Agricultural Aspects of Harmful Algal Blooms (HABs) and Hypoxia in the Great Lakes


To reduce P loading to Lake Erie, water quality management agencies are advocating adoption of conservation tillage. This could increase nitrate and herbicide contamination of area waters. This region’s detailed baseline nutrient and herbicide data provide an opportunity to evaluate the effects of conservation tillage on a variety of water quality parameters. To separate weather-related from management-related effects, an ecosystem approach is advocated.


In contrast with the watersheds draining into Lakes Superior, Michigan, Huron, and Ontario, where forestry is the dominant land use, the dominant land use in Lake Erie’s watershed is row crop agriculture. Consequently, the tributaries draining into Lake Erie carry, on average, much larger loads of sediments, nutrients, and pesticides than do the tributaries entering the other Great Lakes. To support the development, operation, and assessment of agricultural non-point pollution control programs in the Lake Erie Basin, the major tributary watersheds are analyzed as large-scale agroecosystems, using mass balance approaches. Material export from the watersheds is based on detailed tributary loading studies which were initiated in the mid-1970s. The monitoring programs have now been in operation for up to 18 years, producing data that serve: (1) to assess the effectiveness of non-point pollution control efforts, (2) to guide future non-point pollution control programs, and (3) to illustrate many of the regional water quality impacts of agricultural land use. The water quality data illustrate the large day-to-day, season-to-season, and year-to-year variability in both pollutant concentrations and loads, which is characteristic of non-point pollution. The data also illustrate systematic shifts in pollutant concentration and loading patterns that occur in relation to watershed size. Although gross erosion rates in northwestern Ohio tributaries are relatively low, the phosphorus and nitrate export rates are high in comparison with other US streams and rivers. Analysis of the water quality data reveal significant downward trends in time for total and soluble phosphorus and significant upward trends in nitrate. The reductions in phosphorus export apparently reflect the effectiveness of agricultural pollution abatement programs that combine more careful fertilizer management with increasing use of conservation tillage. The increasing nitrate concentrations may reflect a trade-off associated with the adoption of conservation tillage. © 1993


Lake Erie has undergone re-eutrophication beginning in the 1990s, even though total
phosphorus (TP) loads to the lake continued to slowly decline. Using our 1982 and 2007–10 studies of the bioavailability of dissolved and particulate phosphorus export from major Ohio tributaries, together with our long-term TP and dissolved reactive phosphorus (DRP) loading data, we estimated long-term annual export of dissolved and particulate bioavailable phosphorus. DRP was found to adequately represent dissolved bioavailable export while 26–30% of the particulate phosphorus (PP) was extractable by 0.1N NaOH, a frequently used indicator of PP bioavailability. During the period of re-eutrophication (1991–2012), DRP export from nonpoint sources in the Maumee and Sandusky rivers increased dramatically while NaOH-PP export had a slight decline for the Maumee and a small increase in the Sandusky. For the Cuyahoga River, both DRP and NaOH-PP increased, but these changes were small in relation to those of the Maumee and Sandusky. During this period, whole lake loading of both non-point and point sources of phosphorus declined. This study indicates that increased nonpoint loading of DRP is an important contributing factor to re-eutrophication. Although nonpoint control programs in the Maumee and Sandusky have been effective in reducing erosion and PP export, these programs have been accompanied by increased DRP export. Future target loads for Lake Erie should focus on reducing bioavailable phosphorus, especially DRP from nonpoint sources. Agricultural P load reduction programs should address both DRP and PP, and take into account the lower bioavailability of PP.


