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Thinking outside of the lake: Can controls on nutrient inputs into Lake Erie benefit stream conservation in its watershed?

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ABSTRACT

Investment in agricultural conservation practices (CPs) to address Lake Erie's re-eutrophication may offer benefits that extend beyond the lake, such as improved habitat conditions for fish communities throughout the watershed. If such conditions are not explicitly considered in Lake Erie nutrient management strategies, however, this opportunity might be missed. Herein, we quantify the potential for common CPs that will be used to meet nutrient management goals for Lake Erie to simultaneously improve stream biological conditions throughout the western Lake Erie basin (WLEB) watershed. To do so, we linked a high-resolution watershed-hydrology model to predictive biological models in a conservation scenario framework. Our modeling simulations showed that the implementation of CPs on farm acres in critical and moderate need of treatment, representing nearly half of the watershed, would be needed to reduce spring/early summer total phosphorus loads from the WLEB watershed to acceptable levels. This widespread CP implementation also would improve potential stream biological conditions in >11,000 km of streams and reduce the percentage of streams where water quality is limiting biological conditions, from 31% to 20%. Despite these improvements, we found that even with additional treatment of acres in low need of CPs, degraded water quality conditions would limit biological conditions in >3200 stream km. Thus, while we expect CPs to play an important role in mitigating eutrophication problems in the Lake Erie ecosystem, additional strategies and emerging technologies appear necessary to fully reduce water quality limitation throughout the watershed.

Introduction

Reducing nutrient inputs from the western Lake Erie basin (WLEB) watershed is integral to reversing Lake Erie's recent re-eutrophication (Ohio EPA, 2010, 2013; Scavia et al., 2014; Annex 4, 2015). This large watershed (~26,000 km^2) drains a landscape that is >70% agricultural and contains nearly 2 million ha of farmland that is mostly in corn and soybean crop rotations (USDA NRCS, 2011). Multiple changes in local agricultural practices have occurred during the past 30 years, including the type of fertilizer used, the timing of fertilizer application, tillage practices, and increased artificial drainage, the combination of which has increased the potential for nutrient runoff into Lake Erie from the WLEB watershed (Richards et al., 2002; Daloğlu et al., 2012; Smith et al., 2015). When combined with an increasing frequency of single and multi-day severe storms during the winter and spring (Hayhoe et al., 2010) and the widespread nature of legacy loads (Sharpley et al., 2013; Powers et al., 2016), these changes in agricultural practices have contributed to increased loading of highly bioavailable dissolved reactive phosphorus into Lake Erie (Richards et al., 2010; Daloğlu et al., 2012; Scavia et al., 2014). This excess phosphorus loading, in turn, has helped fuel Lake Erie's re-eutrophication (Stumpf et al., 2012; Michalak et al., 2013; Kane et al., 2014; Scavia et al., 2014). Because eutrophication poses a threat to important ecosystem services

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provided by Lake Erie (Ludsin et al., 2001; Hobbs et al., 2002), reducing phosphorus loading from WLEB tributaries is a management priority (Ohio EPA, 2010, 2013; Scavia et al., 2014; Annex 4, 2015).

While efforts to reduce phosphorus loading will benefit Lake Erie, the extent to which these efforts will help improve water quality and biological conditions in the ecologically, culturally, and economically important stream network of the WLEB watershed remains uncertain. This network contains >20,000 km of streams and rivers that historically supported a rich diversity of invertebrates and fish (Trautman, 1981; Krebs et al., 2010). The WLEB watershed, much like Lake Erie proper, provides valuable ecosystem services (e.g., drinking water; recreational opportunities such as fishing and canoeing) to residents in Indiana, Michigan, and Ohio. Unfortunately, stream water quality in the watershed also has become degraded during the past century, owing in large part to the same agricultural sediment and nutrient non-point source (NPS) runoff that has degraded Lake Erie (Karr et al., 1985; Ohio EPA, 2014). Thus, reducing agricultural NPS runoff to help clean up Lake Erie may offer an opportunity to improve water quality and biological conditions throughout the WLEB stream network. Because farmers in the area feel a strong sense of responsibility to protect water quality in their local watersheds (Burnett et al., 2015), they might be more willing to adopt voluntary and potentially costly agricultural conservation practices (referred to as CPs hereafter), if they knew that such practices would benefit their local watershed in addition to benefiting downstream Lake Erie. Such adoption, in turn, could lead to a potential "win-win" for user groups of both Lake Erie and its watershed.

At present, however, perceived benefits of targeted phosphorus load reductions for Lake Erie have not included consideration of the possible benefits to the large stream network contained within the WLEB watershed. Thus, the extent to which targeted load reductions to Lake Erie also might improve water quality, biological conditions, and ecosystem services throughout WLEB tributaries remains an important information gap. A better understanding of where and by how much water quality and biological conditions would change throughout the WLEB watershed because of targeted load reductions to Lake Erie also could help prioritize nutrient management strategies.

