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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. (2016–in this issue) and Lam et al. (2016–in 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., 2016–in 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., 2016–in this issue, Liu et al., 2016–in this issue, Sowa et al., 2016–in this issue, Keitzer et al., 2016–in this issue, Palm-Forster et al., 2016–in this issue, Culbertson, 2016–in 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; Comer et al., 2007). Many of these practices have both on-site effects on productivity and off-site ecological effects on water quality and biological communities, but often the broader ecological effects remain poorly understood (Schnepf and Cox, 2006; Knight and Boyer, 2007). Filling these knowledge gaps is critical, particularly in the Great Lakes Basin, where understanding the potential effects of practices on nearby or distant receiving waters is essential to promote and implement practices that provide a balanced set of benefits to growers and water quality.

Advancing understanding of these broader ecological effects of farm management practices requires complementary sets of field plot, edge-of-field, small watershed and large-scale simulation studies that assess individual and combinations of practices (Maresch et al., 2008). This special section contains examples of these studies covering a variety of practices. In their edge-of-field study introduced above, Lam et al. (2016–in this issue) found that reduced tillage practices did not increase losses of DRP and TP from tile drains. This is an important finding given the extensive use of reduced tillage and tile drainage in the Great Lakes (USDA NASS, 2014). They recommend that a combination of best management practices (BMPs) be employed to reduce P losses via drainage tiles. As mentioned above, both Lam et al. (2016–in this issue) and Van Esbroeck et al. (2016–in this issue) found that the great majority of P loss occurs during high rainfall and snowmelt events outside of the growing season. This finding reinforces past extension advice to growers to avoid fall broadcast applications of P fertilizer.

Gildow et al. (2016–in this issue) used SWAT simulations over a 15-year period in Ohio's Maumee River Basin to compare levels of TP and DRP loss from farm fields in response to the placement of fertilizer and the timing of application. They found that spring P application increased P loading into waterways (especially DRP), but not in a statistically significant manner. More importantly, they found that injection of P fertilizer into the soil could reduce movement into streams of DRP by 42% and of TP by 27%. Another SWAT simulation study by Liu et al. (2016–in this issue) compared the potential effects of four conservation practices on water quantity and quality in Grand River watershed of southern Ontario. Their results suggest that nutrient management and wetland restoration have more significant impacts on nutrient reduction at the watershed outlet than do cover crops and buffer strips.

All of these studies point to the importance of nutrient management for addressing nonpoint source impacts to Great Lakes waters and provide valuable scientific support and information for programs like the 4R nutrient stewardship program discussed by Vollmer-Sanders et al. (2016–in this issue). However, as it is often said there are no "silver bullet" conservation practices and there are several studies showing that nutrient management alone is not enough to achieve Great Lakes water quality objectives (Keitzer et al., 2016–in this issue; Scavia et al., in press).

Helping determine the right amount of conservation practices

It is not enough simply to know what conservation practices can reduce agricultural nonpoint source pollution. Equally important is to have estimates of the area over which those practices should be implemented to achieve desired ecological and socioeconomic outcomes (Tear et al., 2005; Kautz et al., 2006; Wilhere, 2008; Scavia et al., in press). Sowa et al. (2016–in this issue) and Keitzer et al. (2016–in this issue) provide examples of how to generate such estimates by modeling changes in stream water quality and fish community health under different management scenarios for Saginaw Bay watershed and Western Lake Erie Basin, respectively. For the Maumee River Basin, Keitzer et al. find that widespread adoption of conservation practices could reduce total P movement into waterways by more than half, resulting in the number of streams with poor IBI levels falling from 17% to 3%. In general, these studies found that a suite of conservation practices, including in-field and edge-of-field structural practices and nutrient management, must be implemented on most croplands (50 to 100% of total area) to achieve measurable improvements in stream health.

Another key finding of Keitzer et al. (2016–in this issue) comes from a comparison of the estimates on the amount of conservation practices needed to achieve 40% TP reduction goals for Western Lake Erie versus achieving stream health goals throughout the entire Western Lake Erie Basin. Their results suggest that meeting the Lake Erie TP reduction goals is achievable by keeping current practices in place and treating an additional 50% of cropland with a combination of structural and nutrient management practices. Yet, under these management scenarios fish communities would still be limited by agricultural nonpoint source pollution in a high percentage of Western Lake Erie Basin streams. This result is important given the attention currently placed on achieving the Western Lake Erie nutrient reduction targets. It leads Keitzer et al. to stress the need to search for management solutions that simultaneously achieve stream health and Western Lake Erie nutrient reduction goals.