Phosphorus (P) budgets for large watersheds are often used to predict trends in riverine P export. To test such predictions, we calculated annual P budgets for 1975-1995 for soils of the Maumee and Sandusky watersheds of northwestern Ohio and compared them with riverine P export from these watersheds. Phosphorus inputs to the soils include fertilizers, manure, rainfall, and sludge while outputs include crop removal and nonpoint-source export via rivers. Annual P inputs decreased due to reductions in fertilizer and manure inputs. Annual outputs increased due to increasing crop yields. Net P accumulation decreased from peak values of 13.4 and 9.5 kg P ha⁻¹ yr⁻¹ to 3.7 and 2.6 kg P ha⁻¹ yr⁻¹ for the Maumee and Sandusky watersheds, respectively. Thus, P budget analysis suggests that riverine P export should have increased throughout the study period, with smaller increases during more recent years. However, detailed water quality studies show that riverine export of total phosphorus (TP) has decreased by 25 to 40% and soluble reactive phosphorus (SRP) by 60 to 89%, both due primarily to decreases from nonpoint sources. We suggest that these decreases are associated with farmers’ adoption of practices that minimize transport of recently applied P fertilizer and of sediments via surface runoff, coupled with changes in winter weather conditions. In comparison with most Midwestern watersheds, rivers draining these watersheds have high unit area yields of TP, low unit area yields of SRP, and high ratios of nonpoint source- to point source-derived P.

The Great Lakes region encompasses the largest freshwater lake network in the world and supports a diverse network of agriculture, transportation, and tourism. Recently, Lake Erie has experienced increased hypoxia events, which have been attributed to agricultural practices and changes in run-off. Here we examine the projected changes in extreme precipitation events to address concerns regarding regional agriculture, surface run-off, and subsequent water quality. Precipitation projections within the overall Great Lakes Basin and the Western Lake Erie Basin subregion are examined using climate model simulations of varying spatial resolutions to understand historical precipitation and projected future precipitation. We develop three model ensembles for the historical period (1980-1999) and the mid-century (2041-2060) that cover a range of spatial resolutions and future emissions scenarios, including: (1) 12 global model members from the fifth Climate Model Intercomparison Project (CMIP5) using Representative Concentration Pathway (RCP) 8.5, (2) ten regional climate model (RCM) members from the North American Regional Climate Change Assessment Program driven by CMIP3 global models using the A2 emissions scenario, and (3) two high resolution RCM simulations (RCM4) driven by CMIP5 global models using the RCP 8.5 scenario. For the historical period, all model ensembles overestimate winter and spring precipitation, and many of the models simulate a summer drying that is not observed. At mid-century, most of the models predict a 10-20% increase in precipitation depending on the time of year. Daily probability distribution functions from three model ensembles reveal spring seasonal increases in high precipitation event probabilities when compared to the historical period, suggesting an increase in the frequency of high intensity precipitation at mid-century. Overall, the presence of lakes or higher spatial resolution does not ensure improved representation of historical processes, and more complex interactions between large-scale dynamics, local feedbacks, and physical parameterizations drive the model spread. © 2017 Royal Meteorological Society.


Harmful algal blooms (HABs) have increased in frequency and magnitude in western Lake Erie and spring phosphorus (P) load was shown to be a key driver of bloom intensity. A recently developed Bayesian hierarchical model that predicts peak bloom size as a function of Maumee River phosphorus load suggested an apparent increased susceptibility of the lake to HABs. We applied that model to develop load-response curves to inform revision of Lake Erie phosphorus load targets under the 2012 Great Lakes Water Quality Agreement. In this application, the model was modified to estimate the fraction of the particulate P (PP) load that becomes bioavailable, and it was recalibrated with additional bloom observations. Although the uncertainty surrounding the estimate of the bioavailable PP fraction is large, inclusion in the model improves prediction of bloom variability compared to dissolved reactive P (DRP) alone. The ability to characterize model and measurement uncertainty through hierarchical modeling allowed us to show that inconsistencies in bloom measurement represent a considerable portion of the overall uncertainty associated with load-response curves. The updated calibration also lends support to the system’s apparent enhanced susceptibility to blooms. The temporal trend estimated by the model results in an upward shift of the load-response curve over time such that a larger load reduction is
required to achieve a target bloom size today compared to earlier years. More research is needed to further test the hypothesis of a shift in the lake’s response to stressors over time and, if confirmed, to explore underlying mechanisms.

