Environment Canada

Water Science and Technology Directorate

Direction générale des sciences et de la technologie, eau

Environnement Canada

Levels in the Erie Basin: 4000 BP to present

By:
J.P. Coakley

NWRI Contribution # 99-228

99 - 228

MANAGEMENT PERSPECTIVE

Title: Levels in the Erie basin: 4000 BP to present

Authors and affiliations: J.P. Coakley
National Water Research Institute, 867 Lakeshore Road, Burlington, Ontario, L7R 4A6, Canada.

NWRI Publication Number: 99 -228
Citation: Abstract submitted to: Paleo Lake Levels — The Last Four-Thousand Years, a Workshop at Great Lakes Environmental Research Laboratory, Ann Arbor MI, April 13-14, 1999

EC Priority/Issue:

The DOE Great Lakes 2000 policy needs reliable information on climate change and global warming in the Great Lakes region. Long-term (prehistoric) climate trends are crucial in interpreting future lake levels in the Great Lakes

Current Status:

This abstract is intended to summarize and review postglacial trends in Lake Erie levels on the basis of literature reports and my own research.

Next steps:

The results of this review will be combined with collaborative work with Dr. C.F.M. Lewis of the Geological survey of Canada and Dr. Allan Crowe of AERB on the extreme stages in the Lake Erie basin to establish a long time-scale framework against which recent and future lake level changes due to climate change may be realistically assessed.

Paleo Lake Levels — The Last Four-Thousand Years
Workshop at Great Lakes Environmental Research Laboratory
Ann Arbor MI, April 13-14, 1999

Levels in the Erie basin: 4000 BP to present

by

John P. Coakley
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario
john.coakley@cciw.ca

INTRODUCTION

Lake levels in the Erie basin are driven by three major factors: postglacial isostatic rebound of the outlets, regional hydrological and climatic changes, and to a lesser extent, by neotectonic movements of the outlet. Because of a combination of factors, Lake Erie has undergone a complex history of rises, declines, and stability since the close of the glacial period some 12 000 years ago. From a low-level stage more than 50 m below present levels, the lake has risen at its present level under the influence of these three factors primarily.

Postglacial isostatic rebound. It has long been believed that Lake Erie rose from its minimum levels (Early Lake Erie) due to exponentially-decreasing process of crustal rebound of the outlet at the Niagara River caused by the unloading of the crust following deglaciation. Initially the rate of rebound of the outlet was probably much higher than at present, which led Coakley and Lewis (1985) to suggest this rebound, together with the presence of low post-Algonquin levels in the upper lakes and negligible upper lakes drainage though the Port Huron outlet, there could have existed a period where drainage within the Lake Erie watershed had no outlet except evaporation. Such a scenario, however, has not as yet been fully confirmed in the sediment record, but it has been cited by Tinkler et al. (1994) as an explanation for C-14 age sequences found in shells from the Niagara valley Whirlpool site. There are grounds to hypothesize that the postglacial uplift was not always as uniform as predicted on the basis of simple exponentially-decreasing rebound models utilizing a linear hinge-line concept (Hough 1966). It has been argued that geophysical complexities such as lower mantle rheology and the presence of a "peripheral bulge" in front of the ice margin might significantly affect subsequent recovery dynamics of the depressed crust (Pelletier, 1986). Nevertheless, it is assumed that with time, the effect of these rebound-related movements would decline and the other two factors would gradually assume a larger importance.

