ARTICLE IN PRESS

JGLR-00681; No. of pages: 9; 4C:

Journal of Great Lakes Research xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

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

Sediment resuspension in the Lake Erie nearshore

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ARTICLE INFO

Article history:
Received 6 March 2013
Accepted 14 November 2013
Available online xxxx

Communicated by Thomas Bridgeman

Keywords:
Sediment
Resuspension
^{7}Be
^{210}Pb
Sediment trap

ABSTRACT

A decline in water quality in Lake Erie during the last decade, despite increased efforts to limit nutrient loading, may be better understood by examining internal processes in the lake. We employed ^{7}Be, ^{210}Pb and ^{137}Cs measurements of suspended matter in tributaries, in the lake water column, in atmospheric precipitation, in sediment traps and in bottom sediments collected in June and August/September 2011 to estimate the fraction of the suspended matter that is resuspended from the bottom. Mass balances on ^{7}Be and ^{210}Pb using sediment trap material indicated that at the nearshore site ~83–94% of suspended matter in the water column was resuspended bottom sediment, while, offshore, resuspended sediment made up only ~62–75%. A mass balance using the ^{7}Be/^{210}Pb ratio for each sediment source indicated that resuspension of bottom sediment accounted for 52–97% of the suspended material in the nearshore and from 53 to 86% of the suspended matter in the offshore and was greater after the fall overturn. The amount of nutrients delivered to the water column by resuspension indicates that the resuspension loading of particle-bound P to the lake is about the same as the tributary loading, although the resuspended P is likely to be significantly less bioavailable.

Introduction

During the 1960s Lake Erie experienced huge algal blooms, low oxygen waters, and fish kills reflecting the effects of significant eutrophication. Research and empirical and computer ecosystem models (e.g., Charlton, 1980; Di Toro and Connolly, 1980; Schelske and Stoermer, 1971; Vollenweider, 1976) identified phosphorus control as the best means of controlling eutrophication. Target levels for phosphorus loading were determined by binational collaborative programs and led to the implementation of the Great Lakes Water Quality Agreement (IJC, 1978) with a target annual phosphorus loading of 11,000 metric tons and the International Joint Commission (IJC) recommended programs that would achieve those loads. Phosphorus loadings declined steadily beginning in the late 1970s from over 25,000 metric tons/y to their present levels of 8000–12,000 metric tons/y (Dolan and McGunagle, 2001), phytoplankton biomass and cyanobacterial blooms had decreased (Makarewicz, 1993) and oxygen depletion rates decreased (Bertram, 1993). However, since about the mid-1990s, Lake Erie has experienced a number of water quality and ecosystem changes (Matisoff and Ciborowski, 2005). For example, although phosphorus loadings have remained at or below the target loading of 11,000 metric tons/y (except during wet years characterized by marked flood pulses), the extent of harmful and nuisance algal blooms (*Microcystis*; *Cladophora*) has increased (Conroy et al., 2005), bottom waters in the Central Basin appear to have gone anoxic sooner in the late summer months, and the areal extent of the anoxia has increased relative to previous years (Rockwell and Warren, 2003).

There are a number of potential explanations for these ecosystem and water quality changes, including: 1) increased internal loading of phosphorus possibly mediated by dreissenid mussels; 2) underestimation of some phosphorus inputs such as from urban storm water; 3) changes in the ecosystem that have led to changes in the nutrient uptake mechanisms and nutrient balances in the lake; 4) increases in bioavailable phosphorus loading despite relatively constant loadings of total phosphorus; and 5) weather/climate induced changes that affect lake levels and water temperatures and wind events that affect sediment resuspension and transport and nutrient release (Ohio EPA, 2010).

These changes that have occurred since the 1990s appear to have occurred coincident with widespread establishment of dreissenid mussels. The dreissenid mussels, which are in large numbers in the nearshore and shallow waters of Lake Erie, are thought to remove phytoplankton from the water column and deposit organic debris in the form of feces and pseudofeces on the bottom. In this 'nearshore shunt' model (Hecky et al., 2004) the net result is that nutrients are removed from the water column and end up as organic matter in the nearshore bottom sediment. Prior to mussels, the phytoplankton were not consumed to such a degree in the nearshore and therefore much of the organic matter was deposited throughout the lake, including the deeper waters offshore.