sediment and nutrient load reduction strategies, including agricultural best management practice (BMP) implementation and source reduction in various combinations for six watersheds. These watersheds, in order of decreasing phosphorus loads, include the Maumee, Sandusky, Cuyahoga, Raisin, Grand, and Huron, and together comprise 53% of the binational Lake Erie Basin area. Hypothetical pristine nutrient yields, after eliminating all anthropogenic influences, were estimated to be an order of magnitude lower than current yields, underscoring the need for stronger management actions. However, cover crops, filter strips, and no-till BMPs, when implemented at levels considered feasible, were minimally effective, reducing sediment and nutrient yields by only 0-11% relative to current values. Sediment yield reduction was greater than nutrient yield reduction, and the greatest reduction was found when all three BMPs were implemented simultaneously. When BMPs were targeted at specific locations rather than at random, greater reduction in nutrient yields was achieved with BMPs placed in high source locations, whereas reduction in sediment yields was greatest when BMPs were located near the river outlet. Modest nutrient source reduction also was minimally effective in reducing yields. Our model results indicate that an “all-of-above” strategy is needed to substantially reduce nutrient yields and that BMPs should be much more widely implemented. © 2013 Elsevier B.V.


Soil variability in watersheds accounts for the problem of partitioning downstream water quality data and evaluating sources of non-point pollution. This review of previous water quality studies was conducted to examine more closely the influence of soil properties on pollutant export. The approach used in this paper was to start with data from the two largest watersheds (Maumee and Sandusky) and then compare them on a unit area export basis with data from intermediate-size and smaller watersheds. General relationships between pollutant levels at the river mouth and upstream soil conditions are vague and seemingly contradictory at the large-watershed scale. With smaller watersheds, it can be determined that soil texture, slope, and internal drainage are controlling factors for pollutant export. Although Paulding (very-fine, illitic, nonacid, mesic Typic Epiaquept) and Roselms (very-fine, illitic, mesic Aeric Epiaqualf) soils occupy only 5% of the Maumee basin, they generate more than 10 times as much sediment per unit area as the tile-drained Hoytville (fine, illitic, mesic Mollic Epiaqualf) soils that occupy 16% of the Maumee basin. Tile drainage of very poorly drained soils that are formed from either glacial till or silty to sandy lake deposits reduces runoff and increases downward movement of soluble nutrients into tile drains. The assumption that sloping moraine areas are the primary source of pollutants should be reexamined based on this review. Source: WOS


Agricultural best management practices (BMPs) have been implemented in the watersheds around Lake Erie to reduce nutrient transfer from terrestrial to aquatic ecosystems and thus
protect and improve the water quality of Lake Erie. However, climate change may alter the effectiveness of these BMPs by altering runoff and other conditions. Using the Soil and Water Assessment Tool (SWAT), we simulated various climate scenarios with a range of BMPs to assess possible changes in water, sediment, and nutrient yields from four agricultural Lake Erie watersheds. Tile drain flow is expected to increase as is the amount of sediment that washes from land into streams. Predicted increases in tributary water flow (up to 17%), sediment yields (up to 32%), and nutrient yields (up to 23%) indicate a stronger influence of climate on sediment compared to other properties. Our simulations found much greater yield increases associated with scenarios of more pronounced climate change, indicating that above some threshold climate change may markedly accelerate sediment and nutrient export. Our results indicate that agricultural BMPs become more necessary but less effective under future climates; nonetheless, higher BMP implementation rates still could substantially offset anticipated increases in sediment and nutrient yields. Individual watersheds differ in their responsiveness to future climate scenarios, indicating the importance of targeting specific management strategies for individual watersheds.


