

## Eutrophication Management Techniques for Boreal Plain Surface Waters of Western Canada\*

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**Abstract:** *Surface waters in western Canada often experience eutrophication-related problems with water quality, specifically high internal phosphorus loading rates and excessive phytoplankton and macrophyte production, that lead to water column anoxia and restricted fisheries habitat. A group of researchers from across Canada were involved for a seven-year period in cooperative programs for surface water quality management in western Canada, based at the University of Alberta. This paper summarises information on two techniques, hypolimnetic oxygenation and lime ( $\text{Ca}_2\text{CO}_3$  and  $\text{Ca}(\text{OH})_2$ ) application, used in western Canada (specifically, the province of Alberta) to manage eutrophication in standing waters (lakes and reservoirs).*

**Keywords:** *Eutrophication management techniques, surface water, Western Canada*

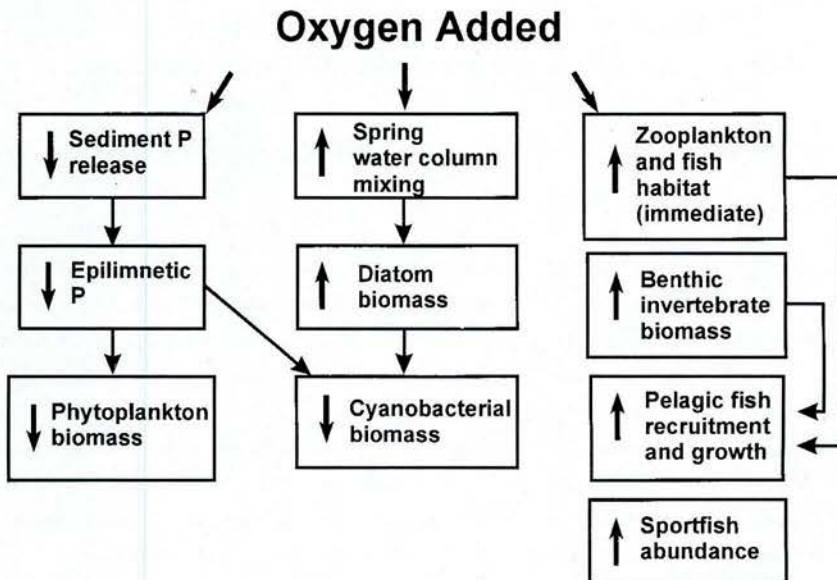
The boreal forest of Canada, comprising about 40 % of the world's total by area, is a ribbon of green that stretches from the west to the east coast of Canada. The Boreal Plain ecozone includes those portions of the boreal forest lying outside the Precambrian Shield and Rocky Mountains Cordillera, and covers approximately 60 % of the province of Alberta (Environment Canada, 1991). Its vegetative cover is largely mixed-wood forest dominated by trembling aspen (*Populus tremuloides*) and spruce (*Picea* spp.) (Strong and Leggat, 1981). The Boreal Plain ecozone has lower precipitation and higher evaporation rates relative to many regions of Canada,

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but is also characterised by an abundance of surface water (Mitchell and Prepas, 1990).

The surface waters of this region lie over a thick layer (up to 100 m) of glacial till rich in orthophosphate compounds, and consequently tend to be naturally productive (Mitchell and Prepas 1990). Most lakes are relatively shallow (<20 m deep at maximum depth) and well buffered (alkalinity between 100 and 300 mg.l<sup>-1</sup> CaCO<sub>3</sub>). The past 50-100 years of European-based settlement in western Canada, with its associated agricultural, petroleum industry and forest-harvesting activities, has exacerbated the eutrophication process for many lakes in this region. Removal of the boreal forest cover leads to blockages of water courses and lowering of water table levels within drainage basins. Increased nutrient inputs into shallow lakes via surface runoff has ultimately led to increased occurrences of summer and winter fish kills. Cyanobacterial blooms are linked with drainage basin disturbance and can lead to unpleasant taste and odours in drinking water supplies and in extreme cases, livestock- and human-health risks from algal toxins (Kotak *et al.*, 1993). Internal phosphorus recycling from the bottom sediments is very prevalent and usually the major source of phosphorus on an annual basis in western Canada (Shaw and Prepas, 1990); therefore, *in-situ* treatment is most appropriate.



**Fig. 1** Anticipated long-term (>2 years post-treatment) impacts of hypolimnetic oxygenation on aquatic food webs in treated hardwater lakes. Arrows indicate direction (increase or decline) of anticipated responses.

