Context for re-evaluating agricultural source phosphorus loadings to the Great Lakes

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Joosse, P. J. and Baker, D. B. 2011. **Context for re-evaluating agricultural source phosphorus loadings to the Great Lakes**. Can. J. Soil Sci. **91**: 317–327. Over the past decade, scientists have been discussing the re-emergence of harmful algal blooms and excessive growth of *Cladophora* in some areas of the Great Lakes. An observation that has emerged from these discussions is that management of non-point or diffuse sources of phosphorus will be more important in the future in order to address symptoms of eutrophication in the nearshore. This paper provides context for this renewed focus on managing non-point source tributary loads and is based primarily on materials and discussions from the Great Lakes P Forum. There are changes that have occurred in the lakes and tributaries in the past 15 yr that indicate a greater need to focus on non-point sources, whether urban or rural. Changes have also occurred in land management to reduce non-point P losses from agriculture. While these changes have reduced sediment and particulate P loading in some Ohio tributaries, the more bioavailable, dissolved P forms have increased. As there is incomplete knowledge about the mechanisms that are influencing algal growth, it could be a challenge to demonstrate, in the near term, improvements in water quality with further P reductions from agriculture alone. Regardless, there appears to be a desire for improved accountability and transparency for agricultural non-point source P management.

Key words: Phosphorus, nearshore, Great Lakes, non-point agricultural source, eutrophication, tributary loading

Joosse, P. J. et Baker, D. B. 2011. **Contexte en vue d'une réévaluation de la pollution des Grands Lacs par le phosphore venant des terres agricoles**. Can. J. Soil Sci. **91**: 317–327. Depuis dix ans, les scientifiques débattent de la réapparition des fleurs d'eau nocives et de la prolifération excessive de *Cladophora* dans certaines parties des Grands Lacs. De ces discussions est ressortie l'observation qu'à l'avenir, la gestion des sources non ponctuelles ou diffuses de phosphore prendra plus d'importance si l'on veut résoudre les problèmes d'eutrophisation dans les régions riveraines. Le présent article remet en contexte cette réorientation vers la gestion de la charge des affluents qui émane des sources non ponctuelles; il repose essentiellement sur la documentation et les débats du Forum sur les Grands Lacs. Les lacs et les affluents ont subi des changements au cours des 15 dernières années, changements signalant qu'il faut se concentrer davantage sur les sources non ponctuelles, qu'elles soient urbaines ou rurales. La gestion des terres a elle aussi évolué, de sorte qu'on a atténué les pertes non ponctuelles de P attribuables à l'agriculture. Bien que ces changements aient diminué la charge de P sédimentaire et particulaire dans certains affluents de l'Ohio, on remarque une hausse de la concentration du P dissous, qu'assimilent plus facilement les organismes vivants. Puisque nos connaissances sur les mécanismes qui influent sur la croissance des algues sont incomplètes, montrer qu'on peut encore rehausser à court terme la qualité de l'eau en réduisant davantage les apports de P uniquement issus de l'agriculture pourrait s'avérer difficile. Quoi qu'il en soit, on semble souhaiter une meilleure imputabilité et plus de transparence dans la gestion des sources non ponctuelles de P agricoles.

Mots clés: Phosphore, zones riveraines, Grands Lacs, source agricole non ponctuelle, eutrophisation, charge des affluents

For the past decade there has been considerable discussion about the re-emergence of harmful algal blooms and excessive growth of *Cladophora* evident in areas of the Great Lakes at forums provided by the Lake Erie Millennium Network, International Association for Great Lakes Research, State of the Lakes Ecosystem Conference and the International Joint Commission. Scientists have been working to synthesize data and bring their concerns regarding nutrients, particularly phosphorus (P) and the nearshore ecosystem, to the attention of policy makers. One of the observations that has emerged from these discussions is that non-point or diffuse sources of P are becoming more important to manage in order to address the re-emerging symptoms of eutrophication in the nearshore of the Great Lakes [International Joint Commission (IJC) 2009a, b].

The purpose of this paper is to set the context for this renewed focus on P and management of non-point agricultural sources in the Great Lakes. The content is largely derived from background materials provided to participants and from presentations and discussions at the Great Lakes P Forum held in Windsor, Ontario in July 2009. This paper is not exhaustive, but attempts to highlight what is known about differences between our historic understanding and management actions for

Abbreviations: **DRP**, dissolved reactive phosphorus; **GLWQA**, Great Lakes Water Quality Agreement; **TP**, total phosphorus non-point agricultural source P and what might be required in the future. This paper provides more detail about the aquatic components of the ecosystem while other papers in this special issue focus on the soil and landscape aspects of non-point agricultural P.

