Journal of Great Lakes Research 42 (2016) 588–598

Contents lists available at ScienceDirect

Journal of Great Lakes Research

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

Groundwater loading of nitrate-nitrogen and phosphorus from watershed source areas to an Iowa Great Lake

Keith E. Schilling [a,*], Matthew T. Streeter [a], Deborah Quade [b], Mary Skopec [b]

[a] Iowa Geological Survey, University of Iowa, Iowa City, IA, United States
[b] Iowa Department of Natural Resources, Des Moines, IA, United States

ARTICLE INFO

Article history:
Received 4 December 2015
Accepted 21 March 2016
Available online 18 April 2016

Communicated by Harvey Thorleifson

Index words:
Lake
Groundwater
Nutrients
Iowa
Okoboji
Mass balance

ABSTRACT

Groundwater discharge to a lake can be an important component to water and nutrient budgets. In this study, we evaluated groundwater loading of nitrate-nitrogen (NO_3-N) and phosphorus (P) to West Lake Okoboji, Iowa, using a watershed-based approach based on groundwater recharge and land cover class. Our objectives were to assess groundwater level fluctuations and nutrient concentrations under representative land use classes and develop an allocation model for groundwater nutrient loads based on land cover class. Monitoring wells were installed at 21 locations around the lake and sampled during a three-year study period. Groundwater quality varied among the land cover types with average NO_3-N concentrations the highest beneath cropped fields (8.8 mg l^{-1}) and residential areas (2 mg l^{-1}), and P concentrations ranging between 0.05 and 0.1 mg l^{-1} throughout the region. NO_3-N loads were the highest under cropped fields and this source accounted for approximately 90% of the NO_3-N, whereas P loads were more evenly distributed among source areas. Groundwater recharge averaged approximately 76 mm $year^{-1}$ for vegetated areas and substantially less for urban areas. Based on mass balance, groundwater discharge may account for 80% of the NO_3-N in the lake compared to 10% of the P. Results are instructive to more effectively target implementation of conservation practices to major nutrient loading areas for reduction of NO_3-N and P delivered to the lake.

Introduction

Groundwater discharge to a lake (also referred to as "exfiltration") is an important, if often underappreciated, component of water and nutrient budgets. Recent reviews by Rosenberry et al. (2015) and Lewandowski et al. (2015) identified 13 different hydrologic and nutrient-related reasons for why groundwater discharge to lakes tends to be neglected, among which heterogeneities in spatial and temporal discharge of groundwater and nutrient concentrations to lakes were commonly cited. Quantifying nutrient discharge to lakes is critical considering that eutrophication is a major threat to lake ecosystems (Smith, 2003; Conley et al., 2009). New approaches for quantifying groundwater contributions of nitrogen (N) and phosphorus (P) to lakes are needed (Meinikmann et al., 2013; Robinson, 2015).

Methods of quantifying groundwater nutrient flux to lakes tend to rely on groundwater observation wells near lake shorelines and application of Darcy's Law (LaBaugh et al., 1997; Harvey et al., 2000), seepage meters and minipiezometers (Lee and Cherry, 1978; Shaw and Prepas, 1990), modeling (Anderson and Munter, 1981; Hunt et al., 2003) or a combination thereof (Simpkins, 2006). Unfortunately, these methods often produce significantly different results, due in part, to differences in measurement scales (Simpkins, 2006). In a study of Lake Arendsee in Germany, Meinikmann et al. (2013) combined well measurements with an integrative groundwater recharge calculation to estimate groundwater P loads to the lake. In their approach, the mean annual lacustrine groundwater discharge to a lake was equal to mean groundwater recharge in the watershed and direct groundwater discharge to the lake was established using lake bed temperature profiles (Meinikmann et al., 2013). Indirect groundwater discharge occurs to the Great Lakes through baseflow to tributary streams that discharge into the lakes (Kornelsen and Coulibaly, 2014; Grannemann et al., 2000). A method of estimating groundwater loads discharged to lakes based on recharge and land use holds promise for many lakes in Iowa where lake water quality is known to be influenced by agricultural activities occurring in the lake watershed (Arbuckle and Downing, 2001).

West Lake Okoboji located in northwest Iowa (Fig. 1) is considered one of Iowa's premier tourist destinations, attracting more than 1,000,000 annual visitors and supporting abundant recreational boating and fishing opportunities (*http://www.vacationokoboji.com/*). The 15.57 km^2 lake is part of a chain of lakes known as the Iowa Great Lakes, consisting of Spirit Lake, East Lake Okoboji, Upper and Low Gar and Minnewashta lakes. Over the past 15 years, concentrations of NO_3-N nitrogen and total phosphorus in West Lake have ranged from <0.06 to 0.22 mg l^{-1} and <0.02 to 0.08 mg L^{-1}, respectively (IDNR,

* Corresponding author.
E-mail address: keith-schilling@uiowa.edu (K.E. Schilling).