We focused on Amisk Lake for hypolimnetic oxygenation studies (Amisk is the Cree word for beaver). This lake was formed from a glacial meltwater channel approximately 10 000 years ago and is deep relative to other lakes in central Alberta (Mitchell and Prepas, 1990). It is a double-



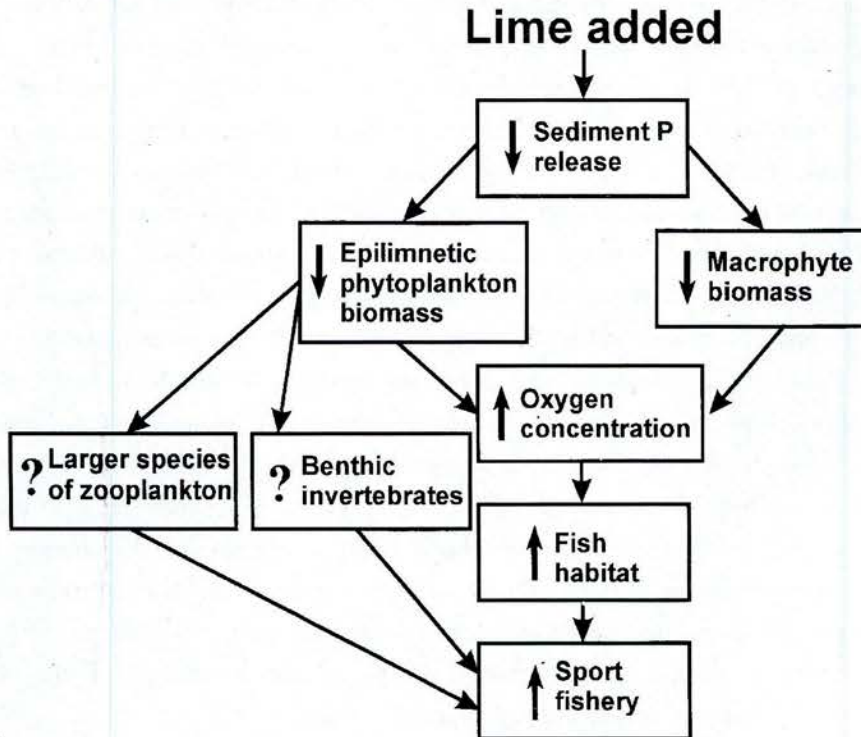
basined lake; maximum depth ( $Z_{\max}$ ) of the north and south basins are 34 and 60 m, respectively. It is a lake with relatively high total phosphorus ( $>30 \mu\text{g}\cdot\text{l}^{-1}$ ) and low total iron concentrations ( $< 5 \mu\text{g}\cdot\text{l}^{-1}$ ). Records for the last 50 years indicate dissolved oxygen concentrations in the deeper waters were consistently low during stratification periods. Amisk Lake is naturally eutrophic, but low oxygen concentrations were enhanced by effluent from a mink farm established in the 1940s, and external phosphorus inputs from limited agriculture and recreational development within the drainage basin (approximately 5 % of its total area) (Mitchell and Prepas, 1990).

Beginning in 1988, pure oxygen was injected for a total of five and one-half years into the northern basin (Prepas *et al.*, 1997). The first one and a half years were a preliminary trial of the system; during the latter four years of the project, up to  $1.3 \text{ t}\cdot\text{d}^{-1}$  of oxygen were injected. Our initial injection of dissolved oxygen improved dissolved oxygen concentrations and increased temperatures up to  $2 \text{ }^\circ\text{C}$  in the hypolimnion. However, thermal stratification was not disrupted during the summer or winter periods. Over the treatment period, total phosphorus concentrations declined in both the treated and south basin of Amisk Lake (Prepas and Burke, 1997). In two reference lakes in the region there were no comparable trends in reduced phosphorus concentrations. Initially, we had hypothesised that there would be no transfer of oxygen from the treated north basin into the south basin via the connecting channel. By 1990, it was clear that approximately half ( $150 \text{ t}\cdot\text{a}^{-1}$ ) of the injected oxygen was being transferred to the south basin (Lawrence *et al.*, 1997). Four mechanisms were likely responsible for this transfer. Two-thirds of it entered the south basin through the connecting channel via diffuser-driven water currents, while another 20 % was transferred by internal seiche pumping. Transfer of the remainder was mediated by water column turnover during the spring and autumn, and during the winter by means of the ice-free patch caused by upwelling from the diffuser.