The Great Lakes regional climate is changing, particularly the frequency and intensity of storms and extent of droughts (Groisman et al., 2012; Pryor et al., 2014). These changes can affect farmer's decisions, including choices of which crops to grow in the Great Lakes Basin. Results in this special section from Culbertson et al. (2016–in this issue) demonstrate that seemingly small changes in farmer behavior in response to climate change might have important impacts on water quality in the Western Lake Erie Basin. Under their SWAT simulations they found decreases in annual TP and DRP loading under near and late-century climate scenarios when holding fertilizer application rates at current levels. However, under these scenarios there is a projected increase in plant uptake of P. If farmers increase fertilizer application rates at the same rate as the increased rate of uptake, the simulations by Culbertson et al. change from projected decreases in TP and DRP to relatively large increases. This demonstrates that understanding such potential changes in behavior is critical, as is more closely monitoring variables like fertilizer application rates to proactively address potential problems before they occur.

Putting science into practice: promoting adoption of sustainable practices

A well-established set of government programs and policies exists in the United States to promote the use of conservation practices on agricultural lands, but their scope and effectiveness are bounded by political, budgetary and administrative factors. On their own and as they currently operate, the existing avenues cannot be expected to resolve the agricultural nutrient runoff problems plaguing large water bodies such as the Great Lakes (Garnache et al., 2016). Several papers in this special section present approaches that can augment or strengthen existing government programs in ways that can help expand conservation efforts and make current programs more effective.

As mentioned above, efforts to promote conservation focus on voluntary adoption. Changing incentives may be needed to influence farmers to adopt conservation measures voluntarily, especially when costs of conservation are incurred on the farm but its benefits are realized elsewhere. The Environmental Quality Incentives Program (EQIP) pays cost-share in exchange for adoption of conservation practices (Claassen et al., 2008), and the Conservation Reserve Program (CRP) pays rental fees to remove from production lands adjacent to waterways where nutrient runoff is expected to have deleterious downstream effects (Claassen et al., 2008). These two programs dwarf other sources of funding for conservation on agricultural land.

This special section contains articles that address three main aspects of implementing conservation practices. First, Zhang et al. (2016–in this issue) examine the characteristics of growers who adopt conservation practices. Second, Palm-Forster et al. (2016–in this issue) and Fales et al. (2016–in this issue) examine ways to make existing programs more cost effective so that existing conservation dollars can have greater impact. Third, Kerr et al. (2016–in this issue) and Vollmer-Sanders et al. (2016–in this issue) examine prospects for new approaches to promote conservation outside of the current major programs.

Understanding farmer adoption of better nutrient management

Agricultural Best Management Practices (BMPs) can only improve Great Lakes water quality if farmers adopt them. An important body of literature seeks to identify the capacity and incentive factors that determine adoption of BMPs (Nowak, 1992). More specifically, the literature on farmer adoption of environmental stewardship identifies several categories of determinants. These include capacity (farm resources, farmer experience and education, information access, income and wealth), attitude (environmental, risk), environmental awareness, and farm characteristics (crop vs. livestock, landscape position) (Baumgart-Getz et al., 2012; Prokopy, 2008), as well as certain off-farm factors (e.g., agricultural input and product prices) (Knowler and Bradshaw, 2007). By identifying key factors that will encourage farmer adoption of BMPs, these studies aim to inform policies to that end.

Information access and type has long been recognized as a key factor for technology adoption (Feder and Umali, 1993), but recent research has begun to probe the degree to which farmers trust and believe in the information available to them. Those feelings, in turn, may affect their willingness to act on the information. In this special section, Zhang et al. (2016–in this issue) examine how a set of socio-psychological, socio-demographic, and farm field characteristics affect the stated willingness of farmers in the Maumee River basin to abandon fall application of phosphorus fertilizer in favor of spring application. Upon analyzing a variety of possible determinants based on responses to a large 2014 farm survey, they find that perceived efficacy is the most influential determinant of farmers' choices of when to apply fertilizer. This finding suggests that educating farmers, either via extension agents or private crop nutrient advisors, can enhance adoption of this BMP—a practice whose adoption would significantly reduce the amount of phosphorus fertilizer exposed to runoff during the winter months. A companion paper from the same study identifies environmental risk perception as another determinant of adopting BMPs that abate phosphorus movement (Wilson et al., 2014).

