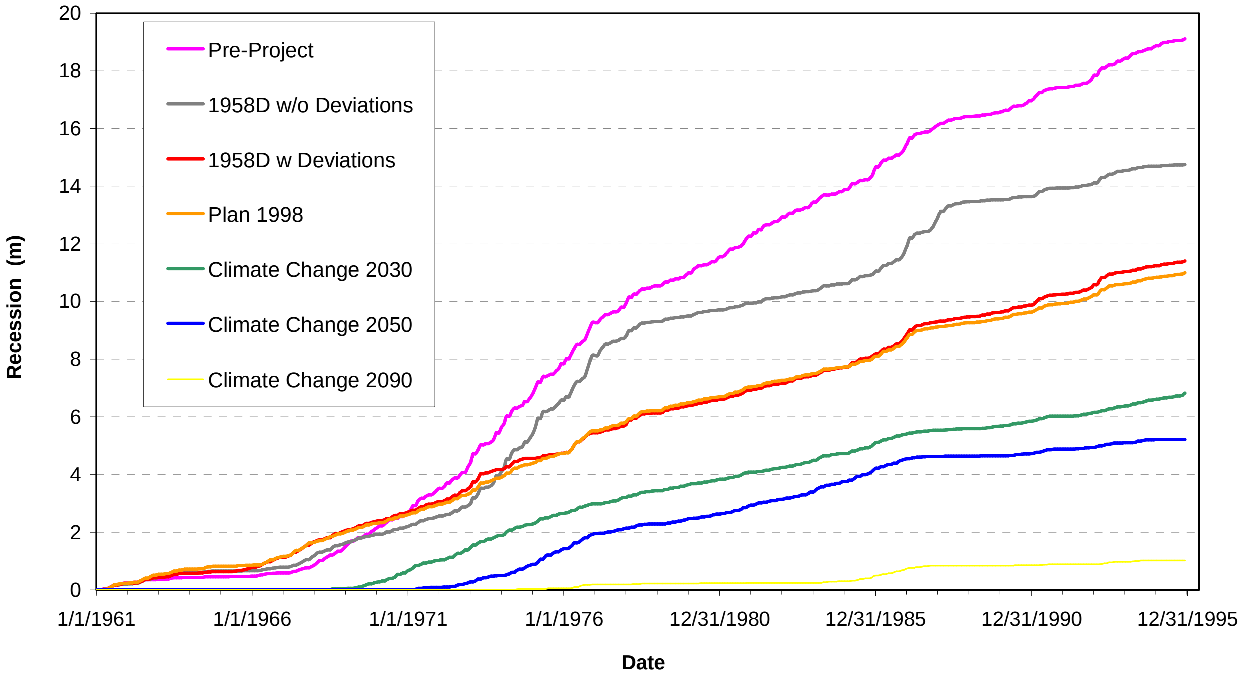


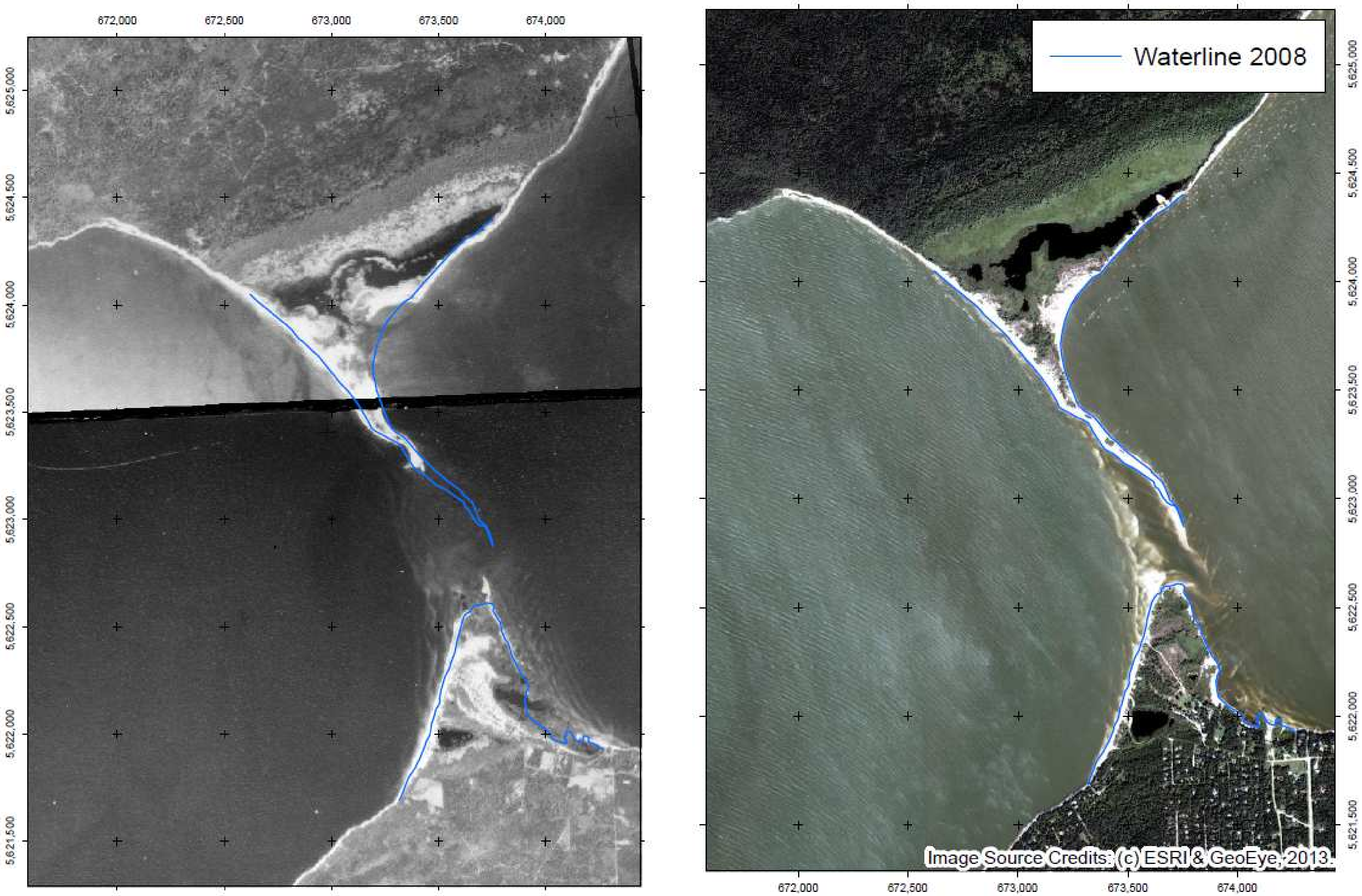
Figure 3.15 Estimates of Cumulative Bluff Recession from the COSMOS Model

3.4 Water Level Regulation Impacts on Accretion Processes

Quantifying the impacts of water level management on sandy shoreline evolution including erosion, rates of sediment transport, and accretion (the deposition of sediment) is more complicated than estimating impacts for cohesive shorelines. For example, the physical processes that influence accretion occur at large scales, are two-dimensional and in many cases three-dimensional in nature, and are often impacted by feedback loops that vary in space and time. Therefore, a single numerical model such as COSMOS, is not capable of simulating sandy shoreline evolution for different water level management scenarios.

Given the reduction in the historical range of water levels on Lake Winnipeg for the post-regulation era, one possible impact is increased stability of sandy geomorphic features, such as beaches and sand spits on Lake Winnipeg. For example, Baird`s (2014) technical studies at Victoria Beach to develop the Shoreline Management Plan documented significant deposition at the southern tip of Elk Island and the northern portion of the Victoria Beach community based on a comparison of the 1948 and 2008 aerial photographs (refer to Figure 3.16). One explanation for this depositional trend is the artificial compression of the historical water level range on Lake Winnipeg. For example, during prolonged high water level periods prior to regulation (e.g., 1965 to 1975), large storm events would have inundated, eroded, and generally destabilized these sandy depositional features. With a reduced range of water levels for the post-regulation era and the elimination of prolonged periods of high lake levels, there is now increased stability of the sand spit feature and thus a strong consistent depositional trend.

This is just one example of sandy shore evolution on Lake Winnipeg that appears to be influenced by water level regulation. A comprehensive technical study of shoreline evolution at a variety of locations around the lake for the pre- and post-regulation era is required to further evaluate possible linkages between water level regulation and sandy shore evolution.



Estimated Lake Level:
217.9 m or 714.7 ft
1948

Estimated Lake Level:
217.9 m or 714.7 ft
2008

Figure 3.16 Comparison of Sand Spit at Southern Shore of Elk Island in 1948 (pre-regulation) and 2008 (post-regulation)

4.0 GUIDANCE FOR FUTURE TECHNICAL STUDIES

This section provides recommendations for future technical studies to quantify the influence of Lake Winnipeg regulation on erosion and accretion processes, along with guidance for government and riparian land owners to mitigate coastal hazards and adapt to fluctuating water levels.