Agriculture is one of the sources of phosphorus (P) that feeds into Lake Erie, impacting water quality. A substantial proportion of the agriculture in Ontario, Michigan and Ohio falls in the Lake Erie drainage basin. We examine trends in the balance of the major inputs and outputs of P to the soils of this region. Only a few decades ago, recommended rates of P application for optimum crop nutrition amounted to considerably more P than crops removed. In recent years, actual P applications have come much closer to balancing removals, while crop yields have increased. This trend has positive implications for both crop productivity and water quality. The P balance serves as an appropriate performance indicator for P management reflecting both economic and environmental aspects of sustainability. Depending on assumptions regarding the recoverability of manure and the current implementation of reduced-P feeding strategies in the livestock industry, estimates of the P balance for the region in 2008 range from a surplus equivalent to 1% of crop removal to a deficit amounting to 23% of the amount of P removed by crops.


In early August 2014, the municipality of Toledo, OH (USA) issued a "do not drink" advisory on their water supply directly affecting over 400,000 residential customers and hundreds of businesses (Wilson, 2014). This order was attributable to levels of microcystin, a potent liver toxin, which rose to 2.5 µg L⁻¹ in finished drinking water. The Toledo crisis afforded an opportunity to bring together scientists from around the world to share ideas
regarding factors that contribute to bloom formation and toxigenicity, bloom and toxin detection as well as prevention and remediation of bloom events. These discussions took place at an NSF- and NOAA-sponsored workshop at Bowling Green State University on April 13 and 14, 2015. In all, more than 100 attendees from six countries and 15 US states gathered together to share their perspectives. The purpose of this review is to present the consensus summary of these issues that emerged from discussions at the Workshop. As additional reports in this special issue provide detailed reviews on many major CHAB species, this paper focuses on the general themes common to all blooms, such as bloom detection, modeling, nutrient loading, and strategies to reduce nutrients.


Soil variability in watersheds accounts for the problem of partitioning downstream water quality data and evaluating sources of non-point pollution. This review of previous water quality studies was conducted to examine more closely the influence of soil properties on pollutant export. The approach used in this paper was to start with data from the two largest watersheds (Maumee and Sandusky) and then compare them on a unit area export basis with data from intermediate-size and smaller watersheds. General relationships between pollutant levels at the river mouth and upstream soil conditions are vague and seemingly contradictory at the large-watershed scale. With smaller watersheds, it can be determined that soil texture, slope, and internal drainage are controlling factors for pollutant export. Although Paulding (very-fine, illitic, nonacid, mesic Typic Epiaquept) and Roselms (very-fine, illitic, mesic Aeric Epiaqualf) soils occupy only 5% of the Maumee basin, they generate more than 10 times as much sediment per unit area as the tile-drained Hoytville (fine, illitic, mesic Mollic Epiaqualf) soils that occupy 16% of the Maumee basin. Tile drainage of very poorly drained soils that are formed from either glacial till or silty to sandy lake deposits reduces runoff and increases downward movement of soluble nutrients into tile drains. The assumption that sloping moraine areas are the primary source of pollutants should be reexamined based on this review. Source: WOS


The prevalence of anthropogenic drainage systems in intensively cropped areas across North America combined with the degradation of important freshwater resources in these regions has created a critical intersection where understanding phosphorus (P) transport in drainage waters is vital. In this study, drainage-associated nutrient load data were retrieved and
quantitatively analyzed to develop a more comprehensive understanding of the P loading and crop yield impacts of agronomic management practices within drained landscapes. Using the Drain Load table in the MANAGE (Measured Annual Nutrient loads from AGRicultural Environments) database, the effect of factors such as soil characteristics, tillage, and nutrient management on P loading were analyzed. Across siteyears, generally less than 2% of applied P was lost in drainage water, which corroborates the order of magnitude difference between agronomic P application rates and P loadings that can cause deleterious water quality impacts. The practice of no-till significantly increased drainage dissolved P loads compared with conventional tillage (0.12 vs. 0.04 kg P ha-1). The timing and method of P application are both known to be important for P losses, but these conclusions could not be verified due to low site-year counts. Findings indicate there is a substantial need for additional field-scale studies documenting not only P losses in drainage water but also important cropping management, nutrient application, soil property, and drainage design impacts on such losses. © American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. 5585 Guilford Rd., Madison, WI 53711 USA. All rights reserved.