DISCUSSION

Historical Success in Lakewide Phosphorus Management

The enrichment of the Great Lakes by P from human activities and the resulting algal blooms, fish kills and beach closures were the impetus to include Annex 3 (The Control of Phosphorus) and Annex 13 (Control of Pollution from Non-Point Sources) in the Great Lakes Water Quality Agreement (GLWQA). This agreement between Canada and the United States was originally signed in 1972 and last amended in 1987 (IJC 1987). The International Joint Commission Pollution from Land Use Activities Reference Group (PLUARG) studies of the 1970s provided important focus on and recognition of the non-point pollution problem (PLUARG 1978) for the GLWQA and lake managers. Models were developed and used to establish target lake loadings and open lake concentrations for P for each Great Lake as well as Saginaw Bay, Georgian Bay and the North Channel of Lake Huron based on external loadings and internal recycling co-efficients (DePinto et al. 2007). The GLWQA underwent extensive binational and public review in 2006 (Agreement Review Committee 2007). As Fig. 1 illustrates, by the end of the 1980s, most open lake TP concentration targets were attained. Habitat and water quality improved as the models predicted. In four of the five Great Lakes (Lake Erie being the exception), data from the late 1990s and early 2000s suggest that the open lake P target concentrations have been overshot and may be leading to "nutrient starved offshore waters" (DePinto et al. 2007). This is a concern for the commercial and recreational fishing industry (Lake Erie Committee 1998).

The Great Lakes Water Quality Agreement has been cited as a successful model for management of trans-jurisdictional waters because of the abatement of

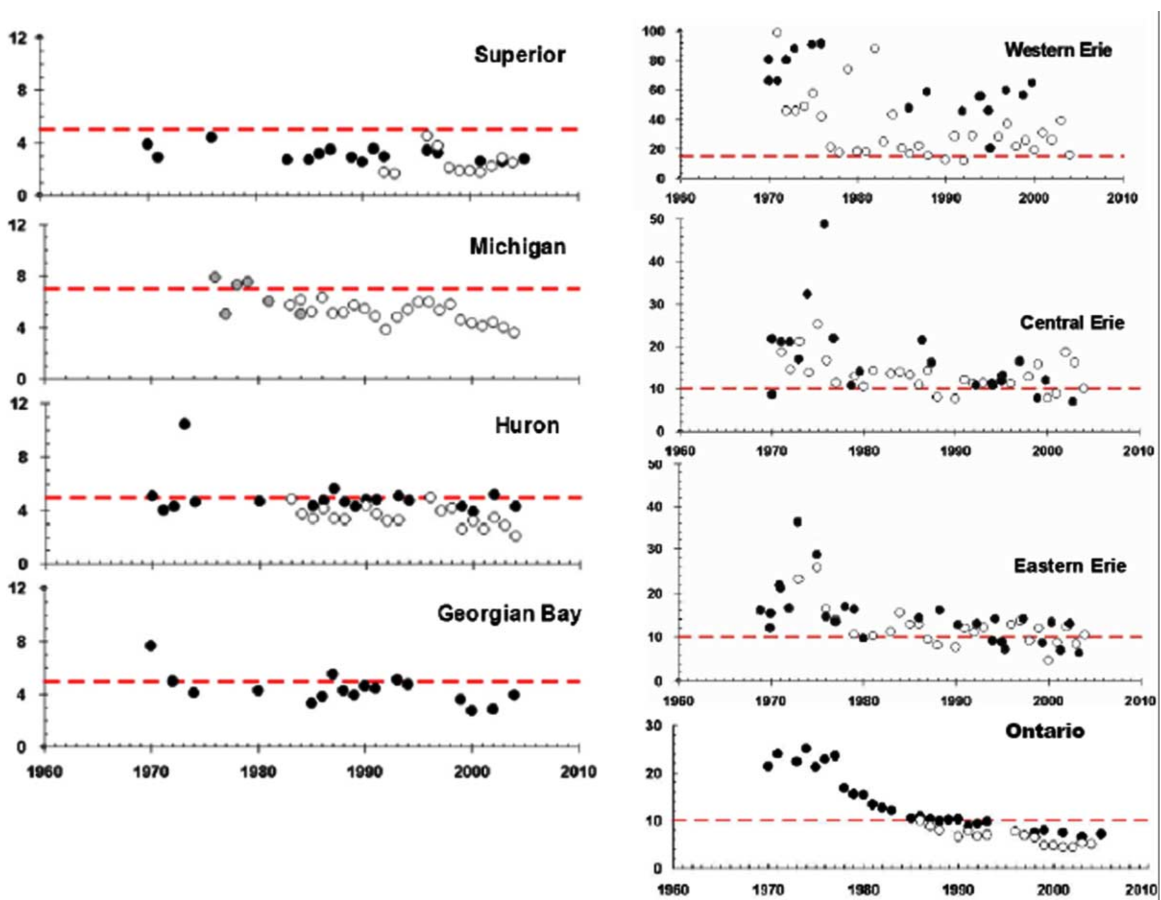

Fig. 1. Mean spring TP concentrations (μg P L^{-1}) for offshore waters. The filled and open circles represent Canadian and US data, respectively. Horizontal dashed lines represent the target water quality objectives under the Great Lakes Water Quality Agreement 1978 as amended by Protocol 1987. (Note difference in *y* axis scale) (Source: DePinto et al. 2007; used with permission).

eutrophication in the late 1970s and early 1980s (Burns 1985; McGucken 2000; IJC 2009b). Much of this success has been attributed to the upgrading and regulation of point sources of P, including sewage treatment plant and industrial dischargers into the Great Lakes, required by the GLWQA under Annex 3. There were also substantial non-point urban and rural investments to improve stormwater, manure, fertilizer and eroded soil P sources. Studies in the Maumee and Sandusky Rivers in agricultural northwest Ohio showed reductions in tributary sediment and particulate P loading (see the section ‘‘In the tributaries’’ below), correlating with investments in practices and structures to protect highly erodible lands, enrolment of conservation reserve program acres and adoption of conservation tillage (Baker and Richards 2002; Richards et al. 2002, 2008). In the case of Lake Erie, significant reductions in dissolved P loading from agriculture also occurred at that time, apparently in response to decreasing P fertilizer sales (Baker and Richards 2002; Richards and Baker 2002).

