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REVIEW OF LITERATURE

CONCERNING EROSION AND ACCRETION
OF THE CANADIAN SHORELINE
OF THE GREAT LAKES

GARY L. BOYD



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REVIEW OF LITERATURE CONCERNING EROSION
AND ACCRETION OF THE CANADIAN SHORELINE
OF THE GREAT LAKES

by

Gary Lee Boyd

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Ocean and Aquatic Sciences
Central Region
P. O. Box 5050
Burlington, Ontario
L7R 4A6

ABSTRACT

Literature concerning the Canadian shoreline of the Great Lakes is reviewed, especially as related to erosion and deposition, from the mid-eighteenth century to the present. A discussion of the major studies is presented, including the most recent (unpublished) Canada-Ontario Erosion Monitoring Programme, while other relevant studies are noted or reviewed. These are presented chronologically in tandem with an interpretation of the reasons for instigating the research and the historical shift in focus for these studies.

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INTRODUCTION

The consequences of shore erosion have been and continue to be a major problem on the Great Lakes shoreline. A great deal of heartache and human effort has been expended combatting this problem, not to mention the millions of dollars property damage that has occurred (Environment Canada/Ontario, 1975), and possibly billions of dollars worth of shore protection that has been installed in the past century. Similarly, hundreds of studies have examined some aspect of shore erosion or coastal zone management. In fact, a recent chronologic bibliography notes an increase in published studies at a geometric rate since the 1940-49 period (Charlesworth et al, 1975).

This paper reviews the *raison d'etre* for many of the studies concerning shore erosion, the data gathering and analytical procedures used in major studies, and includes a comparison with the recent Canada-Ontario Great Lakes Shore Erosion Monitoring Programme. This ongoing Erosion Monitoring Programme commenced in the early 1970's and exists as one of the major studies of erosion on the Canadian Great Lakes shoreline.

THE EARLY YEARS

Much of the early work was directed at identifying the glacial history of North America and the Great Lakes Basin. The seeds of the research were planted by C. Whittlesey (1838) followed by J.S. Newberry (1874a, 1874b), J.W. Spencer (1882, 1890, 1891a, 1891b, 1894) and F. Leverett (1892, 1899, 1902). They outlined the geology and quaternary geomorphology for the Great Lakes region which, although later modified, has provided a basis for understanding the history of the basin.

Other studies in the 18th and 19th century were aimed at collecting baseline data, almost in an exploratory manner. The Great Lakes were a new region and data gathering involved examination of this new frontier. Thus most of the studies involved charting of the lakes and boundaries (Chewitt 1793, 1790s; Bouchette, 1790, 1792; Smith, 1795; Anon, 1817; Dumfrie, 1823; Bayfield, 1828), investigations of lake levels and oscillations due to barometric pressure and winds, currents and temperature (U.S. Bureau Engineers 1849, 1853; Jackson, 1853; Whittlesey, 1860, 1875; Anon, 1869; Abbe 1898a, 1898b) and lake bottom analysis. By the mid to late 1800s the number of studies of harbours and other man-made aspects had increased (Harris, 1839; Munro, 1869; Page, 1869; Canada DPW, 1879; Field, 1906). This is not surprising since these types of studies directly relate to the use of the lakes as a transportation corridor.

Although much of the information collected during this period is now of some use as baseline data and supplementary information, little of it is directly related to shoreline erosion. However, there are some examples where the data has been useful. These include harbour charts which help reconstruct a history of the effects and siltation of harbour developments (Whillans, 1977); early records and diaries that describe features such as wooded slopes that are now bare (Atkins, 1978); changing outlet patterns of rivers such as Big Creek at Long Point (Wood, 1951); and breaching of spits and barrier beaches at Long Point, Point Pelee (Battin, 1975; Whillans, 1977) and Rondeau (Mann, 1977).

Other work of value generally consisted of cadastral surveys and land surveys used to establish municipal and township boundaries. If repeatable, these surveys (Burwell, 1816; Owen, 1855; Tremaine, 1856; Walling, 1877) can be used to establish erosion rates but many times they do not indicate if the measurements were taken to the strandline, water's edge or top of the bluff (Hadfield, 1967; Bradford, 1968).