Western Lake Erie Basin (WLEB) is the most intensively farmed region of the Great Lakes. Because of the flat topography and poorly-drained soils many farmers rely on drainage management practices (e.g., subsurface tile drainage, ditch channelization) to maintain productive agriculture. However, these practices also facilitate the delivery of excess nutrients and sediments to Lake Erie, which have been linked to recurring harmful algal blooms (HABs) and associated environmental degradation. Implementation of inset floodplains in formerly channelized waterways via the two-stage ditch can improve water quality but the efficacy has been tested using only implementation in short reaches. Watershed models are critical tools for assessing watershed-scale implementation and as such can guide effective management. We evaluated the effectiveness of the two-stage ditch in improving water quality in the River Raisin Watershed (RRW), a major subbasin in the WLEB, combining empirical measurements for nutrient reductions from two-stage ditches across the Midwest with output from a Soil Water Assessment Tool (SWAT) model. We modeled two-stage implementation in 25, 50, and 100% of headwater reaches in the RRW, and found that the practice could reduce total annual NO3 --N export by 2, 5 and 10%, respectively. The two-stage was even more effective at reducing total phosphorus (TP) export, which was reduced by 12, 20 and 31%, respectively. Compared to other conservation practices, nutrient reduction efficiency for the two-stage ditch was good, both in terms of percent load reduction and cost, but watershed-scale adoption will be required in order to achieve significant nutrient reductions as called for by policymakers.


© 2016 International Association for Great Lakes Research
For Research Purposes Only ........................................Not for Publication.

nonpoint sources is often implicated as a contributing factor to the proliferation of algal blooms in freshwater ecosystems. However, the influence of subsurface tile drains as a source of P, especially in agricultural areas, has received limited attention. We examined the importance of tile drain effluent in the Macatawa Watershed; this watershed is dominated by row crop agriculture and drains into hypereutrophic Lake Macatawa, which connects to Lake Michigan. Our objectives were twofold: 1) assess the importance of tile drain effluent as a source of P in the Macatawa Watershed by measuring tile drain P concentrations spatially and temporally over a one-year period; and 2) assess the ability of tile drain effluent to stimulate algal blooms using bioassays with natural phytoplankton communities. During March 2015–February 2016, P concentrations varied significantly among sample sites (SRP: < 0.005 to 0.447 mg/L; TP: 0.010 to 0.560 mg/L), and the highest P loads occurred during the non-growing season. Annual SRP yields from the tile drain sample sites ranged from 0.002 kg/ha to 0.248 kg/ha, and annual TP yields ranged from 0.003 kg/ha to 0.322 kg/ha. SRP, on average, accounted for 60% of TP, and the SRP:TP ratio measured at the tile drain outlets was positively correlated with area drained by the tile system. Algal bioassays failed to find a positive relationship between chlorophyll a and tile drain SRP; algal community structure was dominated by diatoms, not by cyanobacteria, as expected.


Recurrent, massive cyanobacterial blooms composed mainly of the genus Microcystis indicate a broad-scale re-eutrophication of Lake Erie. In the past, ameliorating eutrophication relied on intentionally decreasing point-source tributary nutrient, especially phosphorus, loads to the lake. However, recent research has shown that tributaries load not only nutrients but also bloom-levels of phytoplankton, including Microcystis. We built on this previous work by sampling earlier in the year and in much smaller tributaries in both the Maumee and Sandusky systems. We found Microcystis wet biomasses in these tributaries averaged 3.16. mg/L (±. 0.59. mg/L, one standard error of the mean) in 2009 and 3.42. mg/L (±. 0.55. mg/L) in 2010. Importantly, we found Microcystis in small ditches in March, much earlier than previously observed. Microcystis biomass did not directly correspond to measured phosphorus, chlorophyll, or phycocyanin concentrations likely reflecting complexities associated with lagged physiological responses and/or non-linear growth relationships. Consequently, our findings emphasize that Microcystis blooms form a more broad-scale problem than previously documented, occurring far upstream much earlier in the year.