Current Symptoms and Renewed Concern

While there has been success in reducing P on the lake basin scale, the most visible signs of eutrophication – nuisance cyanobacteria (blue-green algae) blooms and shoreline accumulations of the green macro-alga *Cladophora* – have returned to parts of all the Great Lakes except Lake Superior (IJC 2009b). Observations on parts of the lakes except perhaps Lake Superior that are indicative of changing nutrient conditions include:

- the return of harmful algal blooms, but of different species (i.e., *Microcystis*) than historically;
- *Cladophora* blooms (nearshore nuisance algal growths);
- depletion of dissolved oxygen in the bottom waters of the central basin of Lake Erie;
- increases in the frequencies of beach postings or closings;
- botulism toxicity events re-emerging in the late 1990s and early 2000s for the first time in the Great Lakes since 1963–1964;
- total P concentrations in offshore waters well below what the old models said they should be given P loading estimations;
- ‘‘desertification’’ (loss of productivity) in offshore waters (IJC 2009b).

Many of these symptoms result in ecological, social and economic costs such as: increased human and animal health risks; increased costs for drinking water treatment; decreased tourism dollars; decreased shoreline property value; increased industry expense to clean water intakes; and, degraded fish and wildlife habitats, both for species at risk and commercially important species [United States Envivonmental Protection Agency (USEPA) 2009; M. Scanlon, personal communication, Ontario Ministry of the Environment]. The potential for the Great Lakes Economic Region to be a leader and prototype for global economic success as envisioned by the Brookings Institution (Austin et al. 2008) is in jeopardy if these symptoms and their causes cannot be better understood and managed.

Since the mid 1990s and the establishment of dreissenid mussels in the lower Great Lakes, *Cladophora* and cyanobacteria blooms and the attendant concerns associated with these have been re-emerging in the Great Lakes. Yet, open lake TP concentrations have remained relatively stable, bringing into question the reliability of the relationship between loadings, concentrations and trophic indicators and the seeming effectiveness of our P management actions for the current environment (De Pinto et al. 2007).

Changing P Dynamics and Relationships

The eutrophication problem is driven both by internal drivers (changes in the lake ecosystem structure) and by external drivers (changes on the land) (IJC 2009b). The sections below point to evidence of some recent changes in P dynamics and relationships in the lakes, tributaries and the land that coincide with increased shoreline and western basin of Lake Erie algal blooms.

In the Lakes

The symptoms listed above are generally witnessed in the nearshore as this is the interface with the Lakes where most people live, work and play. One of the challenges in summarizing the condition of the nearshore is that different researchers use different definitions. One definition that may be useful for resource managers is that of Mackey (2009), which defines the nearshore as including both higher energy coastal margin areas and lower energy nearshore open-water areas. Coastal margin areas are located between ordinary high water and the 3-m isobath; nearshore open-water areas are located between the 3-m isobath lakeward to the 15-m isobath.

Howell and Hobson (2003) noted a paradox in the re-occurrence of nearshore algae problems despite the fact that offshore nutrient and planktonic algal concentrations were low. They suggested three hypotheses: (1) basin-wide P concentrations are adequate for *Cladophora* growth, (2) alternatively, transient and widespread nutrient enrichment along the shoreline is responsible or, (3) P is being made available as a result of biologically based nutrient enrichment in the *Cladophora* beds due to the trapping and release of nutrients by dreissenid mussels. All three hypotheses have merit and their effects may occur together; and all three hypotheses can be mitigated through P reduction in the affected areas. However, these possible explanations are complicated by the fact that *Cladophora* growth can also be stimulated by clearer water that results from dreissenid filter-feeding (permitting more light to reach the bottom), and by warmer water temperatures (Higgins et al. 2006).

Researchers have advanced the theory of a "nearshore phosphorus shunt" to explain how the establishment of the invasive dreissenid mussels in nearshore waters may have changed both the distribution and form of nutrients available in the aquatic ecosystem and how that may have influenced *Cladophora* growth (Hecky et al. 2004; Ontario Ministry of the Environment 2009). Dreissenid mussels are voracious filter feeders, taking in particulate forms of P from the nearshore and excreting highly available dissolved forms of P. The mussels are thought to stimulate the *Cladophora* directly by excreting soluble nutrients. Furthermore, the mussels' role in improving light penetration into the water column and creating hard surfaces for *Cladophora* attachment on what was previously soft substrate allows the area suitable for *Cladophora* growth to be extended. The mussels also concentrate energy and nutrients in the nearshore in their population and waste products. The accumulating shells of the mussels provide a physical refuge for many species and a place where the mussels' faecal products are retained and recycled. The faecal materials of the mussels are larger and denser than the particulates filtered from the water as food and therefore have a greater tendency to stay in the nearshore. The hypothesis is that nutrients are captured, sequestered and more frequently cycled in the nearshore due to the presence of dreissenids; and that this has made the nearshore and coastal environments of the Great Lakes potentially more sensitive to P inputs [Lake Erie Nutrient Science Task Group (LENSTG) 2009].

