Global warming and lakes

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World freshwater resources are shrinking measurably in many regions because water is being consumed at a rate greater than it can be recharged. Freshwater resources are also shrinking qualitatively because many systems are increasingly polluted with a wide variety of human, agricultural and industrial wastes. Concomitant with these anthropogenic impacts, climate change is expected to directly affect both the quantity and quality of water and may exacerbate the effects of many other human activities on lakes.

Changes in average air temperature, changes in frequency, duration and amount of precipitation, and rising sea levels are predicted due to changes in large-scale atmospheric phenomena as outlined in the IPCC 2007 reports. At higher latitudes, precipitation is expected to increase whereas it is expected to decrease at lower latitudes although the distribution of these changes varies regionally and locally. The effect of all these changes on lakes will be alterations in water temperatures and annual stratification patterns, changes in inflow quantities from surface runoff, changes in the amount and duration of winter ice cover, which will affect evaporation and alter of water levels. Indeed, long-term monitoring records of lake surface water from around the world have indicated that many lakes and reservoirs have experienced increases in water temperature in Africa, the Americas, Europe and Asia (Figure 1). With global warming and reduced precipitation many lakes have been shrinking. These include Lake Chad in Africa. Freshwater lakes may become saline and saline lakes, such as in the semi-arid prairie region of North America, will increase in salinity. During winter of 2001-2002, Lake Erie in North America was ice-free for the entire season, a situation that occurs infrequently. Increased winter evaporation contributed to the already low water levels in the Great Lakes caused by below-average precipitation and increased evaporation from summer warming.

Northern lakes may be particularly vulnerable to global climate changes. Warming of frozen ground, which includes near-surface soil affected by short-term freeze-thaw cycles, seasonally frozen ground and permafrost can lead to ground surface subsidence and the formation of thermokarst that generate marked changes in ecosystems and landscapes (Lemke et al., 2007). Lemke et al. reported extensive thermokarst formation in central Yakutia (Russian Federation) and significant expansion and deepening of thermokarst lakes near Yakutsk from 1992 to 2001. Thermokarst formation might be expected to increase the number of lakes and wetlands in an area but this is not necessarily true. From satellite data Smith
et al. (2005) found a widespread loss of large lakes in Siberia despite slight precipitation increases over an almost 30 year period. However, they also found that the effects of thermokarst formation on lake formation varied: in continuous permafrost total area increased but in discontinuous, sporadic and isolated permafrost there was a decline. They proposed that thermokarst formation should be viewed as a continuum in which initial permafrost warming leads to development of thermokarst and lake expansion and is followed by lake drainage when the permafrost breaks down further and water is released to the subsurface. Smith et al. (2005) concluded that the ultimate effect of continued climate warming on high-latitude, permafrost controlled lakes could result in their widespread loss.

River deltas, such as that of the Mackenzie, along the circumpolar arctic coast are rich in lakes. In the Mackenzie Delta flood pulses generated by ice breakup control the degree to which river water moves off-channel to restore waters in the lakes and wetlands. From an analysis of more than 30 years of water level data from the Mackenzie Delta, Lesack and Marsh (2007) found that river-to-lake connection times had lengthened in the lowest elevation lakes and may have shortened for the highest elevation systems via sea level rise and declining effects of river-ice break-up. As a result, the higher elevation lakes are now at risk of drying up while the lower elevation systems with increased water levels may allow fish to inhabit a greater area of the delta.

Global warming may also affect the chemical and biological attributes of lakes and reservoirs. These will vary for different systems and their geographical location. For example, in a recent study, Flanagan et al. (2003) analyzed published limnological data for arctic and temperate lakes between 41 and 79oN. They found that average algal biomass during the ice-free season increased significantly with phosphorus levels and suggested algal biomass could sharply increase in relatively unproductive arctic lakes with increases in water temperature due to climate warming (including reduced length of ice cover and consequent increased availability of solar radiation for algal growth) and nutrient concentrations due to permafrost melting. Many biogeochemical processes in lakes have some degree of regulation by water temperature. The warming of lake water could increase biological productivity, decomposition and therefore nutrient and energy cycling. Hypolimnetic warming can lead to periods of deoxygenation in deep lakes while warmer waters may exclude cold-tolerant species and thereby alter the biodiversity and food-webs in lakes. Schindler (1997) has summarized the interaction of climate warming impacts on lakes with other human impacts:

- Delayed recovery of acidified lakes;
- Decreasing DOC (dissolved organic carbon) concentrations in warming lakes could be accelerated by acidification;
- Eutrophication may increase, even though nutrient loads may decrease because of increased retention times;
- The impact of oxygen consuming effluents may be more severe as dissolved oxygen saturation decreases with increasing temperature;
- Hypolimnetic oxygen deficits could be increased with longer stratification periods in eutrophic lakes;
- In lakes undergoing warming and acidification, organisms may have increased UV radiation exposure due to decreasing DOC concentrations;
- Climate warming interactions with toxins will be many and complex, ranging from reduced toxin loads and increased retention, to increased revolatilization, decomposition and cycling; and
- Increased human demand for water will interact with climate warming to compound already severe problems in water quantity and quality, impacting all aspects of society and the environment.

Interannual data variability is a major confounding problem to detect changes due to climate warming even with long-term datasets (Jassby et al., 2004). Assessing the impact of climate change on lakes is complicated by the many anthropogenic impacts that have occurred, and are occurring, on the physical, chemical and biological characteristics of lake systems. Although Arhonditsis et al. (2004) noted that several long-term studies have found a coupling between lake water temperature and individual organism physiology, population abundance and community structure, there is generally a scarcity of such long term data records for lakes, particularly for biological processes. Therefore, demonstration of climatic change impacts from field data is similarly rare. Impacts such as changes in land-use and water abstraction may equal or exceed climate-induced changes. Furthermore, our ability to predict climate change impacts on lakes and to devise effective management strategies to cope with, or ameliorate, these are restricted by the quality of climate change predictions at regional scales together with our generally poor understanding of many of the effects of climate change and variability on lake ecosystems (Meyer et al., 1999). As lakes are a major source of renewable fresh water for human societies in many parts of the world (ILEC, 2003), there is an urgency to obtain this information and improve our predictive capabilities.

REFERENCES


Flanagan, K.M., E. McCauley, F. Wrona and T. Prowse. 2003. Climate change: the potential for latitudinal effects on algal blooms in aquatic ecosystems. Canadian Journal of Fisheries and
Aquatic Sciences 60: 635-639.

Figure 1 Examples of changes in mean annual surface water temperature from long-term lake monitoring stations. Lines are 'best fit' linear regressions. Data are from the UNEP GEMS/Water Programme’s global database (GEMStat; www.gemstat.org) that contains data for 425 lake and reservoir stations. Reprinted with permission from Water Quality for Ecosystem and Human Health, 2nd Edition, 2008. UNEP GEMS/Water Programme, Burlington, Canada, 120 + vii p.