Science of the Total Environment 575 (2017) 173–186

Contents lists available at ScienceDirect

Science of the Total Environment

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

Sediment and nutrient distribution and resuspension in Lake Winnipeg

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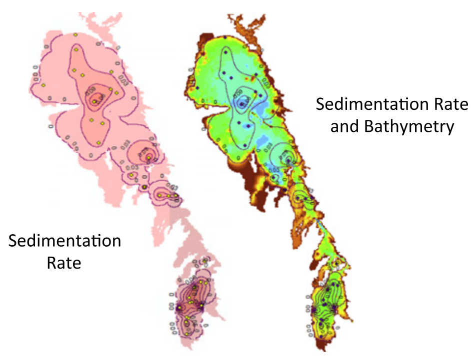
HIGHLIGHTS

- Sediment resuspension results in sediment focusing to deposition in deeper water.
- The majority of sediment in suspension is resuspended off the bottom.
- The upper ~7 cm sediment is resuspended for >20 years in the South Basin.
- ~30% of the TP is bioavailable (BAP).
- Internal loading yields a phosphorus flux comparable to the external loading flux.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 August 2016
Received in revised form 30 September 2016
Accepted 30 September 2016
Available online 11 October 2016

Editor: Jay Gan

Keywords:
Lake Winnipeg
Sediment resuspension
Internal loading
Sedimentation rates
Nutrients

ABSTRACT

Severe algal blooms in Lake Winnipeg since the late 1990s have been attributed to increased watershed nutrient loading, much of which is associated with suspended particles. Within-lake transport and fate of this nutrient fraction and the importance of internal loading via resuspension, however, are unknown. We measured radioisotopes (^{7}Be, ^{210}Pb, ^{137}Cs), metal and nutrient contents of suspended solids in major tributaries and lake-water, in sediment traps and in bottom sediments to estimate sediment resuspension and mass accumulation rates using two models. Sedimentation rates calculated from ^{137}Cs and ^{210}Pb dated cores and sediment traps indicated that most (95–99%) suspended material is derived from bottom sediment; mixing models using ^{7}Be/^{210}Pb and ^{137}Cs yielded similarly high estimates (82 and 84%, respectively). ^{137}Cs profiles in cores indicated that up to ~7 cm remains actively resuspended for times up to 23 years before incorporation into deeper sediments. Total and bioavailable phosphorus (TP, BAP) in this top sediment layer were generally lower in the North than the South Basin, likely reflecting inputs from the Assiniboine and Red Rivers at the southern end of Lake Winnipeg, with an average of ~30% TP as BAP. Estimates of average sediment-associated internal TP loading for the South Basin (0.264 g/m^2/y) were ~2× those for the North Basin (0.146 g/m^2/y). Together, this internal loading is comparable to the magnitude of the external loading. Our results indicate that surficial sediments in Lake Winnipeg will remain a significant and active source of internal nutrient loading for several decades, a process which may delay the response of the lake to external nutrient management.

1. Introduction

Lake Winnipeg (Manitoba) is the sixth-largest freshwater lake in Canada (23,750 km^2), and an important resource for fisheries, hydroelectric power and tourism. Since the late 1990s, the lake has undergone

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http://dx.doi.org/10.1016/j.scitotenv.2016.09.227

a major change in water quality and now experiences the annual summer development of severe blooms of cyanobacteria and diatoms (e.g. Kling et al., 2011). These blooms have been attributed to an increase in runoff and nutrient loading, particularly phosphorus (P), from the large, trans-boundary watershed with extensive agricultural development (Bunting et al., 2011; EC-MWS, 2011; McCullough et al., 2012; Schindler et al., 2012). Nutrient inputs, retention and recycling have also been affected by the conversion of Lake Winnipeg to a reservoir in the 1970s by the construction of dams on the major tributaries (Saskatchewan and Winnipeg Rivers) and at the northern outflow of the Lake.

River inflow to Lake Winnipeg varies significantly among years; between 1999 and 2007, for example, the total annual river inflow ranged between 537 and 6854 m^3/s. The bulk of the river inflow and the external nutrient input is delivered to the shallow South Basin (Fig. 1) via the Red and Assiniboine Rivers (49% and 16% of the hydraulic input, respectively), which account for ~68% of the annual phosphorus loading. A significant fraction of this input is in a highly bioavailable dissolved form (i.e. SRP; e.g. McCullough et al., 2012), but there is less understanding of the particle-bound fraction. Remote satellite imagery and in-lake measures of total suspended solids (TSS) show periodically high levels of suspended material in Lake Winnipeg derived from river inflows, shoreline erosion or bottom resuspension, particularly in the South Basin (10% volume; mean depth (z_m) = 9 m; water residence time = 1.3 y), the Narrows (9% volume, maximum depth (z_{max}) = 60 m) and along inshore areas of the North Basin (81% volume, z_m = 13.3 m; water residence time = 4.3 y) (Brunskill et al., 1980; Lévesque, 2011). This material can be translocated rapidly by winds and water movement across significant areas (e.g. Brunskill and Graham, 1979; Brunskill et al., 1979; McCullough et al., 2001). The composition of suspended solids varies both spatially and temporally across the drainage area and lake (EC-MWS, 2011). The largest external particulate load is delivered from the Red and Assiniboine Rivers, where its composition varies along the channel, largely derived from upstream field and downstream bank erosion (Koiter et al., 2013a). Suspended solids can reach significant levels in the shallow, wind-swept South Basin where they are largely comprised of mineral sediments, while the deeper, clearer North Basin supports enhanced primary productivity, significant blooms and a higher seston organic content (McCullough et al., 2001; EC-MWS, 2011).