Another change in Lake Erie has been the species of blue-green, or cyanobacteria, blooms that are occurring. In the 1960s and 1970s the dominant species in the western basin were *Anabaena* and *Aphanizomenon*. In the re-emerging blooms since the 1990s, *Microcystis* has been the dominant species. An attached blue-green algae, *Plectonema wollei* first appeared in 2006 (Ohio Environmental Protection Agency 2010). The change in harmful algal bloom species indicates the original causal relationships for eutrophication are changing and the required management responses may be different this time around as well.

In the Tributaries

An analysis of Lake Erie loadings from 1967 to 2007 (Fig. 2) shows that the GLWQA annual TP loading target of 11 000 t has been met 15 out of 26 yr since it was first attained in 1981. It is exceeded in years with high precipitation when the tributary loads to the lake increase but is met in drier years. These peaks represent the contribution of non-point sources that are monitored by watershed export studies rather than by municipal sewage treatment plants or industrial dischargers. Non-point sources from tributaries have averaged about 60% of total loads since 1981, while

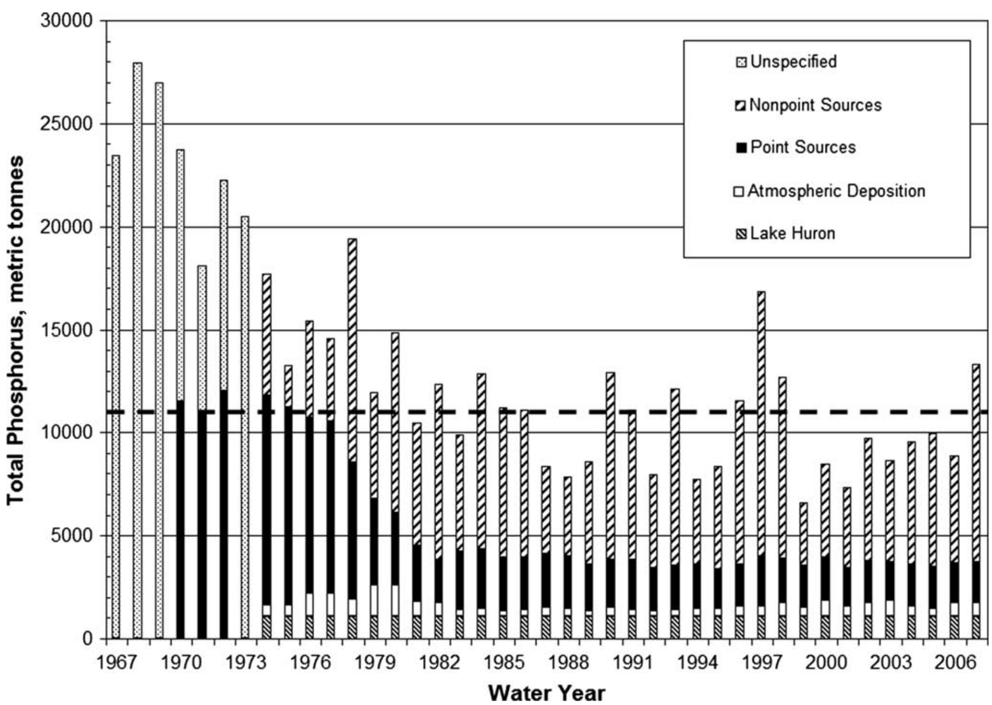

Fig. 2. Long-term trends in total phosphorus annual loading to Lake Erie from various sources (Data Source: D. Dolan and D. Rockwell). Horizontal dashed line represents the 11000 t loading target established for Lake Erie under the Great Lakes Water Quality Agreement 1978 as amended by Protocol 1987.

point source contributions have averaged about 20% of the total loads for the same time.

Figure 2 shows there were substantial reductions in total P loads through the 1970s and that the amount of point or non-point total P loading has not increased in an absolute sense since the 1980s. However, the composition of the total P from agricultural non-point sources has changed markedly, with particulate P decreasing and dissolved reactive P increasing. This is illustrated by data from the Maumee River, which is the largest contributor of agricultural P to Lake Erie (Fig. 3). Dissolved reactive P has increased substantially since the mid 1990s (Fig. 3 A), while particulate P has declined slightly over the period of record (Fig. 3 B) and suspended solids has had somewhat larger declines (Fig. 3 C). Although particulate P loads are higher than dissolved reactive P loads, dissolved reactive P is about 3.5 times more bioavailable than particulate P (DePinto et al. 1981; Baker 2010). Thus, bioavailable P export from the Maumee and other northwest Ohio tributaries to Lake Erie has been increasing even though total P export has undergone little change (Baker 2010). There are questions as to whether changes in the form of P entering the Lakes to a form that is more biologically available to plant communities is occurring in other parts of the Great Lakes basin. Data for tributary concentrations and flows with concurrent agricultural practice data are not as well documented elsewhere (LENSTG 2009).