THE TURN OF THE CENTURY

In the first quarter of the 20th century, many of the preceding studies were continued but in a more sophisticated manner. There were reports about tides, water levels, wind, storms and waves, ice, and hydrology, streamflow and flooding. The number of investigations concerning breakwaters and harbours increased as man attempted to increase his impact on the natural features and processes (Charlesworth et al, 1975).

The first major study of the Canadian Great Lakes shoreline was a report to the Geological Society, "Shoreline Studies on Lakes Ontario and Erie" by A.W.G. Wilson (1907). It was a description of the general geological topography and glacial geomorphology with a comparison of the shores of both Lakes Ontario and Erie and with the glacial Lake Iroquois shoreline. Although it concentrated on the depositional spits and bars of the lakes, it included a concept of process by discussing factors such as sieches, currents, water levels, longshore sediment movement, longshore current, storms, and ice. Since it was a reconnaissance study by nature, it provided little quantitative information but does indicate that a sound understanding of Great Lakes processes existed as much as 70 years ago.

Interestingly, the old glacial Lake Iroquois shoreline received more attention than its modern Lake Ontario counterpart, probably due to its economic (sand and gravel) and academic value. As early as 1845 (Sir) Charles Lyell, an eminent geologist, examined the old Iroquois beaches in Ontario; in 1843 James Hall described the ridges in New York; and in 1861 (Sir) Sandford Fleming, an engineer, mapped the Toronto portion. In 1899 J.W. Spencer published "The Iroquois Beach: A Chapter in the Geological History of Lake Ontario" and in 1907 he published a report on "The Falls of Niagara" with his views on differential uplift and tilting of the beach. In 1904 Coleman presented a detailed account and more complete map but using rough maps and hand levels or aneroid barometers. As more topographic information became available and better access "made it desirable to cover the ground once more", (Coleman, 1936a, p.2) he published "Lake Iroquois" (1936a).

THE WAR YEARS

From the early 1900's until after the 2nd World War, there was a great number of reports categorized as biological, geological or geomorphological and physical (that is, physical factors such as lake levels, lake level oscillations,

weather, and others) (Stirrett, 1968; Jeremin et al, 1974; Charlesworth et al, 1975). Yet there was a paucity of reports concerning the present shorelines. Other than studies of special areas such as the spits of Pelee (Kindle, 1933) Long Point and Toronto (Coleman, 1932) and of the Scarborough Bluffs, only one report stands out, but it is certainly most noteworthy. In 1936, A.P. Coleman published "Geology of the North Shore of Lake Ontario" (1936b), probably the first report containing quantitative data that extended over a number of physiographic regions for the shoreline of the lake. Going from Niagara to Brighton he described the geology and geomorphology of the shoreline as well as listing erosion rates for various locations gleaned from survey records and personal communications. This could be considered a second generation report, A.W. Wilson's in 1907 being the first, which brought together about thirty years of the author's investigations and those of others into a comprehensive report about the entire shore of one lake.

POST WORLD WAR 2

The post-WW2 stage marks the beginning of widespread concern for the shoreline. Due to earlier and more extensive development along the shoreline, the concern for the impacts of shore erosion on man's belongings surfaced in the United States, especially the ocean states but also on the Great Lakes. It follows then that extensive research on the United States shorelines preceded that of Canadian shores, so that in the 1940s there was an outpouring of reports from the U.S. Corps of Engineers (U.S. Corps Engineers 1947), and those of the Public Works agencies for the Great Lakes states (Sowers, 1949). Many of these studies reported not only the physical factors of shore erosion but also focussed on the damage aspects.