Hydrological and climatic factors. Evidence for hydrologically-induced changes in lake levels is based on studies of sediments collected in areas with sediment records that span the postglacial period such as below the three major cuspate forelands of the Erie basin (Coakley, 1985a, 1985b). Lewis and Anderson (1989) found evidence in cores from a deep borehole on Long Point that waters from glacial Lake Algonquin entered the Erie basin around 11 000 years Before Present (BP). Lewis and Anderson (1989) and Tinkler and Pengelly (1995) also concluded that waters from catastrophic releases from Glacial Lake Agassiz to the west of Lake Superior reached

Lake Erie and caused significant, but transient, peaks in Erie levels. The possibility of such a scenario was questioned by others (Rea et al. 1995), but the matter is still as subject of debate. The best documented episode of a singular excursion from the predicted exponential model is that now referred to as the Nipissing rise or "flood", initially proposed by Hough (1966) and expanded upon in Coakley and Lewis (1985) and others. Climatic changes were also postulated by Lewis and Anderson (1989) and by Lewis (this volume) as a reason for water level changes in the Erie and Huron basins. The evidence for climate induced changes in lake levels is most often found in stratigraphic profiles of concentrations of stable isotopes (carbon and oxygen) measured in carbonate and organic material in the lake sediments (Tevesz et al. 1998) and in pollen assemblages (Lewis and Anderson, 1989). However, as changes in isotopic composition can be related to both, it is difficult to separate the effects of climate alone from those related to large-scale changes in hydrology, e.g. Lake Agassiz inflows into the Great Lakes basin.

Evidence for the above dramatic lake level events is admittedly sparse in the Lake Erie basin. Because of the location of the outlet at the northeast end of the basin where uplift was greatest, the lake gradually back-filled from east to west, sequentially drowning and erasing all low-level shorelines or eventually leading to their burial below tens of metres of postglacial sediments. High level stages also are difficult to trace in the present landscape because intense shore erosion during the Holocene over most of the basin has obliterated such shorelines. Furthermore any high-level stands that occurred were apparently too brief to leave well entrenched shoreline features, and in areas where they might have survived, in the bedrock-dominated shores in the eastern parts of the basin, for example, they are ill-defined and controversial. For that reason, evidence for lake evolutionary changes was preserved only below the three major cuspate forelands of the Erie basin (Coakley, 1985a, 1985b) and in other isolated occurrences (Barnet et al. 1985; Barnett 1985).

Role of background neotectonic tilting of the Lake Erie basin. Finally, it is becoming clearer that tectonic factors unrelated to glacial rebound, referred to here as neotectonic factors play an increasing role in recent lake level trends. According to most exponential rebound models (excluding those that are based on complex factors such as a "peripheral bulge" responding in a manner opposite to the area of rebounding crust), substantial rebound of the Niagara outlet at Buffalo should have been reduced by now to virtually zero. Still, recent trends deduced from water-level gauge monitoring at various parts of the lake, and from regional geodetic surveys show that there is an ongoing tilting of the Erie basin. As a result, levels in the western end of the lake are rising at rates of up to 9 cm per century (Tushingham, 1992). Because of the known neotectonic history of this region (Sanford 1993; Mohajer 1993) there is no reason to doubt that these trends represent ongoing linear crustal adjustments that might predate postglacial rebound.

LAKE ERIE LEVELS 4000 YEARS BP TO PRESENT

The Nipissing event. When levels in the Huron basin had reached the level of the Port Huron sill, drainage was shifted from the North Bay (Mattawa - Ottawa River) outlet to southern outlets at Chicago and Port Huron-Sarnia. The timing for this event, which brought in an inflow on the order of 6000 $m^3.s^{-1}$ to the Erie basin, is estimated at between 5500 and 3700 BP (Lewis, 1969) . Archaeological data from campsites at Fort Erie found no artifacts dating older than 4000 years expected to have been enough to overwhelm the then-existing outlet channel in the Niagara River and to cause a sharp rise in Lake Erie levels. Barnett (1985) surveyed deltas in the eastern end of the lake near Port Rowan at 3-5 m above the lake. This, together with analyses by Sanford 1993 elevation controls exerted by various sills in the Niagara River valley, supports the 3 m figure proposed by Coakley and Lewis (1985) as the maximum for the Nipissing rise. Evidence of this event elsewhere in the basin is hard to confirm, but some support is provided by drowned river sections at Clear Creek, Ontario (Barnett et al. 1985), Old Woman Creek, and indirectly by eroded surfaces and models of foreland evolution by Coakley (1976) and Coakley et al. (1997). During 1999, plans are underway to drill a series of boreholes in the eastern end of the lake near the Wainfleet Bog. These new data should provide badly needed confirmation of a Nipissing rise. The duration of this event is open to debate, but it probably ended after a time-period of decades to centuries when the outlet channel was eroded and increased in area to accommodate the increased inflow or when level control shifted to another sill. Levels then fell to their former levels.