Although nutrient and sediment export has large annual variability, the long-term, detailed transport studies on several of Ohio's agricultural and urban watersheds by Heidelberg University do allow detection of loading changes in response to management changes on the landscape (Richards et al. 2008). The declines in particulate P and suspended sediment, although relatively small, are important because they have occurred at the same time stream discharges have been increasing (Fig. 3 D). Since sediment and particulate P concentrations generally increase with increasing stream flow, were it not for the success of agricultural erosion control programs, sediment and particulate P loading would likely have shown large increases. Agricultural erosion control practices, such as no-till, reduced till and buffer strips, have been widely adopted in northwest Ohio and have resulted in substantial reductions in the flow-weighted mean concentrations of particulate P (Fig. 4 B) and suspended sediments (Fig. 4 C). However, these same practices may be contributing to the increased flow-weighted mean concentrations of dissolved reactive P (Fig. 4 A) and its associated large increases in loading.

Within the Great Lakes Basin, and elsewhere, there is also concern about the impacts of both point and non-point P on water quality in rivers. Rivers serve not only as complex transport pathways for the movement of P from landscapes to downstream receiving waters, but as vital water resources themselves. Phosphorus retention

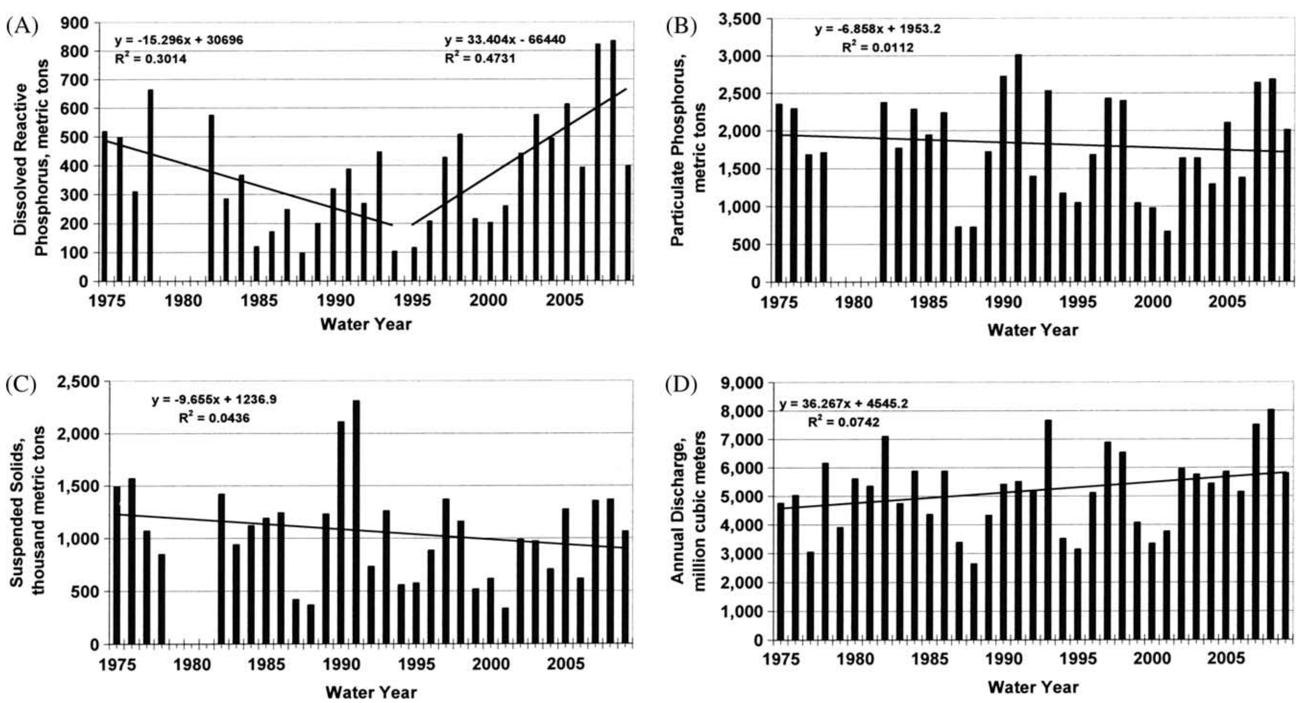

Fig. 3. Average annual loadings and annual discharge for the Maumee River at Waterville (16395 km^2). A. Dissolved reactive phosphorus with separate trend lines for 1975–1994 and 1995–2009; B. Particulate phosphorus; C. Suspended sediments; and D. Annual discharge. (Data source: D. Baker and R. P. Richards).