4.1 Water Level Regulation Impacts on the Shoreline

This report provides a brief overview of technical investigations completed to quantify the role of fluctuating water levels on shoreline evolution, including those fluctuations due to water level regulation. While general conclusions can be drawn on the relevance of these previous technical studies for Lake Winnipeg, a definitive answer on whether water level regulation from 1976 to present has increased or decreased erosion rates will require a detailed technical investigation. The first component involves measuring rates of shoreline change from 1976 to present using historical beach profile data, land surveys, and aerial photographs. Numerical modeling tools similar to those introduced in this report are then required to simulate the pre-regulation (1915 to 1975) erosion rate at various locations around the lake based on the water level hydrograph in Figure 2.11. In addition, the modeling tools must also simulate the hypothetical erosion that would have occurred from 1976 to present based on the scenario of no regulation structure at Jenpeg (as presented in Figure 2.12). With such an investigation, two important questions could be answered: 1) How do the pre- and post-regulation erosion rates compare? and 2) How does the post-regulation erosion rate compare to the hypothetical scenario of no regulation structures from 1976 to present?

4.2 Influence of Climate Variability on Lake Winnipeg

The climate that influences the Lake Winnipeg basin is highly variable, with year to year precipitation trends having the greatest impact on river inflow and ultimately lake levels (McCullough, 2015). In addition to yearly to decadal trends in precipitation, severe storms such as the October 2010 weather bomb, can generate large storm surges and wave heights in the southern basin of Lake Winnipeg leading to damaging erosion events. The impacts of these storms are magnified if the lake level is near or above the upper limit of the operating range (715 feet).

The latest Intergovernmental Panel on Climate Change report projects even greater variability in our weather in the coming decades due to climate change (IPCC, 2014) and McCullough (2015) predicts the trend of increasing inflow to Lake Winnipeg will continue in the future. These anticipated future conditions could lead to higher lake levels unless the rules for regulation are changed or the Jenpeg outflow structure is modified to accommodate higher discharge rates.

Understanding the potential implications of climate variability for the management of the Lake Winnipeg shoreline is a two part process. First, defensible estimates of key physical processes must be generated for future climate change scenarios, such as river inflow volumes, lake level extremes, changes in ice cover, and modifications to the wave climate on Lake Winnipeg. To date, much of the climate change research has focused on potential impacts to precipitation totals, while less attention has been spent on assessing the impacts to ice cover and regional wind fields such as those generating waves on Lake Winnipeg. In a recent technical investigation for the Department of Fisheries and Oceans, Baird (2013) compared wind fields from the Canadian Regional Climate Model for the period 1971 to 2000 to actual wind fields generated from climate stations around Lake Ontario, and found the wind fields in the regional climate model were not suitable for predicting wave conditions over the lake. Without robust regional wind fields for future climate change scenarios, it is not possible to comment on the frequency and intensity of future storms on inland lakes, and thus there remains considerable uncertainty into this important driving force for shoreline change projections in the future.

Once defensible future projections for key physical conditions and processes are established, a technical investigation is required to simulate future erosion and accretion rates, and flooding hazards with process based numerical modeling tools. Finally, these anticipated future changes should be compared to historical conditions to evaluate potential state changes, vulnerable ecosystems, implications for shoreline hazards and infrastructure at risk (now or in the future).

4.3 Strengthening Governance and Management

The governance of Manitoba's shorelines by senior levels of government and local municipalities was recently evaluated by Baird (2014) for the Rural Municipality of Victoria Beach (RMVB). Compared with other Provincial and State jurisdictions with management responsibilities for the large freshwater lakes of North America, the Province of Manitoba has limited policies and regulations to manage shoreline hazards and guide new development. Conversely, municipalities have the majority of the responsibility to evaluate new development proposals, growth plans, and manage existing hazards. In other jurisdictions the Provincial and State agencies develop legislation, policies and programmes to regulate shoreline development, identify and map shoreline hazards, and protect natural resources.

With the absence of senior government policies to guide important management decisions along their shoreline, the RMVB recently developed their own Shoreline Management Plan (Baird, 2014) that quantifies hazards throughout the community and selected a management approach for the various shoreline reaches based on the risks, usage of local beaches, objectives for growth in their Development Plan and extensive community consultation. The SMP will ultimately be integrated into the Development Plan and have the force of the RMVB Council.

Moving forward, the RMVB model is one option that could be adopted elsewhere to map coastal hazards and develop comprehensive solutions to manage shorelines in Manitoba. An alternative or complimentary approach would be enhancing the policy and legislative framework of the Provincial government. The ultimate path forward should be determined by government in consultation with the stakeholders throughout the Province of Manitoba.

4.4 Improving Resilience of Shoreline Communities

A resilient shoreline community has the capacity to sustain disturbances, such as erosion and flooding events during severe storms, and continue to provide the social, economic, and ecological services its citizens rely on for a healthy and prosperous life. Resilience planning has become a mainstream principle in the last decade to address shoreline hazards and vulnerabilities. As resilience increases, risks to our social, economic, and ecological systems attributed to shoreline hazards, decrease. Activities that would increase the resilience of a shoreline community to coastal hazards include enhancing shoreline development setbacks, artificially nourishing shorelines to address shoreline erosion (rather than shore parallel structures), and protecting shoreline ecosystem habitat and function.

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