In Canada, the first public recognition of the problem surfaced in 1945 (Ontario Select Committee on Lake Levels, 1952) with the formation of the Niagara-Toronto Lakeshore Protection Association (later the Ontario Shore and Beach Preservation Association) which marshalled significant political pressure to have Ontario's Ministry of Planning and Development initiate a report on lakeshore erosion, to be headed by G.B. Langford. He completed a report for the shores of Lake Ontario from Niagara to Cobourg in 1949 (revised 1952) and, in 1951, H.A.H. Wood reported on the lakeshore erosion from Long Point to Point aux Pins, Lake Erie. Both reports indicated geomorphic process and rates of erosion. Langford discussed the geological character of the shoreline and indicated some rates of

erosion gleaned from survey records and personal communications; the lake water level changes and its effects; currents; and delved into possible protective measures (structural and non-structural). Wood, in a tightly knit thesis, presented a physiographic description, discussion of the factors of erosion, and worked out some rates of erosion. This was done by field inspection at about 50 locations to gather information on beach width, bluff slope and to collect soil samples. Office work involved the study of aerial photographs. These photos were used to establish the shoreline and then compared to a reconstruction of the early 19th century shoreline established from surveys done at that time, and thereby calculate rates of erosion.

In 1952 the Select Committee on Lake Levels of the Great Lakes reported to the Ontario Legislature about lakeshore erosion. Based on the reports by Langford and Wood, as well as site visits by committee members, it examined erosion on all the Great Lakes (albeit Lakes Superior and Huron only briefly due to the predominantly rocky nature and unavailability of data respectively). However, it is significant that this committee reported not only on the physical rates and processes but also focussed on erosion damage, protection, and policy. It represents a marked change in theme from the study of erosion of the shoreline in the early years to the study of damages due to erosion and investigation of structural and non-structural mitigating measures.

While this was the major thrust of shoreline research in Canada, a great deal of the work being done in the United States carried over into the 1950s and 1960s. Detailed examination of the geology, sedimentology, hydrology, meteorology and limnology of the lakes continued, notably, as related to shore erosion: engineering analysis of bluff erosion by Bishop (1955), Chieruzzi (1957), and Chieruzzi and Baker (1958); on bluff erosion and sedimentation by Pincus (1953, 1959); on structures and sedimentation (Hartley, 1960, 1964); on surges and sieches (Platzman, 1963); on shore protection (U.S. Corp of Engineers, 1966); and on the geology of the Great Lakes (Hough, 1958).

Of course, similar work was being done in Canada. It involved the physiography of Southern Ontario (Chapman & Putnam, 1951); geology and quaternary geomorphology (Dreimanis and Reavely, 1953; Dreimanis, 1958; Karrow, Clark and Terasmae, 1961); sedimentation studies (Lewis, 1966); the geomorphic processes (Zimmer, 1965) and stability of bluffs (Quigley and Tutt, 1968); studies of littoral processes (Le Mahaute and Brebner, 1961); and over the lake winds (Lemire, 1961; Richards and Phillips, 1970).

Certainly there were others who were interested in different aspects of the shoreline that were related to physiography, erosion, and accretion. One such theme was recreation and coastal zone management. For Lake Huron, Bradford (1968) submitted a thesis on recreational access and ownership from a geographical and legal perspective. For Lake Erie, port geography and harbours were studied by Woods (1955) and Bourne (1961), while Hill (1964) examined the physical features and recreational aspects of the northeast shore of Lake Erie. In addition, the Niagara Regional Development Council commissioned J.W. Jackson to report on land use and to provide an evaluation of recreation potential for their portion of Lake Erie. In an extensive review (1967) he outlined the historical and physiographic data, lake hydrology, the recreational situation as well as the legal and administrative aspects of the shore. Nevertheless, a study of local perception of erosion for mid-Lake Erie by Evans (1969) indicated a lack of knowledge and concern about shoreline erosion.

It is interesting that major government studies of shoreline damage and erosion were preceded by extreme lake levels on the Great Lakes. The high water levels in the late 1920s were followed by A.P. Coleman's (1936) review. Similarly, high lake levels in the 1943-1948 period preceded the major government inquiry in the early 1950s. A drop in levels in the mid-1950s may have cooled things down a bit but with the completion of the St. Lawrence Seaway in 1959 and a spot of high water in the early 1960s (but with severe lows in the mid-1960s), the hue and cry for lake level regulation increased. These fluctuating conditions again prompted a government response, this time a reference to the International Joint Commission requesting a study of further water level control. This Great Lakes Levels Study marks the beginning of many of the present government studies.