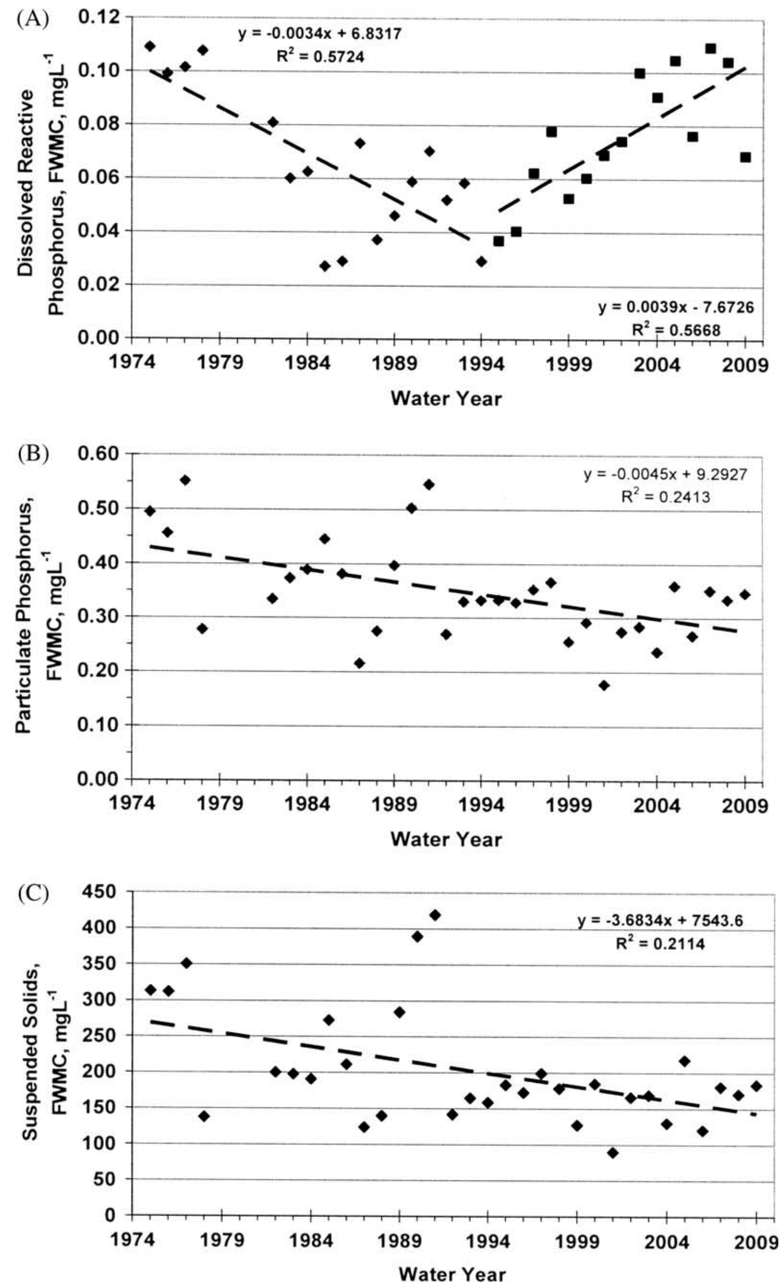

Fig. 4. Average annual flow weighted mean concentrations for the Maumee River at Waterville (16395 km^2). A. Dissolved reactive phosphorus with separate trend lines for 1975–1994 and 1995–2009; B. Particulate phosphorus; and C. Suspended sediments. (Data source: D. Baker and R.P. Richards).

in rivers is highly variable in time and space, and not all of the P entering rivers participates equally in riverine biogeochemical cycles; this depends on the form of P entering rivers, its reactivity and prevailing water residence time (Withers and Jarvie 2008). Phosphorus inputs from point (effluent) sources, which are usually dominated by the more readily bioavailable P fractions (predominantly phosphate), tend to be subject to higher rates of uptake by biogeochemical processing and assimilation. Point sources are most important under low river flow conditions when dilution capacity is reduced and when water retention times are highest, resulting in greater contact time for interactions with sediments and biota. For example, Jarvie et al. (2002) recorded up to 60% net P retention within 2 km downstream of a point source effluent input under summer baseflow conditions in the lowland River Kennet, England.

Non-point P inputs from agricultural land tend to be delivered more intermittently, typically under high flow events in which the particulate P form dominates (PLUARG 1978; Richards et al. 2008). Portions of this P may be delivered directly to lake environments, while other portions may be deposited in downstream river segments. Catchment monitoring studies in Ohio (Baker et al. 2006) and England (Jarvie et al. 2005; Jarvie et al. 2006a) indicate that, in well-oxygenated rivers, agricultural sediment does not provide a major source of DRP to the water column under summer/fall flows. Indeed, fine agricultural sediment deposited on the river bed can be an important P sink and actually help to mitigate DRP from point sources (Jarvie et al. 2006b). Localized DRP release from bed sediments can occur: (a) where there are high organic loadings resulting in anoxia in the surface sediments and redox-related release of DRP in the water column, and (b) immediately after effluent P-stripping, when dramatic reductions in water column DRP concentrations result in a reversal of the diffusion gradient across the bed sediment-water interface (Jarvie et al. 2006a).

