Confronting Climate Change in the Great Lakes Region
Technical Appendix

Impacts of Higher Lake Temperatures

This document is a technical appendix providing further detail on the water resource information in the Report on **Confronting Climate Change in the Great Lakes Region** *available at* http://www.ucsusa.org/greatlakes/ (Kling et al. 2003). *The authors most responsible for this section include (alphabetically) Katharine Hayhoe, Lucinda Johnson, George Kling, John Magnuson, and Brian Shuter.*

Future increases in atmospheric temperature and CO_2 concentration will lead to increasing water temperatures in the Great Lakes (McCormick 1990; Hill and Magnuson 1990) and in the inland lakes and streams of the region (Hondzo and Stefan 1991,1993; Stefan et al. 1993a,b, 1996; DeStasio et al. 1996). In model simulations for inland lakes in summer the surface water temperatures increased 1-7°C (1.8-12.6°F) and the deep water ranged from an 8°C (14.4°F) warming to a counter-intuitive 6°C (10.8°F) cooling. The diverse response in deep waters occurs because warming can cause a small, deep lake to stratify sooner in spring, at a cooler temperature. These predicted temperature changes, and their attending impacts described below, would be even greater using the more recent climate scenarios, especially by 2090. Overall, changes in temperature and stratification set and control the fundamental physical, chemical, and biological processes in lakes.

Changes in summer stratification will likely occur with future climate warming (McCormick 1990; Schertzer and Sawchuk 1990; Meyer et al. 1994; Croley 1994; King et al 1997, 1999; Fang and Stefan 1999; McCormick and Fahnenstiel 1999; Snucins and Gunn 2000). In all but the smallest inland lakes the epilimnion (upper warm layer) likely will become shallower, and in all lakes the duration of the summer stratification period will increase. In the smallest inland lakes the epilimnion may become thicker because in a warmer, dryer climate lakes would receive less dissolved organic carbon (DOC) from inflowing streams and surrounding wetlands that “stain” the water (Schindler et al. 1996). Clearer water allows greater light penetration and heating at depth (Snucins and Gunn 2000). In the Experimental Lakes Area of northwestern Ontario, data indicate that the thickening of the epilimnion owing to declines in DOC might offset thermocline shallowing owing to climate warming (Fee et al. 1992).

Model simulations of warming suggest a partial disappearance of the fall and spring periods of complete mixing that are typical of all the Great Lakes and serve to resupply oxygen and nutrients to the systems. This will occur if surface waters fail to cool to the temperature of maximum water density in winter (3.94ºC or 39.1ºF; McCormick 1990; Schertzer and Sawchuck 1990; Boyce et al. 1993; Croley 1994). Lake Ontario is particularly sensitive to this effect and, under some CO_2 doubling scenarios (Croley 1994; Boyce et al. 1993), the lake would have only a single, short period of complete mixing in late winter and increased bottom temperatures throughout the year. The other Great Lakes would experience a similar suppression of mixing in some years and a significant increase in annual average bottom temperatures (Croley 1994; Peeters et al. 2002). Some forecasts for Lake Michigan suggest that complete mixing may cease altogether, causing the bottom waters to be permanently cut off from the surface waters (McCormick 1990).

Longer stratification periods and warmer bottom temperatures will increase oxygen depletion (hypoxia and anoxia) in the deep waters of the Great Lakes (e.g., Blumberg and DiToro 1990) and will lead to complete loss of oxygen during the ice-free period in inland lakes of at least moderate depth (Stefan et al. 2001). In the very deep Great Lakes, conversion to a single short period of complete mixing will also reduce oxygen in deep waters, which in turn negatively affects most biota. This situation is a primary factor responsible for the much-publicized occurrence of "dead zones" in Lake Erie over the summer of 2001 (see Kling et al. 2003, for further information). Lower oxygen and higher temperatures also promote greater nutrient and contaminant release from the bottom sediments. Phosphorus release would be enhanced (Bostrom et al. 1988; Magnuson et al. 1997; Kalff 2002). Mercury release (Bodaly et al. 1993; Heyes et al. 2000) and uptake by biota (Bodaly et al. 1993; Yediler and Jacobs 1995) would also likely increase. Other contaminants and particularly some heavy metals would likely respond in a similar fashion (e.g., Perkins et al. 2000; Dollar et al. 2001).

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