One aspect of this International Great Lakes Levels Study (1964-1970) was an extensive shoreline inventory, headed in Canada by the Department of Public Works. Each lake was examined by a separate task force which, with minor variations, collected similar data pertaining to the shoreline. Using existing topographic sheets as the onshore base maps, and hydrographic charts for the offshore base data, the shore features were mapped and updated by various field surveys. The precise length of shoreline was calculated, as was the length of shoreline for various physiographic shore types, such as beach, bluff, bluff with beach, and marsh. The hinterland land use information was updated as was the vegetative features of the shore. Field surveys were established to ascertain

onshore cross-sections and offshore profiles for selected locations and soil samples taken to be analyzed. Pertinent man-made features were identified, especially water intake and sewer outfall locations and engineering aspects of piers and harbours. In addition, survey records from local surveyors and land registry offices were searched for historical measurement locations and, where possible, these were remeasured to derive the current shoreline position. From this information rates of erosion were calculated. In this respect, the Lake Erie shore could be considered as a special case since a traverse survey of the shoreline in 1937 provided the task force with an excellent data base to calculate a 30-year erosion rate, and these rates were transcribed onto the appropriate shoreline strip maps.

All this data plus wave climate calculations, recreational boating surveys, property value assessments, and land use projections were used to develop the final product requested by the International Joint Commission. This product was a stage damage curve relating the monetary cost of various water levels with respect to shore properties. These estimates of losses concurrent with various water levels were used as an input for developing the optimum lake level regulation plan.

HERE COME THE SEVENTIES

Many historians point to the past as an indication of the future. In this case, the past included shore damage due to substantial shoreline development and high water levels in the early 1950s followed by the government Select Committee report previously mentioned. By the early 1970s further shore development had occurred, and water levels rose to set some new high water records similarly leading to extensive shore damage and government inquiry. Major storms in November, 1972 and March, 1973, which caused extensive flooding and erosion damage, piqued interest, led to cabinet submissions and was followed by a Federal/Provincial agreement to survey the nature and extent of these damages, subsequently called the Canada/Ontario Great Lakes Shore Damage Survey. In addition, a multi-agency federal task force was established in the spring of 1973 to assemble and assess the information available on erosion of the Canadian shoreline of the Great Lakes-St.Lawrence System.

The Canada Task Force on Available Shore Erosion Information on the Great Lakes-St.Lawrence System (1973) quickly assembled the available data but

found that a complete assessment of the problem required additional information. Part II of the report provided a detailed description of shore erosion by reviewing many of the studies and surveys associated with the topic and from them established a description of the shorelines and the associated flood and erosion damages, followed by a discussion of preventative measures. It, therefore, only summarized available information, adding little new information to the shoreline data base.

However, the Canada/Ontario Shore Damage Survey (Environment Canada/Ontario Ministry of Natural Resources, 1975) was established to supply new information concerning erosion and flooding damages. This survey was restricted to the erodible portion of the Great Lakes from Port Severn on Georgian Bay to Gananoque on Lake Ontario and reported on the damages occurring from November, 1972 to November, 1973. It included data pertaining to land use, land value, land ownership, shoreline physical characteristics, shore damage, existing shore protection in damaged areas and recession-accession rates for the shoreline.

In addition, black and white infra-red aerial photographs were taken in 1973 at a scale of 1:20,000 and were used for the Coastal Zone Atlas. This atlas was produced to cartographically display the information collected by the Shore Damage Survey, and to serve as a data base for future planning and management of the shoreland.

Shore damage values were collected by field parties which traversed the shoreline interviewing owners, sketching, photographing and calculating damages. The shore property inventory of riparian property (approximately 50,000 properties) was collected from Regional Assessment offices to ascertain property location, size, ownership, land use and land value. Erosion rates were established using three methods: firstly, photogrammetrically extracted rates based on comparison of aerial photography from 1952-1954 to those flown in 1973; secondly, historical rates based on land survey data since 1900; and thirdly, from recent ground survey sites measured annually from 1971 to 1973.

To date, the Shore Damage Survey was the most extensive evaluation of erosion and shore damage available on the Great Lakes. Of course pertinent smaller scale studies were initiated and are discussed below.