Nutrient and Sediment Dynamics and Delivery in Western Lake Erie Basin, 2003-06 and 2012

Title. Retrieved from


Phosphorus (P) is an essential element for all life forms. It is a mineral nutrient. Orthophosphate is the only form of P that autotrophs can assimilate. Extracellular enzymes hydrolyze organic forms of P to phosphate. Eutrophication is the overenrichment of receiving waters with mineral nutrients. The results are excessive production of autotrophs, especially algae and cyanobacteria. This high productivity leads to high bacterial populations and high respiration rates, leading to hypoxia or anoxia in poorly mixed bottom waters and at night in surface waters during calm, warm conditions. Low dissolved oxygen causes the loss of aquatic animals and release of many materials normally bound to bottom sediments including various forms of P. This release of P reinforces the eutrophication. Excessive concentrations of P is the most common cause of eutrophication in freshwater lakes, reservoirs, streams, and headwaters of estuarine systems. In the ocean, N becomes the key mineral nutrient controlling primary production. Estuaries and continental shelf waters are a transition zone, where excessive P and N create problems. It is best to measure and regulate total P inputs to whole aquatic ecosystems, but for an easy assay it is best to measure total P concentrations, including particulate P, in surface waters or N/P atomic ratios in phytoplankton.


Landscape composition is consequential to ecological functions, and in agricultural regions a simple descriptor of composition is whether the growing habit of vegetation is annual or perennial. Annual vegetation includes most of the crop species grown in central North America (e.g., corn, soybeans, cereal grains, canola), and perennial vegetation includes hay and forage crops (e.g., alfalfa) and most non-crop land covers (e.g., woodlands, grasslands, wetlands). Recent data show that in farmlands perennial cover is converting to annual cover. Using new remotely sensed annual crop layer spatial data for an intensively farmed region (1,700 km2) of the Lake Huron watershed in Southern Ontario, Canada, this paper describes changes in farmland composition and which transitions are occurring, with suggestions for why the changes are occurring. Perennial cover has rapidly been converted to annual cover in the past five years, with working-lands perennial cover types identified as the most vulnerable to conversion. Other land cover types are relatively static. Implications for agricultural land conservation and stewardship require attention to this rapid change for conservation of soil, water, and biodiversity in the Great Lakes basin.


Study region: Harmful algal blooms (HABs) in the Western Basin (WB) of Lake Erie have
been linked to nonpoint pollution from agricultural watersheds. The Maumee River watershed is the largest in the Great Lakes region and delivers the biggest sediment and nutrient load to Lake Erie. Study focus: Climate change could alter the magnitude and timing of sediment and nutrient delivery to Lake Erie’s WB. Data from four Coupled Model Intercomparison Project Phase 5 (CMIP5) models were inputted into a calibrated Soil and Water Assessment Tool (SWAT) model of the Maumee River watershed to determine the effects of climate change on watershed yields. Tillage practices were also altered within the model to test the effectiveness of conservation practices under climate change scenarios. New hydrological insights for the region: Moderate climate change scenarios reduced annual flow (up to -24%) and sediment (up to -26%) yields, while a more extreme scenario showed smaller flow reductions (up to -10%) and an increase in sediment (up to +11%). No-till practices had a negligible effect on flow but produced 16% lower average sediment loads than scenarios using current watershed conditions. At high implementation rates, no-till practices could offset any future increases in annual sediment loads, but they may have varied seasonal success. Regardless of future climate change intensity, increased remediation efforts will likely be necessary to significantly reduce HABs in Lake Erie’s WB.