Post-Nipissing trends. From the above levels, the lake resumed its rise under the influence of the tectonic uplift component described above. Estimates of this rise is based on the assumption that the relative depth changes noted in the gauges since the mid 1800's are caused by a rise at the Buffalo end of the lake and not a subsidence in the western end. The latter would not lead to a true rise in lake levels elsewhere in the lake. The best treatment of the gauge data is presented in Clark and Persoage (1970) and in Tushingham (1992). In the latter, the rate of change in gauge readings between Buffalo and points in the western end of the lake varies between 9 Cleveland and Kingsville) and 7 $cm.century^{-1}$ (Marblehead). Some rates, eg. 4.5 $cm.century^{-1}$ for Buffalo-Toledo raise some questions as to the stability of these estimates. Nevertheless, a figure of 8 cm. $century^{-1}$ was used in Coakley and Lewis (1985) as the underlying linear component in a composite model of lake levels (Figure 2). This model fitted reasonably well with the data set of dated elevations collected by the authors at sites around the lake basin.

SUMMARY

The causes of postglacial lake level rise in the Erie basin are varied and predicting future trends is difficult without more research and data. However, using past trends as a guide for future levels, it is apparent that levels will continue to rise at rates of approximately 5 to 10 $cm.century^{-1}$, driven primarily by tectonic processes. Such an estimation is valid only if all other factors, such as hydrology and climate remain unchanged. This is an important qualification, however, as there are increasing fears of climate changes taking place on a global scale. Another imponderable in any prediction of lake levels is the effect of increased pressure on Lake Erie water resources for consumptive water uses, irrigation, and the drive for greater efficiency in navigation and shipping. All these activities have the potential for lowering lake levels, especially when coupled by trends to a warmer and drier regional climate. Of all possible scenarios, dramatic lowering of Lake Erie might be the most problematic with its negative impact on coastal wetlands, shipping tonnages, and with its potential to resuspend contaminated sediment deposits by wave action and through the need to increase dredging to maintain channel and harbour depths. The flip side of the coin is the economic impact of shore erosion and shoreline flooding if the lake rises above present levels.

Ultimately, the final chapter in the history of Lake Erie will be written when Niagara Falls erodes its way upstream and intersects the shoreline, leading to the eventual draining of Lake Erie. At its present rate of approximately 1 $m.a^{-1}$ it is not expected to occur for more than 10 000 years.

REFERENCES

Barnett, P.J., 1985, Glacial retreat and lake levels, north central Lake Erie Basin, Ontario, in Karrow, P.F. and Calkin, P.E. (editors), Quaternary Evolution of the Great Lakes, Geological Association of Canada Special Paper 30, p. 185-194.

Barnett, P.J., Coakley J.P., Terasmae J., Winn C.E., 1985. Chronology and significance of a Holocene sedimentary profile from Clear Creek, Lake Erie shoreline. Can. Jour. Earth Sciences, vol. 22, no. 8, pp. 1133-1138.

Clark, R.H. and Persoage, N.P. 1970. Some implications of crustal movement in engineering planning. Can. Jour. Earth Sci. v. 7, p. 628-633.

Coakley, J.P., 1976. The formation and evolution of Point Pelee, western Lake Erie. Can. Journal Earth Sciences, 13(1), p136-144.

Coakley J.P., 1985. Evolution of Lake Erie based on the postglacial sedimentary record below the Long Point, Point Pelee and Pointe-aux-Pins forelands. Unpubl. Ph.D. Thesis, Dept. Earth Sciences, Univ. of Waterloo, 362 pages.