Considerable effort has been devoted to estimating the total and dissolved P external loading and its export from the lake (McCullough et al., 2012; Zhang and Rao, 2012), but to date, the role of sediments in external nutrient loading and within-lake processing and recycling (transport, resuspension and retentive burial) has not been well characterized. Based on a few Red River samples (n = 9) collected at US-Canada border, McCullough et al. (2012) asserted that relative to the dissolved P loading the particulate fraction is low, and only

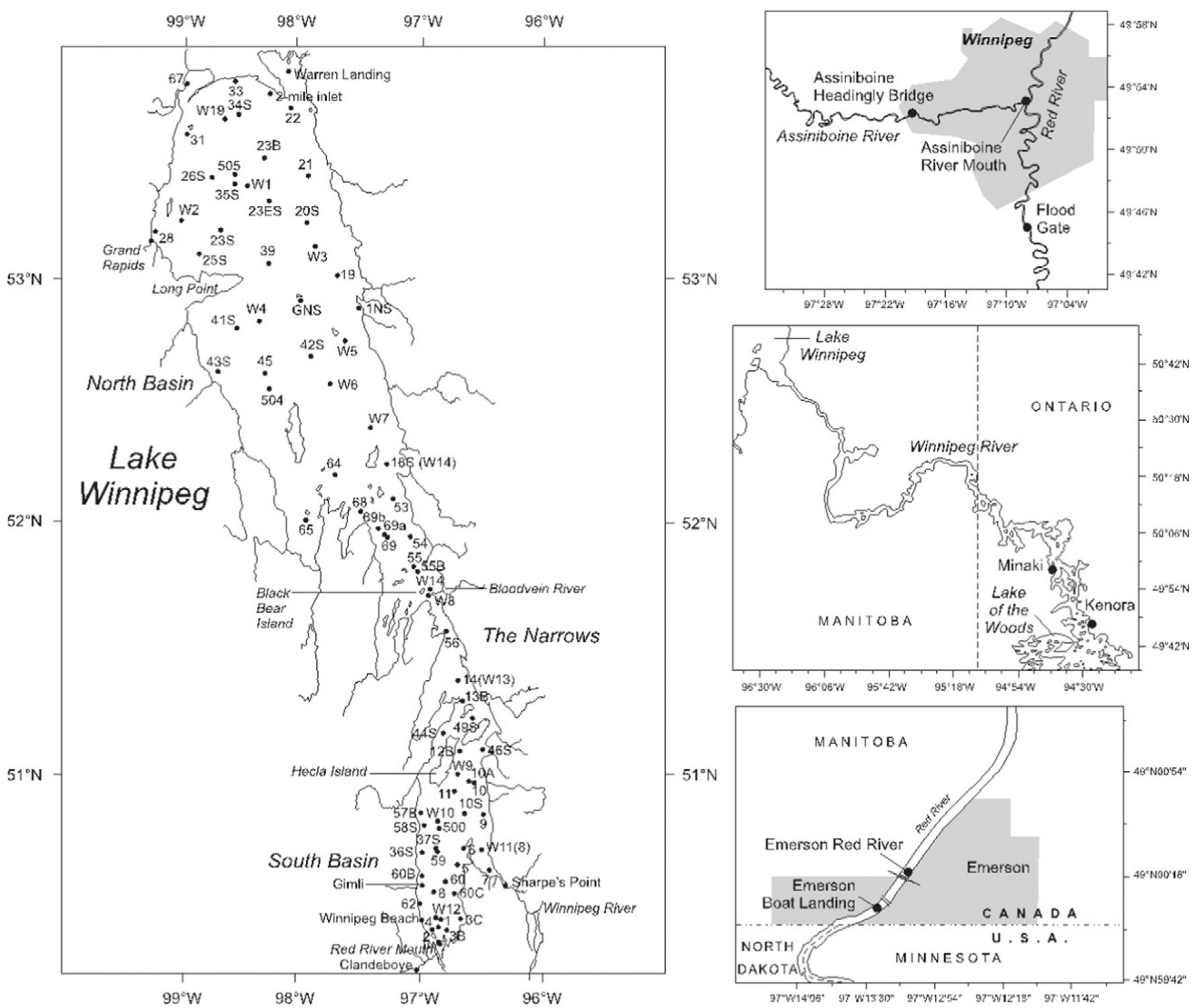

Fig. 1. Map of Lake Winnipeg showing core, suspended matter and sediment trap locations.