Rivers may also function largely as conduits, transporting, with minimal processing, the cumulative inputs they receive from their watersheds to downstream receiving waters during storm runoff events. Thus the nutrient and sediment concentrations observed at the watershed outlet often closely reflect the particular conditions on the landscape at the time of the rainstorm or snowmelt event. Although export is driven by hydrology and its attendant seasonality, this seasonality in nutrient and sediment export is modified by differing seasonal availability of dissolved P and nitrate, as well as seasonal patterns of ground cover.

Satellite imagery has facilitated studies of the relationships between storm runoff events that deliver P into the Great Lakes and associated algal bloom development. Such images appear to show direct connections between rainfall-runoff events in the Maumee watershed and algal blooms in the western basin of Lake Erie (Baker 2008). Additional ground truth data are being collected to verify these linkages.

Since tributaries constitute the major connections between the land and the lakes, additional studies are needed to better establish the watershed-scale linkages between landscapes and tributaries, and between tributaries and nearshore zones. Such studies will guide in the identification of tributary management practices that are stressors in particular watersheds and nearshore zones.

Changes in hydrology due to alterations in land use and the shoreline may also be influencing the transport of non-point or diffuse sources of P and impacts on the nearshore (Keller et al. 2008; Mackey 2009). Poor soil structure, impervious surfaces, channelizing of streams, and removal of functioning floodplains and wetlands can all contribute to reduced infiltration, increased flashiness of streamflows and increased erosion of streambanks and thus increase the transport of water and P from the landscape (Baker et al. 2004; Bukaveckas 2007; Nemery and Garnier 2007). The potential for increases in high-intensity rainfall events due to climate change in the Great Lakes basin and the impact this could have on overland flow and stream processing add uncertainty to controlling non-point sources of P and realizing water quality improvements.

On the Land

The Ohio Lake Erie Phosphorus Taskforce has been analyzing the correlations between increases in dissolved reactive P levels and corresponding increases in algal blooms in the western basin of Lake Erie, both trends that began to appear in the mid-1990s (Ohio Environmental Protection Agency 2010). In the Ohio watersheds studied by Heidelberg University, one of the changes in the agricultural landscape concurrent with an increase in DRP in the tributaries is an increase in the adoption of conservation tillage practices (Richards et al. 2002). Conservation tillage has been promoted since the 1980s to help control the losses of particulate bound P, the dominant form lost from most agricultural land (PLUARG 1978; Baker and Laflen 1983). A paired watershed study in Manitoba, a cold, dry region where nutrient export is snowmelt driven, has found that P losses are primarily in the dissolved form under these conditions, making conservation tillage less effective (Tiessen et al. 2010). Heidelberg University and others in Ohio are investigating several possible mechanisms to determine their potential contribution of agricultural land to increased DRP in tributaries, including alterations to the timing, amounts and incorporation of fertilizers, P stratification in the soil due to the adoption of no-till, as well as the degree of soil P saturation due to possible local P accumulations.

Since long-term, detailed tributary loading data are seldom available, watershed nutrient budgets and other indicators have been used to predict and assess the potential nutrient build-up in soils and potential changes in nutrient export to aquatic ecosystems. Studies that have looked at the P budget for agricultural land in the province of Ontario (Van Bochove et al. 2011) and specifically the Lake Erie basin (Baker and Richards 2002; Bast et al. 2009; Bruulsema et al. 2011), have found that the annual P balance has been improving over the period since the GLWQA was signed. P inputs (fertilizers and manures) to Lake Erie basin cropland generally exceeded crop removals of P prior to 1990. There have now been negative P balances on an annual basis in the Lake Erie basin in the past 11 yr as manure and fertilizer applications have been relatively stable but crop yields, and therefore removals of P, have increased (Bast et al. 2009; Bruulsema et al. 2011). The amount of P fertilizer used in agriculture production in Ontario significantly decreased by 60% from 10.5 kg P ha^{-1} in 1981 to 4.9 kg P ha^{-1} in 2006 and the amount of manure P input has remained fairly stable at 11 kg P ha^{-1} between 1981 and 2006 (Van Bochove et al. 2011). For the Maumee and Sandusky watersheds in Ohio, annual fertilizer inputs were 39 and 30% lower, respectively, for 1993–1995 than for 1979–1981 (Baker and Richards 2002). Annual manure inputs decreased 13 and 28% for the Maumee and Sandusky, respectively, between the 1976–1978 average and the 1993–1995 average. While there have been improvements in P balance, historic applications above crop removal have led to increases in soil test P and the potential for P desorption (Van Bochove et al. 2011). The Potash and Phosphorus Institute (2005) compiled results for soil test P from soil samples submitted in fall 2004 and spring 2005 to private and public laboratories. As soil tests vary by laboratory, they were converted to Bray P-1 test equivalents for comparison. The dominant Lake Erie jurisdictions of Ohio, Ontario and Michigan had 25, 47 and 49%, respectively, of soil samples submitted testing greater than 50 ppm on a Bray P-1 test equivalent basis, which was the highest soil test level consistently measured and reported for laboratories in all three jurisdictions (PPI 2005).

Though there have been improvements in P balance on a regional scale, there may still be nearshore, localized issues because of changes in land use, distribution of P inputs, and altering of the hydrologic functioning of the landscape, which contribute to peak non-point loadings at the local scale. Historical accumulations of P in stream sediments may also be keeping non-point sources of P from being lowered quickly, as well as contributions from other diffuse sources in the landscape (i.e., rural septic fields, urban non-point runoff) even though agricultural inputs of P have decreased over time.