Coakley, J.P. & C.F.M. Lewis, 1985. Postglacial lake levels in the Erie basin. In: P.F. Karrow and P.E. Calkin, (Eds), Quaternary Evolution of the Great Lakes, Geol. Assoc. Canada Special Paper 30, pp. 195-212.

Coakley, J.P. and Crowe, A.S., and Huddart, P.A. 1997. Subsurface sediment profiles below Point Pelee, indicators of postglacial evolution in western Lake Erie. NWRI Contrib. 97-110, Can. Jour. Earth Sciences, 35: 88-99.

Hough, J.L., 1966. Correlation of glacial lake stages in the Huron - Erie and Michigan basins. Jour. Geology 74: 62-67.

Kite, G.W. 1972. An engineering study of crustal movement around the Great Lakes. Environment Canada Inland Waters Directorate Technical Bulletin No. 63, 57p.

Lewis, C.F.M. and Anderson, T.W. 1989. Oscillations of levels and cool phases of the Laurentian Great Lakes caused by inflows from glacial Lakes Agassiz and Barlow-Ojibway. Journal of Paleolimnology 2, 99-146.

Mohajer, A.A., 1993. Seismicity and seismotectonics of the western Lake Ontario region. Géographie physique et Quaternaire 47, 353-362.

Pelletier, 1986. Deglaciation-induced vertical motion of the North American continent and transient lower mantle rheology. Jour. Geophys. Res. V. 91, p. 9099-9123.

Pengelly, J.W., Tinkler, K.J., Parkins, W.G., and McCarthy, F.M., 1997, 12,600 Years of Lake Level Changes, Changing Sills, Ephemeral Lakes and Niagara Gorge Erosion in the Niagaran Peninsula and Eastern Lake Erie Basin, Journal of Paleolimnology, v. 17, p. 377-402.

Rea, D. K., Moore, T.C., Anderson, T.W., Dodson, D.M., Dettman, Smith, A.J., and Mayer, L.A. 1995. Great Lakes paleohydrology: complex interplay of glacial meltwater, lake levels, and sill depths. Geology, v. 22, p. 1059-1062.

Sanford, B.V. 1993. St. Lawrence Platform — Geology: Chapter 11. In Stott, D.F. and Aitken, J.D. (eds.) Sedimentary Cover of the Craton in Canada, Geology of Canada no. 5, p. 723-786 (also Geological Society of America, The Geology of North America, D-1).

Tevesz, M.J.S.; Smith, J.E.; Coakley, J.P.; and Risk, M.J. 1997. Stable isotope records (C and O) from Lake Erie sediment cores: mollusk aragonite 3500 BP - 500 BP. NWRI Contrib. 96-92. Jour. Great Lakes Res. 23 (3): 307-316

Tinkler, K.J., Pengelly, J.W., Parkins, W.G., and Asselin, G. 1994. Postglacial recession of Niagara Falls in relation to the Great Lakes. Quaternary Res. V. 42, p. 20-29.

Tinkler, K.J. and Pengelly, J.W., 1995. Great Lakes response to catastrophic inflows from Lake Agassiz: some simulations of a hydraulic geometry for chained lake systems. Jour. Paleolimnology v. 13, p. 251-266.

Tushingham, A.M. 1992. Postglacial uplift predictions and historical water levels of the Great Lakes. J. Great Lakes Res. V. 18, p. 440-455.

Environment Canada | Environnement Canada

Canada

Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

St. Lawrence Centre
105 McGill Street
Montreal, Quebec
H2Y 2E7 Canada

Place Vincent Massey
351 St. Joseph Boulevard
Gatineau, Quebec
K1A 0H3 Canada

Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington (Ontario)
L7R 4A6 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon (Saskatchewan)
S7N 3H5 Canada

Centre Saint-Laurent
105, rue McGill
Montréal (Québec)
H2Y 2E7 Canada

Place Vincent-Massey
351 boul. St-Joseph
Gatineau (Québec)
K1A 0H3 Canada