Journal of Great Lakes Research 38 (2012) 6–13

Contents lists available at SciVerse ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

Review

The rapid eutrophication of Lake Winnipeg: Greening under global change

David W. Schindler [a,*], Robert E. Hecky [b,1], Gregory K. McCullough [c,2]

[a] Department of Biological Sciences, University of Alberta, Edmonton, AB, Canada T6G 2E9
[b] Large Lakes Observatory, University of Minnesota Duluth, 2205 E 5th Street, Duluth, MN 55812, USA
[c] Centre for Earth Observations Science, Department of Environment and Geography, 482 Wallace Building, University of Manitoba, Winnipeg, Canada R3T 2N2

ARTICLE INFO

Article history:
Received 12 January 2012
Accepted 23 April 2012
Available online 19 May 2012

Communicated by Ram Yerubandi

Keywords:
Climate change
Flooding
Phosphorus
Agriculture
Cyanobacteria blooms

ABSTRACT

Nuisance blooms of heterocystous Cyanobacteria in Lake Winnipeg have nearly doubled in size since the mid 1990s. The increases are the result of a recent rapid increase in loading and concentration of phosphorus. The rapid increase in phosphorus is largely the result of two factors. The first factor is the result of rapidly increased livestock production and use of synthetic fertilizer in the Red River Valley, with smaller contributions of phosphorus from the city of Winnipeg and other human development in the Red and Winnipeg river basins. The second factor is the increased frequency and intensity of spring floods in the Red River watershed in recent years, which have greatly enhanced the transfer of phosphorus from the landscape to the lake, as well as slower increases in nitrogen. Because the low ratio of nitrogen to phosphorus in the increased inputs favors nitrogen fixing species of Cyanobacteria, these nuisance forms account for most of the increase in phytoplankton. Recovery of the lake will require reducing both agricultural and major urban sources of phosphorus and, if possible, the frequency and intensity of flooding in the Red River watershed. Flooding will be increasingly difficult to control if modeled predictions for increased precipitation under climate warming materialize. Even with targeted reductions in phosphorus inputs of 50% and measures to control flooding, recovery of the lake is expected to be slow because of phosphorus recycled from sediments and the climatic sensitivity of this shallow lake and the flooding of the Red River.

Contents

Introduction

Between 1990 and 2000 the phosphorus concentration of Lake Winnipeg doubled (McCullough et al., 2012) and algal blooms, dominated by nitrogen fixing Cyanobacteria, proliferated (Kling et al., 2011). Although much of the lake's catchment had been converted to agriculture and the human population had been slowly increasing over the previous century, the rapid eutrophication late in the 20th century was unforeseen, and how to reverse it is controversial. In recent years, several other great lakes such as tropical Lake Victoria (Hecky et al., 2010) and lakes Huron and Michigan (Evans et al., 2011) have also undergone rapid, unpredicted changes in trophic condition, as a result of changing inputs of nutrients and invasive species, causing concern for their long term sustainable use. Significant changes in nutrient concentrations in these large lakes have occurred in less than a decade, clearly illustrating that lake size alone provides little protection to lake condition. Such rapid changes challenge

* Corresponding author. Tel.: +1 780 492 1291.
E-mail addresses: d.schindler@ualberta.ca (D.W. Schindler), rehecky@gmail.com (R.E. Hecky), gmccullo@umanitoba.ca (G.K. McCullough).
[1] Tel.: +1 218 726 9726.
[2] Tel.: +1 204 474 9980.

0380-1330/$ – see front matter © 2012 International Association for Great Lakes Research. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.jglr.2012.04.003

aquatic science for explanation. The papers in this volume, many generated through major federal and provincial studies that responded to public concern about the future of Lake Winnipeg, illustrate many changes to the lake following the rapid eutrophication since the early 1990s. Here, we synthesize the findings of some of these studies and other recent research to assess the relative contributions of sewage, land use change and climatic variability to the rapid eutrophication, and to identify possible actions that might reverse the recent eutrophication of Lake Winnipeg.

When one of us (DWS) first studied Lake Winnipeg in 1969 as part of a team of scientists from the now defunct Fisheries Research Board of Canada (FRBC), the lake was already moderately eutrophic, (summarized by Brunskill, 1973; and in unpublished data reports), and biologically altered from the initial observations on the lake in the 1920s (Bajkov, 1934; Patalas and Salki, 1992). At the time, we deduced that the Red River watershed was yielding more nutrients than it had under pristine conditions, because most of the basin had been transformed from long grass prairie to agricultural land within the 20th century, but it was not clear how much the nutrient input had increased over natural background.

Unfortunately, following the demise of the FRBC in the 1970s and despite the construction in 1977 of a control structure which controls the lake level and the outflow of the lake for hydroelectric purposes, little research attention was paid to Lake Winnipeg (Fig. 1; McCullough et al., 2012), resulting in a long hiatus in real time observation. When surveys were resumed in the early 1990s, it first appeared that the lake had changed very little in the intervening two decades. However, rapid increases in nutrient inputs and associated symptoms of increasing eutrophication began to occur by the mid-1990s.