The improved hypolimnetic oxygen concentrations resulted in changes throughout the food web of Amisk Lake (Fig.1). In the phytoplankton community, cyanobacteria numbers dropped, diatom numbers increased and overall phytoplankton biomass decreased (Webb *et al.*, 1997). For the zooplankton, no species changes were noted but there was an increase in biomass and numbers deeper in the water column (Field and Prepas, 1997). Similarly, although there were no species changes in profundal macroinvertebrates, biomass and numbers increased dramatically over five years in the deeper waters (Dinsmore and Prepas, 1997). The pelagic fish community of Amisk Lake made an immediate habitat shift to take advantage of the increased oxygenated water column at deeper depths (Aku *et al.*, 1997).

The second eutrophication management technique, applied to four lakes and up to a dozen small artificial farm ponds (dugouts), involved the application of lime ( $\text{Ca}_2\text{CO}_3$  and  $\text{Ca}(\text{OH})_2$ ) (Murphy *et al.*, 1990; Prepas *et al.*, 1990; Babin *et al.*, 1994). Experimental lime dosages applied to these water bodies ranged from  $15 \text{ mg}\cdot\text{l}^{-1} \text{ Ca}_2\text{CO}_3$  to  $>250 \text{ mg}\cdot\text{l}^{-1} \text{ Ca}(\text{OH})_2$ . Both single and multiple applications per year were employed and treated lakes were monitored for up to seven years after treatment. Multiple applications of  $\text{Ca}(\text{OH})_2$  at dosages  $<100 \text{ mg}\cdot\text{l}^{-1}$  in hardwater lakes reduced total phosphorus concentrations and epilimnetic phytoplankton by 50 and

30%, respectively, with minimal pH-shock to other aquatic biota (Fig. 2). In farm dugouts, high dosages of  $\text{Ca}(\text{OH})_2$  ( $>200 \text{ mg}\cdot\text{l}^{-1}$ ) reduced total phosphorus concentrations and epilimnetic phytoplankton by 88 and 80%, respectively, often for several years after application. Reductions in cyanobacterial and in macrophyte biomasses were also noted. Observed responses were similar in dugouts treated with high dosages and in lakes treated multiple times.



**Fig. 2** Anticipated long-term ( $>2$  years post-treatment) impacts of lime ( $\text{Ca}_2\text{CO}_3$  and  $\text{Ca}(\text{OH})_2$ ) on aquatic food webs in treated hardwater lakes. Arrows indicate direction (increase or decline) of anticipated responses; question marks indicate uncertainty as to direction of post-treatment response.

In conclusion, development of hypolimnetic oxygenation and lime application as water quality management techniques involved teamwork among academic researchers, local residents, government agencies and private industry. Water quality could be safely enhanced by hypolimnetic oxygenation and liming at a relatively low cost. For example, the estimated cost to treat Amisk Lake was some \$30 000 (CDN) per year. Unfortunately, at the time when our involvement in these programs was concluded, there were no public or private interests with the necessary funding in place ready to assume control. We hope that more opportunities will unfold in the future.

We will conclude with a brief overview of a recent opportunity to study the impact of forest



harvesting and land manipulation practices on surface waters in northern Canada. In 1989, the province of Alberta made a decision to begin harvesting the largest remaining virgin tracts of boreal mixed-wood forest in the world, covering some 200 000 km<sup>2</sup>. This development received much criticism from environmental groups, boreal researchers, Aboriginal peoples and the general public. Beginning with the Northern River Basins Study in 1990 and followed by the Sustainable Forest Management Network (SFMN) in 1995, the provincial government of Alberta opted to complement its rapidly expanding forest industry with a co-operative university-based research initiative to examine the repercussions of this growth.

The SFMN is the first Canada-wide partnership between university, industry and government interests formed to develop general models for ecosystem management of forested regions. Some 25 Canadian universities and 80 scientists from the fields of engineering, forestry, social sciences, and biology are studying how natural disturbance could be used as a model for forest management. The aquatic portion of this program focusing on lakes looks at the effects of natural disturbance regimes, particularly forest fire, on surface waters and compares them with the impacts on boreal systems associated with forest harvesting. The intent of the SFMN is to build on the Northern River Basins Study, moving beyond managing solely for sustained yield and aesthetic values within boreal systems, and to develop new approaches to the land-water interface in the boreal forest of Canada. *In-situ* treatment of eutrophication-related water quality issues may still be necessary, but with a better understanding the land-water interface before it changes irreversibly, we may be able to rationalise the process.

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