If nutrients are removed from the water column and end up as particulate organic matter in the nearshore bottom sediment, then resuspension will move nutrients from the nearshore to the offshore. The nearshore shunt hypothesis predicts that much of the phosphorus

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http://dx.doi.org/10.1016/j.jglr.2014.02.001

Please cite this article as: Matisoff, G., Carson, M.L., Sediment resuspension in the Lake Erie nearshore, J Great Lakes Res (2014), http://dx.doi.org/10.1016/j.jglr.2014.02.001

released is sorbed to or in particles that can be resuspended and transported to the outflow or to the offshore profundal environment (Hecky et al., 2004). We are testing this hypothesis by calculating the resuspension and measuring the nutrient concentrations in surficial and suspended sediments in both nearshore and offshore locations in different areas of the lake.

This paper is part of a collaborative study to better understand the movement of phosphorus and other nutrients and particles between the nearshore and the offshore zones in Lake Erie. To gain insight into the sources of the suspended matter we use naturally-occurring radionuclide tracers to distinguish bed sediments from other sources of suspended matter and to calculate the fraction of the suspended matter that is resuspended from the bottom. Naturally-occurring fallout radionuclides, namely ^{7}Be ($t_{1/2} = 53.3$ days) and ^{210}Pb ($t_{1/2} = 22.3$ years), may be used as tracers to differentiate the sources of suspended sediment (Olley et al., 1993; Walling and Woodward, 1992; Whiting et al., 2001, 2005; Wilson et al., 2005, 2007, 2008; Yeager et al., 2005). These radionuclides have been used previously as independent tracers to monitor sediment transport in rivers and coastal waters (Bonniwell et al., 1999; Cornett et al., 1994; Dominik et al., 1987; Fitzgerald et al., 2001; Jweda and Baskaran, 2011; Jweda et al., 2008; Matisoff et al., 2002a, 2002b, 2005; Olsen et al., 1986; Robbins and Eadie, 1991) and in atmospheric deposition (Baskaran et al., 1993; Lamborg et al., 2000; Turekian et al., 1983).

Both ^{7}Be and ^{210}Pb are produced continuously in the atmosphere; ^{7}Be is formed by cosmic ray spallation of nitrogen and oxygen in the stratosphere, and ^{210}Pb is an intermediate in the ^{238}U-decay series. Atmospheric ^{7}Be and ^{210}Pb are delivered to the landscape and the lake surface primarily by precipitation (Todd et al., 1989; Wallbrink and Murray, 1996). The radionuclides strongly adsorb to particles (K_d for ^{7}Be ~0.1–2.3 × 10^{5} L/kg; K_d for ^{210}Pb ~0.1–6.5 × 10^{5} L/kg; Hawley et al., 1986; Jweda et al., 2008), have Kds ~10^{5} at the pH of lake water (Kaste and Baskaran, 2011), and are therefore good tracers of particles. This atmospheric delivery of radionuclides results in suspended matter which has a characteristic signature that can be monitored as the particles travel from source areas in the upper parts of the watershed to the final deposition areas (Matisoff et al., 2005; Wilson et al., 2005). The ^{7}Be/^{210}Pb ratio can be used to differentiate between freshly delivered sediment and resuspended bed sediment because of differences in half-lives and time since the suspended matter sorbed the ^{7}Be and ^{210}Pb (Matisoff et al., 2005; Wilson et al., 2005, 2007). This ratio decreases with time due to the more rapid decay of ^{7}Be compared to ^{210}Pb and/or due to the mixing of fresh sediment derived from the landscape with older bed sediment. Sediment, which has been in residence on the lake bed for some time, is depleted in ^{7}Be relative to ^{210}Pb because the radionuclides have undergone decay (Matisoff et al., 2005; Wilson et al., 2005). The ^{7}Be/^{210}Pb ratio of the bed sediments is extremely low (<0.5; Matisoff et al., 2005) relative to the freshly tagged sediment (range: 2 to 16; Matisoff et al., 2005). In this study we measure the ^{7}Be and ^{210}Pb activities of suspended matter in tributaries, in the lake water column, in atmospheric precipitation, in sediment traps and in bottom sediments and develop mass balances to estimate the fraction of the suspended matter that is resuspended from the bottom. These data will then help in interpreting the transport of nutrient and material fluxes between the nearshore and the offshore and how those differences vary between the Eastern, Central and Western Basins of Lake Erie.