http://dx.doi.org/10.1016/j.jglr.2016.03.015

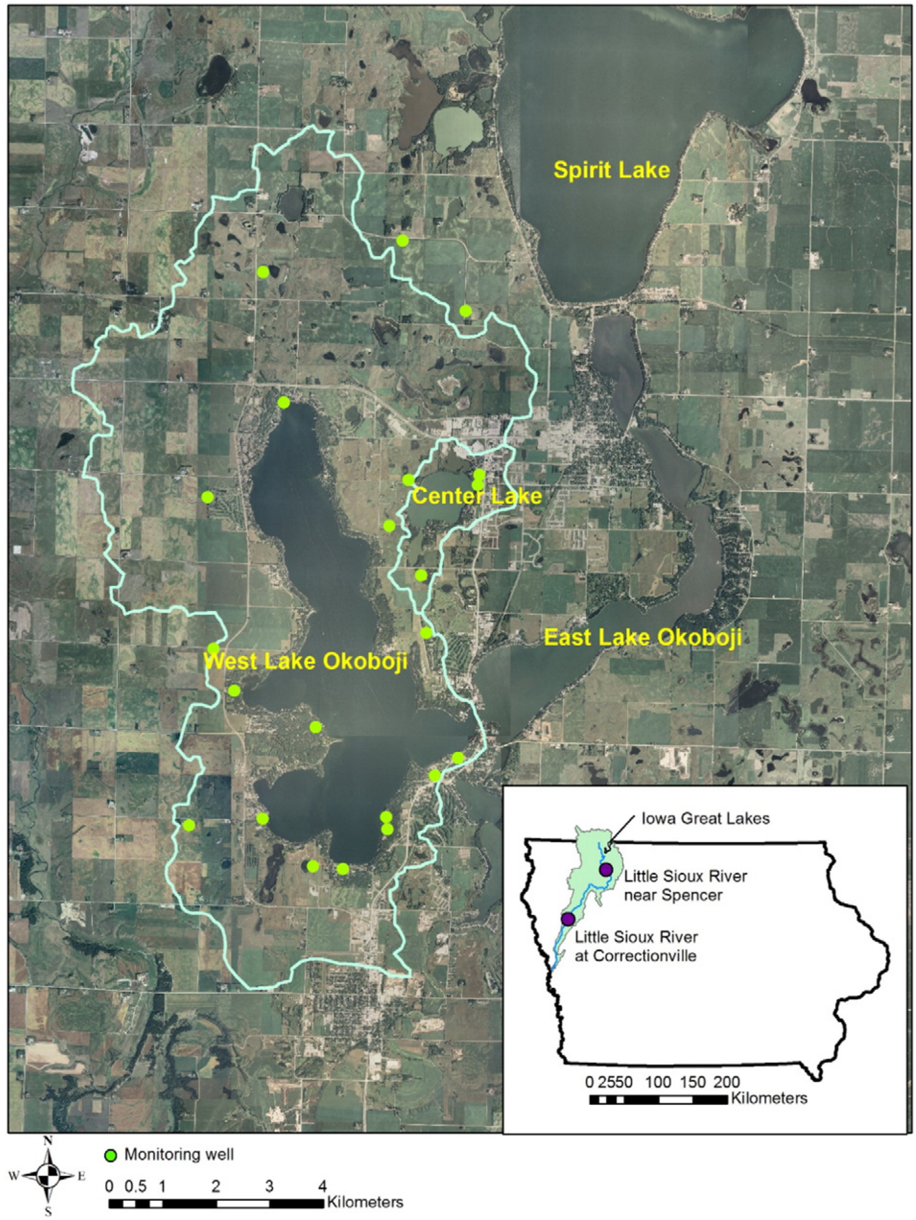

Fig. 1. Location of West Lake Okoboji, Iowa, monitoring well installations and regional baseflow sites.

2015). Although not particularly elevated compared to other Iowa lakes (IDNR, 2015), it is the ratio of N and P that influences algae species composition, productivity and trophic status (Arbuckle and Downing, 2001; Downing and McCauley, 1992). Hence, it is important that sources of N and P to West Lake Okoboji be quantified so that future eutrophication threats to the lake and the resulting impacts on the regional economy can be mitigated.

In the case of West Lake Okoboji, efforts directed at quantifying groundwater nutrient flux using point measurements near the lake shoreline (i.e., wells, seepage meters) would be prone to substantial error. As the deepest natural lake in Iowa, reaching a maximum depth of 41.4 m, the lake penetrates a thick sequence of heterogeneous glacial sediments in the subsurface that contribute an unknown amount of groundwater to the lake. It would be exceedingly difficult and expensive to intercept potential groundwater flow paths where they discharge (or exfiltrate) into the lake. Furthermore, groundwater flow paths in the watershed are complex and influenced by many factors such as subsurface tile drainage and ponds/wetlands, and N and P are often transformed along flow paths due to biogeochemical processes.

To address these challenges, our study focused on quantifying the contribution of nutrient concentrations and loads from various land cover source areas in the watershed. Using a watershed-based approach, we quantified the groundwater loading of NO_3-N and P by land cover class to assess the potential for these land areas to contribute nutrient loads delivered to West Lake Okoboji through groundwater recharge. The objectives of this study were to: 1) assess groundwater level fluctuations and recharge in the West Lake Okoboji watershed; 2) quantify groundwater nutrient concentrations under representative land use classes; and 3) develop a load allocation model for groundwater nutrient inputs to the lake that can be used to target future nonpoint source load reduction strategies.

Hydrogeological setting

Iowa Great Lakes Region (IGLR) is located along the southwestern edge of the Des Moines Lobe (DML) ice sheet, the southernmost extension the Laurentide Ice Sheet that surged into Iowa approximately 15,000 years ago (Bettis et al., 1996). The initial advance of the DML