Because agriculture is the dominant form of land use in the WLEB watershed, one approach to reducing nutrient loading from this watershed is to increase implementation of CPs. These CPs could include erosion control practices such as filter strips and cover crops, as well as nutrient management, which includes altering the rate, timing, amount, and method of fertilizer application. Since the mid-1970s, CPs, in particular erosion control practices such as conservation tillage, have been widely adopted in the WLEB watershed (Richards et al., 2002). These practices appear to have reduced nutrient and suspended sediment concentrations in some Lake Erie tributaries (Richards and Baker, 2002; Richards et al., 2009), and are correlated with recent improvements in stream biological conditions (Miltner, 2015). How effective additional investment in these and other widely adopted CPs would be for meeting Lake Erie nutrient reduction goals remains unknown. Even more uncertain is how additional conservation treatment of cropland would affect stream conditions and the resident aquatic biota within Lake Erie's watershed.

Herein, we provide findings from a coupled physical–biological modeling study that sought to quantify the potential benefits of increasing investment in CPs to stream biological conditions within Lake Erie's watershed. More specifically, we linked an existing high-resolution watershed-hydrology model for the WLEB watershed (Daggupati et al., 2015a) to a predictive statistical model of an Index of Biotic Integrity (IBI) developed from several long-term state-agency datasets to forecast potential benefits of additional investment in CPs. While our simulations were not designed to provide the most cost-effective solutions nor model stream impacts of reducing phosphorus loads to the levels recommended for Lake Erie, several of them more than satisfactorily met the targeted reductions in phosphorus loading to the lake. Ultimately, we discuss the potential of CPs to simultaneously meet water quality goals in Lake Erie and benefit stream biological conditions within the WLEB watershed.

Methods

Study area and species

We focused on the WLEB watershed because it is integral to effective Lake Erie nutrient management (Ohio EPA, 2010, 2013; Scavia et al., 2014; Annex 4, 2015). This relatively flat watershed (average slope is <2%) drains an ~26,000 km^2 area in portions of Ohio, Indiana, and Michigan (Fig. 1). Most of the watershed falls within the Eastern Corn Belt Plains or the Huron/Erie Lake Plains Ecoregions, although a small portion (<2%) is in the Southern Michigan/Northern Indiana Drift Plains. Historically, this watershed was comprised of a mixture of hardwood forests, wetlands, and prairie, which eventually succumbed to rapid and widespread land clearing, wetland draining, and stream channelization that began during the mid-1800s (Trautman, 1981). Today, >70% of the watershed is in row-crop agriculture, with patchily distributed urban and forested lands each making up ~12% of the remaining area. Because of this topography and land-use history, most streams in the WLEB watershed are low gradient and slow flowing, carrying heavy nutrient and sediment loads that have negatively impacted native stream biodiversity and Lake Erie (Trautman, 1939; Trautman and Gartman, 1974; Karr et al., 1985; Scavia et al., 2014).

The stream network of the WLEB watershed historically supported a diverse fish fauna (Trautman, 1981). At least 98 native fish species that span a wide range of reproductive (e.g., nest builders, crevice spawners, broadcast spawners), feeding (e.g., detritivores, herbivores, invertivores, piscivores), and habitat (e.g., benthic, pelagic, littoral) guilds have been observed in the watershed. These species have different sensitivities to nutrient and sediment pollution (Trautman, 1981; Ohio EPA, 1987). In turn, different fish communities occur throughout the WLEB watershed, with their composition likely determined to some degree by the magnitude and intensity of agricultural runoff impacts on water quality. Degraded water quality in this watershed has indeed negatively affected piscivores, herbivores, and insectivores in particular, leading to fish communities dominated by omnivorous species (Karr et al., 1985).

Modeling stream water quality

We simulated sediment and nutrient processes and stream hydrology using the Soil and Water Assessment Tool (SWAT; Arnold et al., 1998). SWAT is a semi-distributed, continuous-time model developed by the United States Department of Agriculture — Agricultural Research Service for large-scale watershed simulation. SWAT is a robust and flexible approach for simulating agricultural effects on hydrologic processes that performs well relative to other watershed models in the WLEB watershed (Gebremariam et al., 2014).

We used SWAT to develop a watershed model (Daggupati et al., 2015a) at the 1:100,000 resolution using the National Hydrography Database Plus Version 2 (NHDPlusV2) dataset (http://www.horizon-systems.com/NHDPlus/NHDPlusV2_home.php). However, because conducting simulations at this resolution was too computationally expensive, we initially calibrated model parameters at a broader watershed resolution (12-digit hydrologic unit code, HUC-12). Afterwards, we transferred those parameters to the NHDPlusV2 model to provide reasonable starting points for parameter values for this finer-resolution model. We further calibrated monthly stream flow, suspended sediment, total phosphorus (TP), and total nitrogen (TN) for the NHDPlusV2 model using five river gauges that had historical data with these attributes: 1) the Raisin River near Monroe, MI; 2) St. Joseph River near Newville, IN; 3) St. Marys River at Wilshire, OH; 4) Maumee River at Waterville, OH; and 5) Sandusky River near Fremont, OH. Detailed descriptions of the calibration and validation

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