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Sustainable management of Great Lakes watersheds dominated by agricultural land use

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ABSTRACT

Runoff of agricultural nutrients and sediments has led to re-eutrophication of lakes and impaired stream health in the Great Lakes Basin since around 2000 following earlier success in protecting water quality. Substantial investment in conservation actions has had insufficient impact, due in part to a limited basis for understanding the likely environmental outcomes of those investments. This article introduces a special section focusing on promoting investment that produces environmental outcomes as opposed to investing in conservation actions with unknown effects. The special section contains articles in three main categories: 1) studies based on fine-grain SWAT and other simulation modeling that can guide the type, amount, and location of conservation investments to increase their environmental impact; 2) edge-of-field measurement studies that provide updated knowledge to assist in further refining models to increase their predictive power; and 3) articles presenting innovative approaches to incentivizing outcome-oriented conservation investment. Implementation approaches discussed include certifying private crop nutrient advisors as recommending only appropriate timing, amount, and placement of nutrients; working within the existing public drain management system to incentivize conservation; and others. The special section shows that advances in SWAT modeling provide a powerful basis for targeting conservation investments to protect water quality in the Great Lakes Basin, while also demonstrating opportunities to further refine the models. It illustrates both the opportunity and the need to engage in more innovative institutional design of agricultural management programs that go beyond the traditional government programs and do more to reward outcomes and not just actions.

Introduction

Over the past 15–20 years the Laurentian Great Lakes of Canada and the United States have seen a resurgence of serious eutrophication symptoms that had largely disappeared following the implementation of phosphorus load reductions of the 1970s. Large harmful algal blooms in Lake Erie have been in the news in the last 15 years and particularly since 2011, but the problem also extends to other major bays, such as Green Bay in Lake Michigan, Saginaw Bay in Lake Huron, and the Bay of Quinte in Lake Ontario. Additionally, nearshore algal problems (e.g., *Cladophora*) and hypoxia have plagued parts of the Great Lakes, in some cases covering a greater area than such problems did in the 1970s and causing a significant loss of ecosystem services in the Great Lakes Basin (Scavia et al., 2014; IJC, 2014; Smith et al., 2015; Michalak et al., 2013). Impairments to stream water quality and fish community health in the Great Lakes Basin have accompanied these problems (Karr et al., 1985; Rankin et al., 1999; Diana et al., 2006.)

Until the recent problem of re-eutrophication, intense nutrient pollution in the Great Lakes Basin was largely seen as a problem of the past. Great strides to control nutrient pollution were made in the 1970s thanks to the United States Clean Water Act and the Great Lakes Water Quality Agreement between the U.S. and Canada (DePinto et al., 1986a; Botts et al., 2001; Jetoo et al., 2015). These initiatives addressed mainly point sources of water pollution such as municipal and industrial wastewater effluents that were the major causes of nutrient pollution at the time. Further progress in the 1980s contributed to an understanding of the role of nonpoint source pollution, particularly from agricultural production. This led to a substantial reduction in nonpoint source loading of both nutrients and suspended solids to Lake Erie, largely through a broad implementation of no-till and conservation tillage practices in Lake Erie agricultural lands (DePinto et al., 1986a).

Recent monitoring, modeling, and research have implicated agricultural nonpoint source nutrient loads of bioavailable phosphorus as a major driver for the resurgence of eutrophication symptoms in the Great Lakes Basin (Scavia et al., 2014; IJC, 2014; Smith et al., 2015). Nutrients from agricultural runoff also have contributed to stream impairments (Wang et al., 2007; Weigel and Robertson, 2007). This is worrying because over the years, impressive investments have been

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made to develop, test and deploy conservation practices (best management practices); expand federal soil and water conservation programs; expand voluntary payment-for-environmental-services programs; and increase grant-making to public and private sector agencies and organizations. Yet water quality appears to be declining, as indicated both by algal blooms and by in-stream biological integrity in many places. As a consequence, the ecosystem services that people enjoy from Great Lakes watersheds are being impaired, notably municipal drinking water, recreational swimming and beach use, and fishing. Clearly the current efforts to limit agricultural nonpoint source pollution are inadequate (Garnache et al., 2016).

This special section presents and synthesizes integrated ecological-economic research on Great Lakes agricultural watersheds with the goals of providing management guidance at the watershed scale and to identify and prioritize future research needs in this area. Several key facts underlie the research presented. First, despite the large volume of research on nonpoint source pollution from agriculture, there is a need for a better quantitative prediction of the linkage between individual actions at the field scale with environmental performance indicators at the watershed scale.

Second, the major conservation investments over the years have focused primarily on the extent of area covered by conservation practices. Limited understanding of the actual conservation outcomes associated with specific practices has made it impossible to maximize the conservation impacts of those investments. An increased focus on the connection between conservation actions and environmental outcomes is essential to begin to overcome the water pollution problems associated with intensive agricultural production.