RECENT UNIVERSITY STUDIES

At the University of Western Ontario much of the work has centred on the high bluffs of Lake Erie. Since the establishment of their geography research site near Port Bruce in 1964, research has focused on factors of erosion such as mass wasting and gullying, the cyclic erosion instability relationships and stress analysis for deep-seated failures (Packer, 1969, 1971; Welch, 1972; Lo and Lee, 1973; Gelinas and Quigley, 1973; Quigley and Gelinas, 1976; Quigley et al, 1976).

At the University of Guelph, Kruetzwizer (1977) has examined the costs of shore management while geomorphological research on the pleistocene slopes and nearshore morphology for the Wasaga Beach and Georgian Bay areas continued (Martini, 1974, 1975; Martini and Hoffman, 1976; Davidson-Arnott et al, 1978; Davidson-Arnott and Pember, 1978; Ball, 1978). Similarly, at the University of Toronto analysis of nearshore change and sediment movement has been done (McGillivray, 1976; Greenwood and McGillivray, 1978) while examination of the pleistocene shorelines of Lake Algonquin were completed (Nakashima, 1974; Mittler, 1975).

At Queen's University research has been concentrated on applied and the fundamental aspects of coastal engineering and especially experimental laboratory work (Kamphuis, 1976) as well as nearshore and onshore beach processes (Peat, 1973; Bartlett, 1976; Smith, 1978; Belanger, 1976; Ernsting, 1976; Mitchell, 1976).

At the University of Windsor, coastal work has been done for Point Pelee (Dickie and Cape, 1974; Hudec, 1975; LaValle et al, 1979) while at Lakehead studies of onshore erosion and longshore bar and trough systems in bays (Mothersill, 1976; Phillips, 1978) as well as Lake Superior sedimentation rates (Mothersill, 1978) have been completed. Similarly, nearshore beach morphology for Lakes Ontario, Erie and Huron was studied at McMaster University (Gillie, 1974).

At the University of Waterloo, the resources management aspects of shoreline flooding and erosion have been investigated (Nelson et al, 1975; Batton, 1975; Day et al, 1977; Mann, 1978; Needham, 1976, 1977; Heffernan, 1978; Jessen, 1979) in addition to the physical aspects of erosion on Lake Ontario (Boyd, 1974; Hegler, 1974; Rutka, 1975).

RECENT GOVERNMENT STUDIES

Of course, the government is the major supplier of primary data and a great number of reports. The primary data available includes historical information and charts from the Public Archives of Canada, the Provincial Archives and Surveyor General's office; air photos from the National Air Photo Library and the Provincial Archives and Ministry of Natural Resources; Great Lakes water levels supplied through the Marine Environment Data Service and the Canadian Hydrographic Service; meteorological information from the Atmospheric Environment Service; lake bathymetry via the Canada Hydrographic Service Charts; as well as harbour dredging data and coastal engineering aspects of harbour structures from the Department of Public Works.

Many other government studies have a dual role of providing primary data as well as analytical results. The Hydraulics Research Division at the National Water Resources Institute undertook a programme to document the nearshore sediments of the Great Lakes (Rukavina 1969, 1970, 1976; Rukavina and St.Jacques, 1971; St.Jacques and Rukavina, 1972, 1973, 1976) and a time lapse camera study of nearshore sediment transport (Rukavina, 1978). This Division also studied the geotechnical aspects of high bluff erosion near Port Burwell (Zeman, 1976, 1978); wave energy, longshore sediment transport and harbour model studies (Skafel, 1973, 1975a, 1975b, 1977; Skafel et al, 1978); as well as shore erosion studies for western Lake Erie and Point Pelee, western Lake Ontario and littoral drift investigations (Coakley, 1972, 1976, 1977, 1978; Coakley and Cho, 1972, 1973; Coakley et al, 1973; Coakley and Nelson, 1974; Coakley and Boyd, 1979).