Improving P Management Performance and Accountability

Management of algal blooms will require an understanding of the local context of the source watershed and the associated nearshore zone of the receiving Great Lake. Each watershed and shoreline segment has unique characteristics and stressors. In developing strategies to manage P on a watershed basis, each watershed will need to look towards the nature of P that is causing undesirable symptoms locally, non-point source contributions, including agriculture, relative to other sources, and the nature of agricultural production in its boundaries. Then the appropriate actions, both economically and environmentally, to address the timing, forms and sources of P causing issues can be discussed. Annex 13 of the GLWQA contemplated a watershed approach to non-point source P management and provided for watershed management plans, but these have not been adopted within the context of the GLWQA (IJC 2009a). While watersheds are a common integrated management framework they have not always been a common research study framework. This creates a challenge for those managers trying to ensure there are well-documented problems and well-studied processes underpinning management recommendations at the watershed scale. Phosphorus and flow experiments must be developed at temporal and spatial scales commensurate with the scales of management. This will require landscape and watershed scale manipulation and monitoring (Anonymous 2009).

Farm and field level management decisions are supported by frameworks developed through field research, such as nutrient management plans and P indices. Phosphorus indices systematically assess P sources and transport to rank fields based on their relative risk of P loss depending on individual field, landscape and production characteristics (Maguire et al. 1998). Scientists and extension agents are acutely aware of the variability of nutrient application, landscape and weather scenarios that influence P losses at the edge of a field, let alone at a watershed scale. It is important to realize that the name "Phosphorus Index" is being applied to different tools that can have different objectives. Strong points were made by panellists and participants at the Great Lakes P Forum, that regulators, including the USEPA (2009), and the public, need measures to ensure that progress is being made on P management from non-point sources. The P index has not been a convincing tool to show that agriculture is "doing their part" (Anonymous 2009).

For farmers and advisors, the simplicity of a P Index is paramount for ease of understanding and to have an affect on management decisions. Those who are involved in advising farmers and other land managers to change their production systems or management of P seem most comfortable with keeping P indices simple and practical to serve as an educational tool for behavioural change. For others, simplicity is not the most important consideration; rather, an index or any tool must be able to prove to regulators that a farm is not contributing more than their fair share of P (Anonymous 2009). Regulators desire more quantitative predictions of P losses from edge of field that require more complex data and simulation modelling. Those who develop tools such as a P Index are aware of their limitations and prefer their use in a voluntary context. Relying on voluntary change is challenging, as presently there are no clear consumer-driven market signals to economically reward farmers to adopt more "phosphorus friendly" practices or systems (Anonymous 2009).

The Forum also highlighted the need to strive for consistency in how P indices and soil tests are utilized. The science used to assess the relative risk of field loss through a P index is generally accepted; there is more debate about the appropriate management responses assigned by each jurisdiction to the calculated risk classes. To improve transparency and accountability of P indices to the public, there needs to be more consistent application of management recommendations and/or regulatory requirements on a defensible biophysical basis (Anonymous 2009).

There is an opportunity for P Indices to be a link between farming and regulatory communities to better relate farm practices to watershed P losses; adapting landscape and watershed models to the task of field assessment (e.g., Oklahoma's PPM calculator) is a step in this direction (Anonymous 2009). Management tools must be selected with consideration for the needs and challenges posed by the individual management unit. Regardless of the form of a site assessment tool, the measure of success is whether there is implementation of an appropriate management recommendation or ultimately an impact on water quality. Existing and innovative approaches to site assessment must therefore be (1) accurate; (2) practical (useable); (3) applicable to the selection of alternative management practices; and (4) meaningful in affecting water quality change (Anonymous 2009).

CONCLUSION

Much of the data regarding tributary loads from agriculturally dominant watersheds presented here comes from Lake Erie because it has the most complete and detailed monitoring record, the most extensive agricultural land use among Great Lakes basins and the most dramatic response to P inputs. It is evident from the discussions taking place at many bi-national tables, that future management of P in the Great Lakes basin will likely entail a greater focus on non-point sources, both urban and rural. There will be challenges because of incomplete scientific knowledge regarding nearshore P transformations and non-point sources, difficulties in determining appropriate management tools and questionable ability to identify and engage responsible parties.

The Great Lakes Water Quality Agreement that was successful in influencing P management previously in the Great Lakes is currently being renegotiated. The role of non-point agricultural sources of P is being reconsidered and re-evaluated. Agricultural sources are being held to account for how they manage P inputs and the agricultural landscape. This is an opportunity for the agricultural community to demonstrate the stewardship it has applied and can apply in the future to the P issue. There are many tools available, from soil testing, nutrient management planning, P indices, to record keeping that can be applied in a concerted and transparent effort. Applying the latest science and understanding to improve these tools will facilitate accountability and sustained food production in the Great Lakes basin. Improving scientific tools such as a P index to help with quantitative site assessments is underway. Ultimately, public confidence will be raised by management changes that are real, documented and transparent.

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