Third, any steps taken to promote conservation must recognize and accommodate the extremely important role of agriculture in the economy of the Great Lakes Basin. Agriculture occupies over a third of the land area of the Basin, supporting 7% of American and nearly 25% of Canadian farm production. The Great Lakes Basin generates about $15 billion annually in the U.S. in livestock, dairy, grain and corn products. Farmland values alone account for billions of dollars in underlying capital investments. Advances in conservation are needed that minimize tradeoffs between protection of water quality with economic output from agriculture.

A related point is that laws in the US and Canada decree that for the most part growers have the right to manage agricultural production in the way that they deem most suitable, without liability for downstream effects of their practices (Rabotyagov et al., 2014; Rajsic et al., 2012). In particular, there are few restrictions preventing practices that would limit the escape of added nitrogen and phosphorus from agricultural fields into waterways. Under current conditions, efforts to promote conservation on agricultural lands must focus on encouraging voluntary adoption (Claassen et al., 2008).

This special section contains articles that help establish better connections between conservation actions and outcomes, and articles that expand understanding of how to promote grower adoption of agricultural conservation practices in ways that achieve cost-effective environmental outcomes while also supporting a healthy agricultural industry. Fundamentally, the approach aims to establish relevant, realistic outcome goals and achieve them by deploying appropriate practices at the appropriate time, place and scale. The special section provides examples of the science needed to manage for the appropriate time, place, and scale of practices, examples of programs and policies that are informed by this science, and situation analysis of current and future desired conditions.

Science to inform policies and programs

Understanding key sources of agricultural nonpoint source pollution

Considerable research has focused on developing a better quantitative understanding of the relationship between agricultural practices on the land and bioavailable phosphorus stream transport and loads reaching the Great Lakes from tributaries such as the Maumee River (Smith et al., 2014; Jarvie et al., 2013; Scavia et al., 2016). Researchers have recognized that phosphorus on agricultural fields can be exported to the stream network of a watershed by a number of pathways, including surface runoff, soil erosion (including ephemeral gullies), near-surface interflow, and tile drainage systems. The greatest concern is the export of algal available phosphorus. Previous research showed that 25–50% of particulate phosphorus (PP) and close to 100% of dissolved reactive phosphorus (DRP) coming off agricultural land is ultimately available for growth of nuisance algae (DePinto et al., 1981, 1986b, 1986c). Because of the recent dramatic increase of DRP loads from Lake Erie tributaries whose watersheds are dominated by agricultural lands (i.e., the Maumee and Sandusky Rivers) (Richards, 2006; Richards et al., 2010), scientists have increasingly recognized the need to understand the effects of changes in the practices and conditions on these fields on phosphorus transport processes (Kleinman et al., 2015; Smith et al., 2014; Jarvie et al., 2013; Michalak et al., 2013). In this special section, a combination of studies based on field measurement and studies based on simulation modeling contribute to knowledge regarding phosphorus transport from agricultural land. Articles examine both impacts on eutrophication of lakes and damage to fish habitat in rivers and streams.

Field measurement studies

Because DRP typically moves through drainage tile, its measurement had been overlooked by studies that focused on surface flows of mineral P attached to soil particles. In careful new edge-of-field studies included in this special section, Van Esbroeck et al. (this issue) and Lam et al. (this issue) have measured total P and DRP movement from sandy loam crop fields in southern Ontario over multiple years. Both of these articles find that the great majority (over 80%) of P movement from agricultural fields into waterways occurs outside the growing season (Van Esbroeck et al., this issue). They also find that most of the loss of P occurs through tile drains. In particular, tile drains exported 19–67% of total annual DRP load, largely because tiles carried 78–90% of annual water export. These studies provide important updates to the scientific measurement basis, both for direct advice to farmers and for improved parameterization of models like SWAT (Gassman et al., 2007) that are being refined to better partition P movement between surface runoff and DRP in tile lines.

Modeling studies

Simulation models make it possible to conduct simulation experiments under varied weather conditions for many sites and multiple management treatments – far more than would be practical in the field. Several studies in this special section use SWAT (Gildow et al., this issue, Liu et al., this issue, Sowa et al., this issue, Keitzer et al., this issue, Palm-Forster et al., this issue, Culbertson, this issue). In addition to analyzing P movement at the basin scale, Sowa et al. and Keitzer et al. apply a version of SWAT linked to the Index of Biotic Integrity (IBI), a statistical measure of fish community health. Both of these studies find that managing for multiple water-quality and biological stressors – N, P, and sediments – is vital because all of them are limiting to stream fish communities and they often co-occur. This means that focusing management actions on just one stressor could make things worse for another. This is an important finding given the extensive focus on TP and DRP across the Great Lakes.

Helping determine the right conservation practices

Extensive efforts over the past half-century to develop conservation practices for more sustainable agricultural land management have led to over 250 documented conservation practices for controlling soil erosion and runoff, conserving soil moisture and improving soil health, protecting crops, and managing nutrients and pests (Brady, 2007;