The Research and Development Division, Shore Properties Studies Section, of Ocean and Aquatic Sciences, Central Region is primarily interested in shore problems and is charged with monitoring shoreline erosion and accretion. In addition to the joint Canada-Ontario Shore Damage Survey Technical Report (1975), Coastal Zone Atlas (1975), and 100-year Flood and Erosion Prone Area Maps (1978), this Division has reported on methods for recording shoreline change (Haras et al, 1976; Haras, 1978; Boyd, 1978a), shore processes at specific locations (Shaw, 1978; Boyd, 1978b; Bukata et al, 1975), storm surges (Freeman et al, 1972; Boyd, 1976), and shore management aspects (Shaw et al, 1978) of the Great Lakes. The estuaries of James Bay have also been examined (Haras et al, 1978).

Occasionally, certain government reports, not directly aimed at shoreline phenomenon, do relate to the subject. These would include geological surveys for instance (Feenstra, 1972; Cooper, 1972; Burwasser and Boyd, 1974) or special studies like Owens' (1979) "Coastal Environments and the Cleanup of Oil Spills" which focussed on contingency planning for oil spills yet classified and discussed the physical aspects of the Great Lakes shoreline. Other contracted reports such as Acres' (1976) shoreline vegetation study, Conservation Authorities reports, or pre-project studies for major hydro, industrial, or recreational sites also deal with specific areas of concern.

THE CANADA-ONTARIO GREAT LAKES EROSION MONITORING SURVEY

Most of the studies reviewed so far were short term or specific to a certain locality. The Erosion Monitoring Programme is a long-term study encompassing the entire erodible portion of the shores of the Great Lakes. In 1976 a federal-provincial agreement was signed initiating this five year study in response to a recommendation contained in the Shore Damage Survey Technical Report (1975) that the shoreline processes be monitored and the Great Lakes shoreline inventory be updated to ensure maintenance of current information on shoreline characteristics.

The preliminary data base for the Erosion Monitoring Programme is the Department of Public Works shoreline inventory prepared by Shore Property Task Forces for the International Joint Commission's Great Lakes Levels Study. It includes much of the information used to produce the strip maps showing shoreline characteristics, land use and erosion. Later, additional information was added and used for the Canada-Ontario Great Lakes Shore Damage Survey (1975). Therefore, most of the erosion study locations were established by 1973 and are to be monitored at least annually until 1981.

The procedure used involves about 162 sample locations which are intended to represent various homogeneous reaches of the entire shoreline. A repeatable onshore profile or cross-section is surveyed down the bluff or across the beach and is continued offshore by hydrographic methods. When two annual surveys at the same site are compared, the morphological changes and the volumetric erosion or accretion rates can be established. Soil samples were taken and analyzed as well as an inventory of site vegetation. To extrapolate between this ground-based information, a library of 1955 and 1973 high-altitude air photo-

graphy exists, as well as 35 mm photography taken at an oblique angle to the shoreline from about 150 m above ground. The timing of this photography was staggered in the early years but flown completely in 1977 while in 1978 a colour video system was used to tape the shoreline.

The use of photography in tandem with the erosion survey stations allows an analysis of the extent of the various geomorphic processes at work. Quantitative and qualitative information concerning single and multiple rotational slips, block falls, non-circular slides, mudflows, gullying and surface sloughing provides valuable insight concerning bluff processes. Knowledge of the different erosional and depositional traits in different localities and the extent of the linkages between these areas should effectively complement many of the reports previously mentioned in this review. It is planned that an interim report be prepared for April 1980 while the final report be published in 1981.

SUMMARY

A great deal of research has been done on the various aspects and factors of shore erosion and accretion. Originally, simple reconnaissance studies of the physical nature of the shoreline and studies reconstructing the glacial history of the Great Lakes basin dominated the research. As man began to increase his impact on the natural shoreline processes, he also increased the number of studies relating to the coastal engineering aspects of shore development. By the end of the Second World War widespread shoreline development was in place and, subsequently, extensive shore property damage occurred. This sparked large scale studies concerning the extent of damage and the alternatives available for mitigating flood and erosion damages, generally in response to extreme lake water level conditions. Recently there has been an increased number of studies relating to different facets of shoreline processes and problems. One of the more prominent studies is the Erosion Monitoring Programme which is a long term project covering the entire erodible portion of the Canadian shores of the Great Lakes.

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