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A total phosphorus budget for the Lake of the Woods and the Rainy River catchment

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ABSTRACT

The overall goal of this study was to quantify the major and minor sources and losses of total phosphorus (TP) to the Lake of the Woods (LOW), summarized as a nutrient budget. This research was initiated in response to degradation in lake water quality, including elevated TP concentrations and increased cyanobacterial blooms, which has resulted in LOW's classification as an "Impaired Waterbody" in Minnesota. The whole-lake LOW TP budget shows that tributary inflow is largely dominated by a single source, the Rainy River, draining 79% of the LOW catchment by area. Currently, there is only a small TP contribution from shoreline residential developments (6 t; ~1%) at a whole-lake scale, relative to the large TP loads from atmospheric deposition (95 ± 55 t; 13%) and the Rainy River (568 ± 186 t; 75%). Overall, the annual TP load to LOW was ~754 t with ~54% TP retained within the lake. The nutrient budget for the Rainy River catchment revealed that contributions from point sources along the river constitute the largest anthropogenic TP source to the Rainy River and eventually to LOW. Historical load calculations along the Rainy River show that this load has been significantly reduced since the 1970s, and presently just over 100 t of P enters LOW from anthropogenic point sources. These TP budgets provide insights into the major sources of TP influencing the overall LOW water quality and with future refinement may provide a greater understanding of linkages between TP loading and spatial and temporal water quality changes in the LOW.

Introduction

The Lake of the Woods (LOW) (48°50′16″ to 49°45′37″N, 93°49′56″ to 95°19′26″W) is an international water body straddling the borders of the Canadian provinces Ontario and Manitoba and the state of Minnesota, USA (Fig. 1). The LOW has a surface area of approximately 3850 km^2 and, together with its drainage basin (69,750 km^2), comprises 47% of the Winnipeg River drainage basin (DeSellas et al., 2009). The lake experiences vast, toxic cyanobacterial blooms that occur annually, which is a concern shared with many other lakes in North America (e.g., Lake Winnipeg and other Ontario lakes; Chen et al., 2009; Winter et al., 2011). Due to elevated total phosphorus (TP) and chlorophyll concentrations in the lake, LOW has recently been listed as an "Impaired Waterbody" in the state of Minnesota, and an International Joint Commission Task Force has been created to recommend management and governance options for this international lake. Since LOW provides drinking water to many towns and cities, including the cities of Winnipeg, MB and Kenora, ON, its water quality is of great concern. With increasing political attention, there is a need for basic water quality research on LOW (DeSellas et al., 2009). Nutrient work, including the development of the first TP budget presented here, has been identified as a significant data gap.

Although historical accounts dating back to the 1800s suggest that cyanobacterial blooms were a component of past aquatic conditions on the LOW (McElroy and Riggs, 1943), there is a growing perception that the magnitude and duration of these blooms has increased in the northern regions of the LOW. An increase in the magnitude of these blooms may be exacerbated by eutrophication and/or conditions associated with global climate change (e.g., higher air temperature and an increased period and strength of stratification; Chen et al., 2009; Rühland et al., 2010). As a first step, knowledge of the major sources of P to the LOW is needed to address the potential causes contributing to this reported degradation in water quality.

In addition to providing a significant source of drinking water, the LOW water quality has wider significance downstream to Lake Winnipeg. Nutrient loading to Lake Winnipeg via the Winnipeg River catchment is the second largest source of nutrients to Lake Winnipeg (13% of the TP load; Salki et al., 2006), with more than half of the Winnipeg River flow originating from the LOW. Given that stricter P regulations are likely to form part of a management strategy for LOW, it is important that we fully understand the relative sources of TP to the lake, and explore possible relationships between nutrient levels and recent algal