Methods

Suspended and bottom sediments were collected at four onshore to offshore transects throughout Lake Erie. Sampling locations, sampling dates, water depths and a general description of each site is given in Table 1 and the locations are shown in Fig. 1. The transects were located east or west of the tributary inflows. The Eastern Basin transect was located near Cattaraugus Creek; the Central Basin transects were located near the Ashtabula River and the Grand River; and the Western Basin transect was located off Sterling State Park near the River Raisin. The nearshore sites were located in a 5 m water depth, and the offshore sites were located in a 20 m water depth except in the Western Basin where the offshore site was located in an 8 m water depth. Two additional sites were sampled in June. In addition, the tributaries were sampled upstream of their inflow to Lake Erie near their respective USGS gage stations.

Sediment traps were deployed and retrieved at two of the sampling sites (Table 1). One trap was located at the shallow water site near the Ashtabula River and was deployed on 16 June 2011 and retrieved on 19 August 2011 (64 days). The other site was located in the deep water site off Cattaraugus Creek and was deployed on 6 June 2011 and retrieved on 26 August 2011 (81 days). Sediment traps were constructed from 5/8″ thick 6″ ID PVC pipe and had a 1:5 width to length ratio (Bloesch and Burns, 1980; Gardner, 1980a,b). Traps were deployed in a vertical mooring 1 m above the lake bottom and marked with a surface buoy. Trap material was collected through a funnel at the bottom of the trap into a 1-L bottle within which formalin had been added to prevent degradation of trap material prior to collection and analysis. Collected trap material was dried and analyzed for TP, TN, ^{7}Be and ^{210}Pb. Radionuclide activities were decay-corrected to the mid-point of the deployment interval.

Atmospheric deposition (wet plus dry) of the radionuclides was monitored before and during the study period. Atmospheric bulk deposition samples were collected using a polyethylene bucket with a 20-L volume and a 630-cm^{2} surface area. Fifty milliliter of 1 N HCl was added to the bucket at the time of deployment to decrease the potential volatilization loss of ^{7}Be and ^{210}Pb, but the amounts of radionuclides

Table 1
Location ID with dates sampled and site descriptions.

Site ID	Latitude/longitude	Dates sampled	Site description
WB-SS-5 m	41° 40.00′N/083° 10.10′W	6/22/2011[a] and 9/21/2011	Nearshore West Basin (Sterling State Park) Site, Depth 5 m
WB-SS-8 m	41° 53.41′N/083° 09.59′W	6/2/2011[a] and 9/21/2011	Offshore West Basin (Sterling State Park) Site, Depth 8 m
CB-GRE-5 m	41° 46.2281′N/081° 13.6168′W	6/9/2011	Nearshore Grand River East Site, Depth 5 m
CB-GRW-5 m	41° 44.818′N/081° 19.316′W	6/9/2011 and 8/18/2011	Nearshore Grand River West Site, Depth 5 m
CB-GRW-20 m	41° 48.6200′N/081° 26.0803′W	6/1/2011[a] and 8/18/2011	Offshore Grand River West Site, Depth 20 m
CB-ASH-5 m[b]	41° 54.4296′N/080° 48.4578′W	6/16/2011[a] and 8/19/2011	Nearshore Ashtabula River Site, Depth 5 m
CB-ASH-20 m	41° 59.5001′N/080° 49.2903′W	6/1/2011[a] and 8/19/2011	Offshore Ashtabula River Site, Depth 20 m
EB-CCW-5 m	42° 33.3589′N/079° 10.8192′W	6/6/2011 and 8/26/2011	Nearshore Cattaraugus Creek West Site, Depth 5 m
EB-CCW-10 m	42° 33.822′N/079° 09.858′W	6/6/2011[a]	Nearshore Cattaraugus Creek West Site, Depth 10 m
EB-CCW-20 m[b]	42° 35.6284′N/079° 13.0839′W	6/6/2011[a] and 8/26/2011	Offshore Cattaraugus Creek West Site, Depth 20 m
MR-Trib	41° 30.00′N/083° 42.77′W	6/2/2011 and 9/21/2011	Maumee River near USGS Gauge Station 04193500
GR-Trib	41° 43.152′N/081° 13.689′W	6/8/2011 and 8/21/2011	Grand River near USGS Gauge Station 04212100
AR-Trib	41° 52.412′N/080° 46.892′W	6/7/2011 and 8/21/2011	Ashtabula River near Cederquist Park
CC-Trib	42° 27.906′N/ 078° 56.156′W	6/7/2011 and 8/21/2011	Cattaraugus Creek near USGS Gauge Station 04213500

[a] Indicates sediment core collection on the date indicated.
[b] Indicates sediment trap at the site was deployed in June and retrieved in August.

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