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Lake Levels in the Erie Basin: Driving factor and recent trends

By:

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MANAGEMENT PERSPECTIVE

Title: Lake levels in the Erie basin: driving factors and recent trends

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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. The work is aimed at conserving and restoring priority ecosystems.

Current Status:

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

Next steps:

The results of this review will be combined with collaborative work with Dr. C.F.M. Lewis (G.S.C., Atlantic) and Dr. Allan Crowe (AERB/NWRI) on the extreme stages in the 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
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Lake levels in the Erie basin: driving factors and recent trends

by

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INTRODUCTION

Lake levels in the Erie basin are driven by three major factors: postglacial isostatic rebound of the crust at their outlets, regional hydrological and climatic changes, and to a less dramatic extent, by long-term neotectonic movements of a continental nature. Under the influence of the above 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 to its present stage. The heavy solid line in Figure 1 represents a reconstruction of postglacial lake levels in the Lake Erie basin based on radiocarbon-dated strandline indicators collected by the authors and others at sites around the lake basin (see Table 1 in Coakley and Lewis, 1985). The upper limits of the original envelope of probable levels proposed by Lewis (1969) is shown as a light dotted line.

Postglacial isostatic rebound. It has long been believed that Lake Erie rose from its minimum levels (Early Lake Erie) due to crustal rebound of the outlet at the Niagara River from its glacier-depressed state, and that the recovery rate decreased exponentially with time. Reconstruction models based on exponential rebound alone (using different reasonable values for the half-life, or time-constant), such as that of Andrews (1970) grossly over-estimated the initial rise in levels, compared to that based on the strandline indicators; however, the curve based on a composite model of exponential uplift, originally proposed by Mörner (1980) and shown in Figure 1 as a heavy dashed line, provided a much more reasonable fit to the data points. Both curves represents lake levels in the central and eastern basins assuming confluence of these basins and overflowing conditions at the outlet. Two important discrepancies are evident from the two curves:

- Most of the indicators in the western basin lie above the reconstructed level curve indicating that this part of the lake was exposed or contained perched bodies of water.
- The difference in elevation between the composite model curve and that based on dated strand-line indicators suggests that the effect of the rapid initial rebound, together with negligible upper lakes inflows though the Port Huron outlet at the time, resulted in a period where drainage within the Lake Erie watershed had no outlet except evaporation, in other words, a period of closed conditions. Such a scenario, still to be confirmed in the sediment record, has been cited by Tinkler et al. (1994) as an explanation for anomalous radiocarbon age sequences in shells from the Niagara Whirlpool site.

The irregular fit of the lake level curve has encouraged the belief that postglacial uplift was not always as uniform over time as predicted on the basis of simple or composite rebound model utilizing a fixed hinge-line (Hough 1966). It has been argued that geophysical complexities such as lower mantle rheology and the presence of a "peripheral forebulge" in front of the ice margin might perturb significantly the rebound dynamics of a glacier-depressed crust (Pelletier, 1986). Also, pre-existing crustal movement might play a role (see section below). Nevertheless, it is assumed that with time, the effect of rebound-related movements would decline and the other two factors would gradually assume a larger importance.

Hydrological and climatic factors. A number of significant hydrological events, involving major changes inflow, outflow, and evaporation-precipitation, have occurred in postglacial Lake Erie. Evidence for changes in lake levels caused by such effects is based on sediment records that span the postglacial period, such as those from below the three major cuspate forelands of the Erie basin (Coakley, 1976; 1985). Lewis and Anderson (1989) found evidence in sediment cores from a deep borehole on Long Point that waters from glacial Lake Algonquin discharged briefly into 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 event 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 (Fritz et al. ,1975; Tevesz et al. 1998) and in pollen assemblages (Lewis and Anderson, 1989). However, as changes in isotopic composition can be related to both climate and hydrological events, it is difficult to separate their individual effects.

Sedimentary evidence for the above dramatic lake level events is sparse in the Lake Erie basin, especially when compared to the excellent records preserved in the Lake Michigan beach ridges (Thompson, 1999, this volume). 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 or eroding 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 indicators, 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, useful evidence of 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). Furthermore, because of the erosive environment of the lake, material capable of providing good radiocarbon dates (e.g. trees in growth position) are hard to find, and there is a problem with transported organics and other error-producing effects. These deficiencies are discussed in detail in Coakley and Lewis (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 forebulge" responding in a manner opposite to that of 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). Such a massive inflow is 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. 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 lower sill. Levels then fell to their former levels.

The timing of this event is Archaeological data from campsites at Fort Erie found no artifacts dating older than 4000 years. 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 1993elevation 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, Ohio, and indirectly by eroded surfaces beneath the three coastal forelands of the north shore (Coakley 1976; 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.

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 most comprehensive treatment of the gauge data is presented in Clark and Persoage (1970), in recent reports of the Coordinating Committee on Lake Levels (1977), 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 $cm.century^{-1}$ (Buffalo - Cleveland and Kingsville) and 7 $cm.century^{-1}$ (Buffalo - Marblehead). However, 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 1). This model appears to fit reasonably well with the dated lake level indicators.

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 tonnage, 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.

As is evident from the list of references below, there is a lack of recent research into long-term lake level trends. There are plans for borehole drilling and sampling by National Water Research Institute and for further archaeological investigations, both in the more promising eastern part of the lake. These efforts, and others yet to be published, will no doubt add considerably to our understanding of late Holocene levels in the Erie basin.

REFERENCES

Andrews, J.T. 1968. Postglacial rebound: similarity and prediction of uplift curves. Canadian Journal of Earth Sciences, 5: 39-47.

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.

Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data 1977. Apparent Vertical Movement Over the Great Lakes. Chicago, Illinois, and Cornwall, Ontario. Printed by the Detroit District, US Army Corps of Engineers, July 1977.

Fritz, P., Anderson, T.W., and Lewis, C.F.M. 1975. Late Quaternary climatic trends and history of Lake Erie from stable isotope studies. Science V.190: 267-269.

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. 1969. Late Quaternary of lake levels in the Huron and Erie basins. Proc. 12th. Conference on Great Lakes Research. P. 250-270.

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.

Mörner, Nils-Axel, 1980. The Fennoscandinavian uplift: geological data and their geodynamic implications. In: Mörner, N.-A. (Ed.), "Earth Rheology, Isostasy, and Eustacy", Int. Union of Geological Sciences Geodynamics Proj., Report no. 49, p. 251-284.

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.

Figure captions

Figure 1. Reconstructed history of postglacial Lake Erie levels (heavy solid line) based on radiocarbon-dated level indicators reproduced from Coakley and Lewis (1985). The heavy dotted line is an hypothesized level curve assuming a composite model of uplift and overflowing conditions at the outlet; the light dotted line is the upper fit envelope in Lewis (1969). The curve is applicable to the central and eastern basins only. The radiocarbon dated points shown numbered are referenced to Table 1 in Coakley and Lewis (1985)

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