Paleolimnological studies using nutrient concentrations and algal remains in lake sediments have filled in the early history of the lake and provide a baseline against which to evaluate the recent observed changes since the early 1990s. These paleolimnological studies concluded that, like many lakes of the western prairies, Lake Winnipeg was mildly eutrophic in its natural state (Bunting et al., 2011; Kling, 1998; Kling et al., 2011; Mayer et al., 2006) as a consequence of phosphorus-rich soils in the western and southern parts of the lake's catchment. Increasing clearing of the basin for agriculture and inputs of synthetic fertilizers and manure during the 20th century and a slowly increasing human population caused a slow increase in the lake's phytoplankton abundance over time. However, eutrophication increased very rapidly after the mid-1990s (Armstrong and McCullough, 2011; Kling et al., 2011; Figs. 2 and 3) as the result of the combination of factors reviewed below.

Changes to the watershed of Lake Winnipeg

Since the mid 20th century, several large reservoirs have been built on the Saskatchewan River, which was once the largest source of water to the lake (Fig. 1). The river drains a large, semi-arid area of Alberta and Saskatchewan. The reservoirs serve as traps for nutrients and silt, as well as sites of increased evaporation. The Saskatchewan watershed had warmed over 2 °C since the mid 20th century, mostly in winter and spring. The watershed has shown a strong trend to less precipitation, less snow, and earlier spring melts than it once had

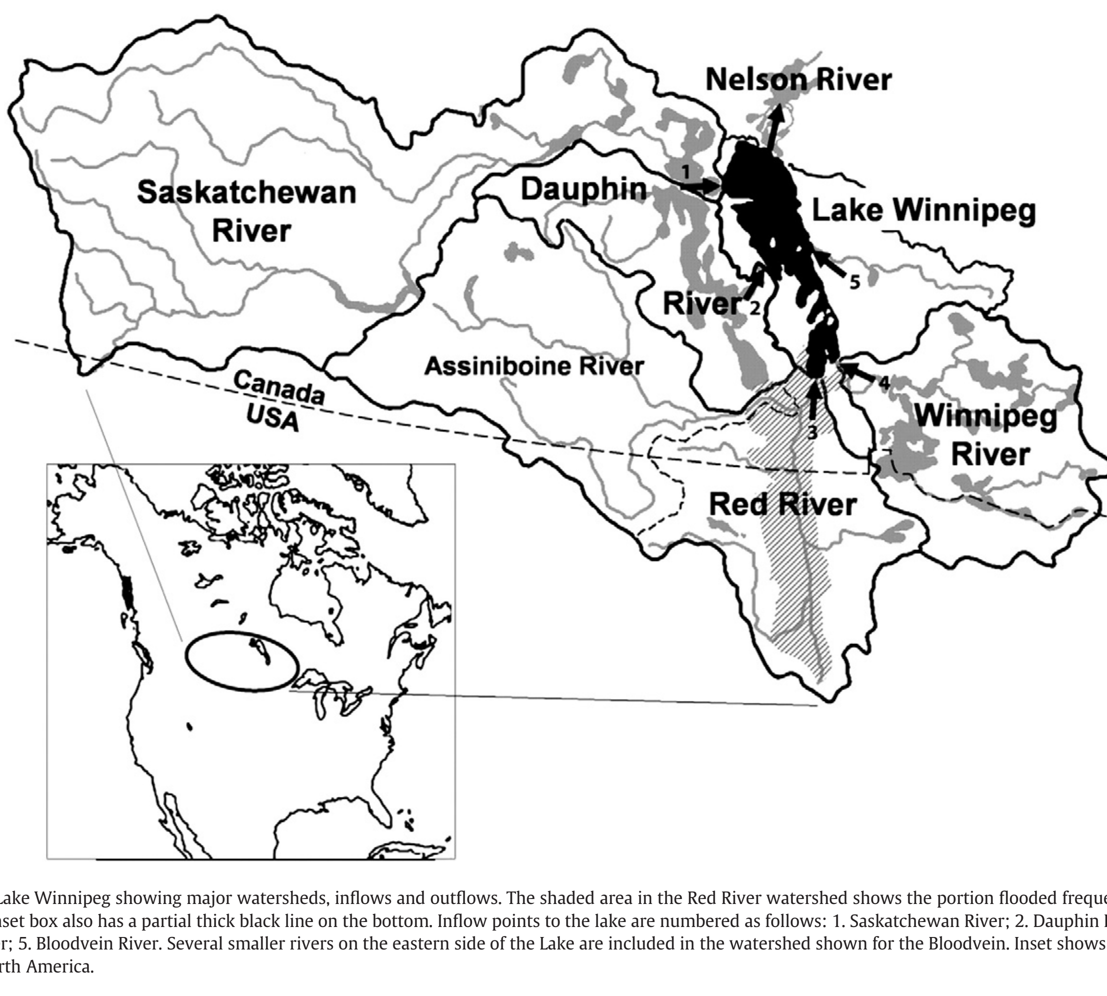

Fig. 1. A map of Lake Winnipeg showing major watersheds, inflows and outflows. The shaded area in the Red River watershed shows the portion flooded frequently during spring snowmelt. The inset box also has a partial thick black line on the bottom. Inflow points to the lake are numbered as follows: 1. Saskatchewan River; 2. Dauphin River; 3. Red River; 4. Winnipeg River; 5. Bloodvein River. Several smaller rivers on the eastern side of the Lake are included in the watershed shown for the Bloodvein. Inset shows the position of the watershed in North America.