Combining reverse auctions with watershed modeling

As introduced above, programs that assist in covering the cost of conservation implementation should aim to pay for environmental performance, not just conservation actions. In this case the goal is to obtain the most conservation possible per dollar spent. Over the decades, US Federal Government programs promoting conservation on agricultural lands have gradually improved the extent to which they target payments for maximum environmental impact (Claassen et al., 2008; Hellerstein et al., 2015). For example, the Environmental Quality Incentives Program (EQIP) aims to increase environmental impact by operating in highly sensitive, impaired watersheds, and the Conservation Reserve Program prioritizes parcels with the combination of higher expected environmental benefits and a lower contract price that the owner is willing to accept (Jacobs et al., 2014). However, environmental targeting under EQIP remains coarse because little distinction is made between parcels in different parts of the watershed (Fales et al., 2016–in this issue). Improving targeting on the basis of both environmental impact and cost is important because the budget available for conservation investments is inadequate to cover the needs. Maximizing cost-effectiveness in targeting will yield the greatest impact from the available budget.

Palm-Forster et al. (2016–in this issue) combine experimental reverse auctions with SWAT modeling to evaluate an effort to award conservation contracts in northwest Ohio on the basis of cost-effectiveness as determined by the combination of the bid price and the simulated environmental impact. Participation in the conservation auction was very limited because farmers perceived high transaction costs of participation, especially on rented land. In addition, using SWAT to prioritize location of conservation investments was problematic due to high sensitivity in the model to parameters for DRP concentration. Yet proper modeling of DRP is increasingly important as tile-drained area has risen since 2007 in response to high crop prices, making DRP-laden water from tile lines a greater source of P in many inland lakes (Kleinman et al., 2015). This suggests that despite recent modeling improvements, making these models effective requires better understanding and modeling of DRP flows in order to simulate how agricultural BMP adoption will influence P entering water bodies. In other words, both least-cost targeting and environmental targeting are promising ideas, but both face continued challenges to becoming fully operational.

Linking watershed modeling to goal-setting, targeting and recruitment

Sowa et al. (2016–in this issue) demonstrate that funding from existing government programs in the US is insufficient to address conservation objectives, but that targeting conservation practices with the help of SWAT modeling can greatly improve the cost-effectiveness of available funds by allocating them to the places where they can have the greatest impact. Fales et al. (2016– in this issue) take up the question of how to link such modeling to actual implementation. They present three case studies to demonstrate the steps involved in a pay-for-performance approach they call Strategical Agricultural Conservation, including setting goals, targeting, overcoming administrative hurdles, and conducting short- and long-term evaluation. In addition to using SWAT to set goals at the watershed scale, for finer-grain targeting they use a user-friendly, web-based tool that enables field-level simulation of various conservation measures at specific points within a watershed. This approach makes it easier to implement targeted conservation with local partners because anyone can use it to view simulated changes in runoff and sedimentation resulting from different conservation practices. Using a pay-for-performance approach, the payment to a given landowner in exchange for adopting conservation measures can be determined directly from the simulated conservation impact. The paper reports on approaches taken to build partnerships with various local collaborators in the Saginaw Bay Watershed in Michigan including conservation districts, conservation organizations and agribusinesses. The partners were generally receptive to a pay-for-performance approach, which the case studies used to the extent feasible within the (sometimes formidable) constraints of the programs in which they operated.

Using drain management institutions to promote conservation

Throughout the Midwestern United States, networks of public drains have long facilitated agricultural production by draining croplands of excess water. These systems charge landowners a tax or fee in exchange for this service, with specific arrangements varying by state and even by county. In Michigan, the system for determining how much each parcel contributes to the cost of managing the drain has been guided by the implicit assumption that all lands of a given use, size and location benefit equally from a drain, contributing equal runoff and sediment into it. However, improved, finer-grain watershed modeling technology now presents the possibility of estimating much more specifically the benefits that any given parcel derives from the drain and levying the charges accordingly.