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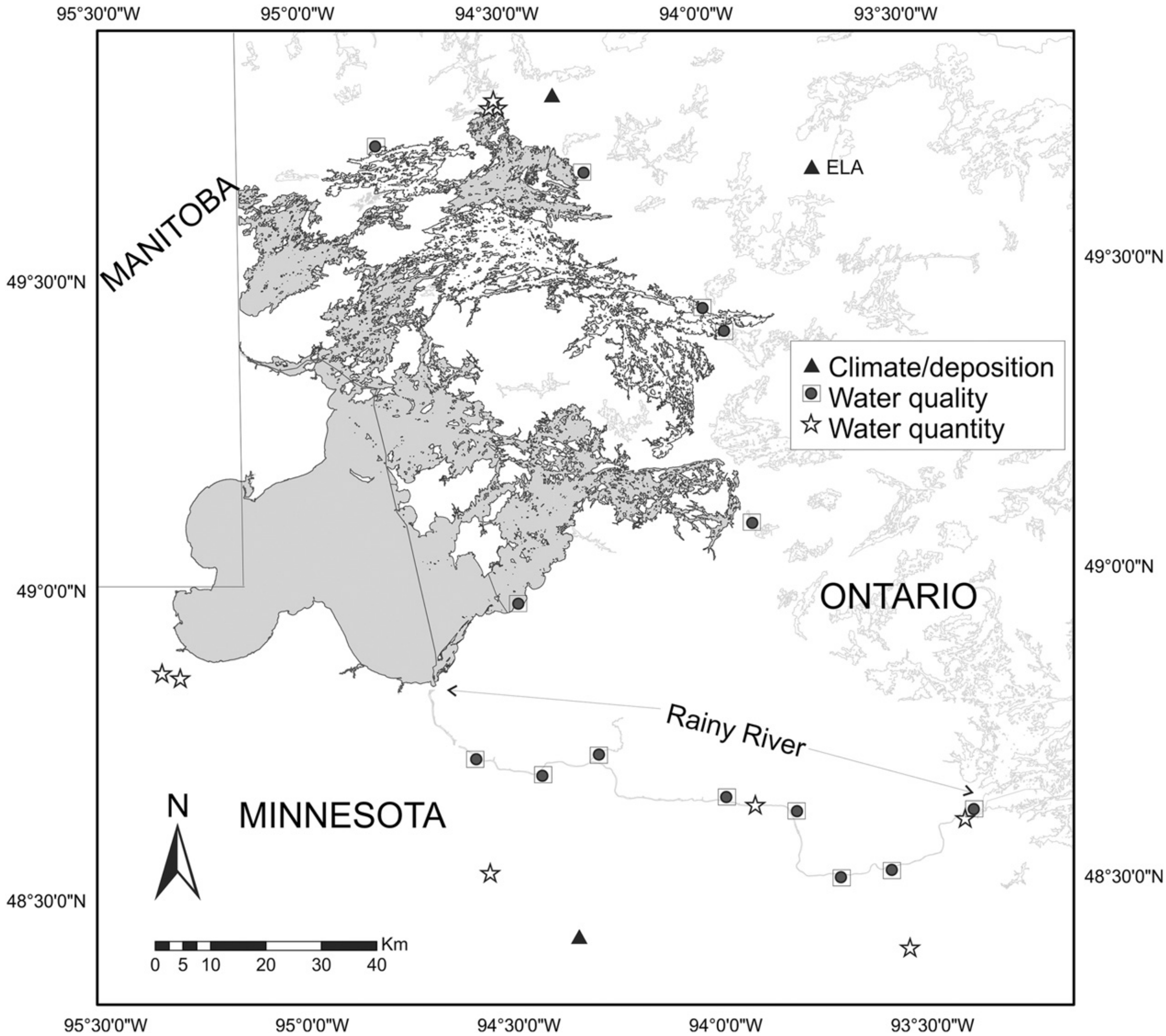

Fig. 1. Location of the Lake of the Woods and the Rainy River, showing locations of climate and tributary monitoring stations.

blooms to further our knowledge on both LOW and Lake Winnipeg water quality.

Phosphorus loading (i.e., the amount of P added to the lake per unit area per unit time), has been commonly used to measure the nutrient status of a lake (Dillon and Molot, 1996; Dillon et al., 1993; Hutchinson et al. 1991; Winter et al., 2007). A lake P budget by definition is a quantification of the sources and sinks of P into and out of a lake (Reckhow and Chapra, 1983). Once a lake nutrient budget is established, models can utilize these data to make predictions about current and future lake P concentrations under different management regimes, and other water quality indicators such as chlorophyll and dissolved oxygen concentrations (e.g., Molot et al., 1992; Nicholls and Dillon, 1978).

External components of lake P budgets that are commonly considered include atmospheric deposition, tributary inflow, non-tributary runoff, shoreline residential development, and anthropogenic point sources including wastewater treatment plants and industry discharge. In the LOW, most of the tributary inflow is captured by a single source, the Rainy River, which drains 79% of the LOW catchment. Of particular interest is the drainage area southwest of Fort Frances-International Falls, where the Rainy River discharges into the LOW. This area captures the 130 km long stretch of the Rainy River and represents 31% of the total area of the Rainy River basin. Within this region, herein referred to as the Lower Rainy River basin, there are ten point sources discharging directly into the Rainy River, a population of over 40,000 residents, and 13.9% of the land use is agriculture (DeSellas et al. 2009). Anthropogenic contributions likely play a dominant role in this region of the LOW drainage basin. Therefore, important insights into the different components of the Rainy River P entering LOW would be gained from a P budget for the Rainy River.

Although P is found in several forms, and orthophosphate is the form of P that can be most easily assimilated by bacteria, algae and plants (Correll, 1998; Currie and Kalff, 1984), TP is the fraction of P most commonly measured in lakes for several reasons. It is relatively easily measured with good precision, it is a chemical measurement of a fraction that can be readily defined, and it is the P measure best related to the trophic status of a lake. All TP at some point is likely to be converted to orthophosphate or other bioavailable forms (Brett and Benjamin, 2008; Dillon and Reid 1981). Moreover, historical data collected in the LOW and the Rainy River is based on TP concentrations.

To gain a better understanding of the TP sources to and losses from the LOW, three tasks were carried out: (1) identification and quantification of the major and minor TP fluxes to the LOW which also included the creation of a water budget for the lake, (2) development of a basic TP budget for the Rainy River catchment, and (3) evaluation of historical TP loading to the LOW (from 1960) and the Rainy River.