Kerr et al. (2016–in this issue) present a case study of a pilot program from Van Buren County, Michigan, in which landowners can reduce the portion of the overall drain maintenance cost charged to a given parcel by installing conservation measures on it. Although the pilot program's cost effectiveness was questionable due to high transaction costs, the program offers an institutional model that could be used in places where the value of reduced runoff and sedimentation is greater. This could be the case should agricultural drainage systems become more accountable for the quality of the water they discharge. In particular, a current lawsuit by the Des Moines Water Works (DMWW) against three upstream Iowa counties charges that their agricultural drainage systems discharge water high in nitrate concentration, making it unsafe to drink and leaving DMWW with high costs of purifying it (Des Moines Register, 2016). Should DMWW win the case, which is scheduled for court in 2017, an arrangement such as the one in Van Buren County may prove useful for determining how to hold individual landowners within the drainage system accountable for drainage water quality and for incentivizing all landowners to adopt measures to reduce nutrient runoff.

4R certification to promote conservation through the private sector

Harnessing market forces to promote voluntary adoption of conservation practices could potentially dwarf any gains that can be achieved merely by increasing the cost-effectiveness of government programs. Vollmer-Sanders et al. (2016–in this issue) present an effort to do just that. Their article discusses a partnership with private sector agricultural nutrient service providers to certify them as promoting 4R nutrient stewardship: helping growers in the Western Lake Erie Basin use the Right fertilizer source, at the Right rate, at the Right time, and with the Right placement.

Spurred by a large harmful algal bloom in Lake Erie in 2011, a group of industry-funded research institutes worked together to develop the 4R certification approach. 4R offers the prospect of increasing farmers' profits while also reducing agricultural pollution, because it helps them to apply only as much fertilizer as their crop can actually absorb. Any excess beyond that represents a wasted investment. Farmers tend to rely on private crop advisors or nutrient service providers for guidance regarding nutrient application. Most would prefer to find guidance from a trusted nutrient service provider who has been 4R-certified to recommend fertilizer levels that will maximize their net returns while also helping them in their role as stewards of the natural resource base.

As Vollmer-Sanders et al. (2016–in this issue) describe, an advisory committee containing representatives of agri-business, state and federal agencies, research institutions, and conservation organizations worked together to develop 4R certification, which includes third party verification. Such diverse membership was essential to addressing such a multifaceted, politically divisive problem. The certification program was launched in 2014 and by April 2016, 30 nutrient service providers had been certified with a customer base covering 35% of the farmland in the Western Lake Erie Basin. Because the program is so new, it is too soon to evaluate fully its impact but initial efforts are underway. Progress is also being made to expand the approach to other parts of the United States.

Lessons from these studies

These studies offer a number of insights regarding the prospects for science to inform conservation. First, important advances in watershed modeling have improved the ability to target payment-for-environmental-services programs towards actions with a greater likelihood of producing intended environmental outcomes. This is an important step towards paying for conservation outcomes as opposed to paying only for conservation practices. At the same time, limitations in watershed models mean that this approach is still evolving. As Palm-Forster et al. (2016–in this issue) describe, the SWAT model in their study was still subject to high sensitivity to certain parameters, and as Fales et al. (2016–in this issue) and Kerr et al. (2016–in this issue) describe, the model that their case studies relied upon was only capable of predicting outcomes of a limited number of known conservation practices. In a true pay-for-performance approach any kind of conservation practice would be acceptable as long as it achieves the desired conservation outcome, but that remains beyond the capability of the existing models.

Second, transaction costs to an outcome-based approach can be high, limiting the prospects for practical implementation. This is the case for both the outcome-based drain management approach that Kerr et al. (2016–in this issue) described and the auctions that Palm-Forster et al. (2016–in this issue) presented.

Third, transitioning to an outcome-based approach to conservation will require opening the minds of public program managers who are not accustomed to thinking this way. Fales et al. (2016–in this issue) and Kerr et al. (2016–in this issue) both describe programs that have not traditionally taken an outcome-based approach and that will have to change some of the ways in which they operate in order to do so. Willingness to make such changes is variable, making the transition to a greater orientation towards outcomes rather than inputs a gradual process.

Fourth, the 4R certification case (Vollmer-Sanders et al., 2016–in this issue) demonstrates that there are potentially good prospects for engaging the private sector to promote conservation. The 4R certification program is quite new, and it is too soon to know how it will perform. But to date there has been rapid expansion of the number of nutrient service providers who have registered to be certified. The study by Zhang et al. (2016–in this issue) demonstrates that the information that nutrient service providers have to offer can have important impacts on conservation adoption.

Looking to the future

Recent advances in the science of agricultural nonpoint source pollution (NPS) provide a strong basis for action to reduce algae blooms in the Great Lakes and to protect fish populations in their tributaries. Improved understanding of the connection between agricultural practices and runoff of nutrients into waterways leading to the Great Lakes has greatly improved the prospects for promoting adoption of conservation in a way that rewards for environmental performance rather than paying for practices with unknown impacts. Articles in this special section demonstrate ways to put this approach into practice.

The articles in this special section also point to several key areas requiring further progress to combat the continuing challenges associated with agricultural NPS. First, there remains a continuing need to improve scientific understanding of agricultural NPS via accurate measurement, particularly as agricultural practices continue to evolve. Second, there is also a need to continue to strengthen models of agricultural NPS in order to predict the likely effects of changing climate and management practices at watershed scales. Third, while better models can help inform programs that promote expansion of conservation practices, those programs need to operate more innovatively in order to focus on improving actual environmental performance as opposed to promoting poorly targeted expansion of conservation practices. Fourth, such innovative conservation initiatives must incorporate thorough evaluation plans.

Measurement

The papers in this special section measuring nutrient runoff from farm fields (Van Esbroeck et al., 2016–in this issue; Lam et al., 2016–in this issue) demonstrate the important role of tile drains in exporting total P and DRP and show that the vast majority of P export takes place during the non-growing season. Both of these studies took place on sandy loam soils and although they are based on data from multiple years, their authors call for similar studies to be conducted under different soil types and hydrologic conditions.

These papers complement other recent work reported elsewhere. In Ohio, King and co-workers (King and Williams, 2016; Williams et al., 2015; Williams et al., 2016) have conducted significant monitoring of edge-of-field export of DRP through drainage tiles. Their studies have shown highly variable nutrient concentrations in tile drainage, making load calculation relatively uncertain unless DRP sampling was done once or twice per day. The Palm-Forster et al. (2016–in this issue) paper in this special section highlights the importance of correctly quantifying the phosphorus concentration in tile drainage for understanding impacts and quantifying the benefits of tile management.

All this work suggests the need for considerably more research and monitoring of tile drains to reduce uncertainly in understanding the quantitative dependence of tile drain DRP on important governing factors. It also justifies efforts being undertaken to develop and implement phosphorus removal structures in tile drain systems (Penn et al., 2016).

Modeling

While well validated simulation models are tremendously powerful, evolving science and technology require updating of models if they are to remain useful decision-making tools. For example, the importance of DRP delivery parameters in simulation models has drawn attention in light of farmers' expanded use of tile drains and scientific measurements that identify substantial components of total P entering Lake Erie as DRP.

SWAT is one of the preferred and most widely used watershed models for evaluating the type, location, and amount of agricultural conservation and Best Management Practices (BMPs) needed to achieve desired nutrient and sediment loads and concentrations. However, like all watershed models, SWAT could benefit from improvements of input data and refinements in the representation and parameterization of ecosystem processes. The distribution and abundance of BMPs such as crop rotation, tillage practices, and drainage tile management are important input data for SWAT, but accurately characterizing them at the fine scales needed for accurate sub-basin simulations is difficult. Improving these input data can only be accomplished through coordinated, local scale, post-BMP monitoring programs such as are currently taking place in several projects in Saginaw Bay (Fales et al., 2016–in this issue). Better representation of phosphorus movement through tile drain systems, especially in high clay content soils, also needs to be developed (Kleinman et al., 2015). This will require similar coordinated field monitoring, research, and modeling programs focused on movement of P, such as is currently being undertaken to evaluate the 4R Nutrient Stewardship Program in Ohio (Vollmer-Sanders et al., 2016–in this issue).

Programs

Although farmers and agribusinesses have been characterized as slow to adopt costly conservation practices (Ribaudo, 2015), articles in this special section show that effective organization can take advantage of farmers' goodwill and lead to adoption of stewardship practices that abate P movement. Vollmer-Sanders et al. (2016–in this issue) show that agribusinesses in northwest Ohio have rapidly enrolled in a certification program that promotes fertilizer application only when, where, and as it is needed. Kerr et al. (2016–in this issue) find acceptance by farmers and drain commissioners of a new approach to managing agricultural drains that rewards farmers for adopting conservation practices known to reduce sediment deposition. And Fales et al. (2016–in this issue) find that farmers are willing to adopt conservation measures in programs focusing on maximizing conservation outcomes as opposed to just actions. However, Fales et al. find that existing conservation programs come with administrative burdens that hamper both farmer participation and orientation towards conservation outcomes. As such, these papers illustrate both the opportunity and the need to engage in more innovative institutional design of conservation programs that go beyond the traditional government programs. These papers suggest potential advantages to allocate Federal conservation funds more widely and creatively, to encourage innovative conservation approaches that reward for outcomes and not just actions.

Overcoming the logistical and socioeconomic barriers to conservation initiatives and programs calls for a long-term perspective and adaptive management. Shared goals are needed, along with the understanding that they likely will need to evolve over time. The scientific foundation of any given program will need constant improvement. In light of improved scientific understanding and evolving human behavior, implementation plans will need to change. But much progress has been made towards better agricultural water quality in the Great Lakes, including learning how to build the partnerships and initiatives that will accelerate that progress in the years to come.

Evaluation

Emerging, innovative approaches to generating conservation outcomes need to build evaluation directly into their design so that there is a basis for knowing whether they should be expanded and replicated. The 4R certification program (Vollmer-Sanders et al., 2016–in this issue) and Regional Conservation Partnership Program (RCPP) reported in Fales et al. (2016–in this issue) both build evaluation directly into their design, but these programs are too new to report evaluation findings. Evaluation is particularly important as innovative programs attempt to expand their scale, because success at a small scale may provide limited indication of success as a program scales up (Manski, 1995).

Looking forward, important questions remain to be resolved. What conditions will foster and enable an approach that rewards environmental outcomes as opposed to conservation practices with unknown impacts? Who is best positioned to drive change? Who is accountable for change and can demonstrate and validate new solutions? How does the necessary information flow to all farmers? What roles can federal, state, provincial and local policies play to increase adoption of practices to levels needed to achieve outcomes? Is there a role for federal, state, provincial or local tax policy? How would expanded costs be distributed? How might the agricultural industry take on leading roles in expanding and delivering practices (e.g. the 4R nutrient program)? Answers to these questions remain beyond the scope of this special section but are important to address moving forward.

A broader view

For reducing flows of agricultural nutrients like P into the Great Lakes, multiple intervention points are possible and probably necessary. This special section has focused on source reductions from farm fields. But apart from source reduction, P and other nutrients can be treated through engineering approaches that physically remove nutrients from the water flow. These include precipitation of minerals from water (Penn et al., 2016) and downstream structural and vegetative practices like two-stage ditches and floodplain wetlands that can trap, use and transform nutrients before they reach the Great Lakes (Fisher and Acreman, 2004; Mitsch and Day, 2006; Davis et al., 2015).

The research described in this special section on sustainable management of agriculture in the Great Lakes basin focuses on the two most pressing areas at the current time: harmful algal blooms in the lakes and fish populations in tributary streams. These water-related areas are critically important in the Great Lakes watershed, but agricultural sustainability is much larger in scope. By changing the way that they manage crop fields, field margins, and the surrounding landscape, farmers can generate a host of ecosystem services. Apart from conservation of soil and water quality, these services include pollination and natural biocontrol of crop pests, climate stabilization via carbon sequestration and reduced greenhouse gas emissions, and aesthetic and recreational benefits from conservation of wildlife habitat (Swinton et al., 2006; Wratten et al., 2012; Karpovich et al., 2016). Future research must continue to expand the scope of agricultural sustainability and move towards more comprehensive assessment of its ecological and socioeconomic costs and benefits.

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