Climate change holds great potential to affect the Lake Erie ecosystem by altering the timing and magnitude of precipitation driven river discharge and nutrient runoff in its highly agricultural watershed. Using the SWAT hydrologic model and an ensemble of global climate models, we predicted Maumee River (Ohio) discharge during the 21st century under two Intergovernmental Panel on Climate Change (IPCC) greenhouse gas emissions scenarios: RCP4.5 (mid-range, moderate reductions) and RCP8.5 (high, “business as usual”). Annual discharge was projected to increase under both scenarios, both in the near-century (RCP4.5=6.5%; RCP8.5=2.0%) and late-century (RCP4.5=9.2%; RCP8.5=15.9%), owing to increased precipitation and reduced plant stomatal conductance. Holding fertilizer application rates at baseline levels, we found that reduced winter surface runoff and increased plant phosphorus (P) uptake led to a respective decrease in annual total P (TP) runoff in the near-century (RCP4.5=−4.3%; RCP8.5=−6.6%) and by the late-century (RCP4.5=−14.6%; RCP8.5=−7.8%). Likewise, soluble reactive P (SRP) runoff was predicted to decrease under both scenarios in the near-century (RCP4.5=−0.5%; RCP8.5=−3.5%) and by the late-century (RCP4.5=−11.8%; RCP8.5=−8.6%). By contrast, when fertilizer application was modeled to increase at the same rate as plant P uptake, TP loading increased 4.0% (0.9%) in the near-century and 9.9% (24.6%) by the late-century and SRP loading increased 10.5% (6.1%) in the near-century and 26.7% (42.0%) by the late-century under RCP4.5 (RCP8.5). Our findings suggest that changes in agricultural practices (e.g., fertilization rates) will be key determinants of Maumee River discharge during the 21st century.

In the last decade, Lake Erie, one of the great lakes bordering Canada and the USA has been under serious threat due to increased phosphorus levels originating from agricultural fields. Large scale watersheds contributing to Lake Erie from the USA side are being simulated using hydrological and water quality (H/WQ) models such as the Soil and Water Assessment Tool (SWAT) and the results from the model are being used by policy and decision makers to implement better management decisions to solve emerging phosphorus issues. On the Canadian side, modeling applications are limited to either small watersheds or one major watershed contributing to Lake Erie. To the best of our knowledge, no efforts have been made to model the entire contributing watersheds to Lake Erie from Canada. This study applied the SWAT model for Northern Lake Erie Basin (NLEB; entire contributing basin to Lake Erie). Various provincial, national and global inputs of weather, land use and soil at various resolutions was assessed to evaluate the effects of input data types on the simulation of hydrological processes and streamflows. Twelve scenarios were developed using the input combinations and selected scenarios were evaluated at selected locations along the Grand and Thames Rivers using model performance statistics, and graphical comparisons of time variable plots and flow duration curves (FDCs). In addition, various hydrological components such as surface runoff, water yield, and evapotranspiration were also evaluated. Global level coarse resolution weather and soil did not perform better compared to fine resolution national data. Interestingly, in the case of land use, global and national/provincial land use were close, however, fine resolution provincial data performed slightly better. This study found that interpolated weather data from Environment Canada climate station observations performed slightly better compared to the measured data and therefore could be a good choice to use for large-scale H/WQ modeling studies.


Watershed simulation models are used extensively to investigate hydrologic processes, landuse and climate change impacts, pollutant load assessments and best management practices (BMPs). Developing, calibrating and validating these models require a number of critical decisions that will influence the ability of the model to represent real world conditions. Understanding how these decisions influence model performance is crucial, especially when making science-based policy decisions. This study used the Soil and Water Assessment Tool (SWAT) model in West Lake Erie Basin (WLEB) to examine the influence of several of these decisions on hydrological processes and streamflow simulations. Specifically, this study addressed the following objectives (1) demonstrate the importance of considering intra-watershed processes during model development, (2) compare and evaluated spatial calibration versus calibration at outlet and (3) evaluate parameter transfers across temporal and spatial scales. A coarser resolution (HUC-12) model and a finer resolution model (NHDPlus model) were used to support the objectives. Results showed that knowledge of watershed characteristics and intra-watershed processes are critical to produced accurate and realistic hydrologic simulations. The spatial calibration strategy produced better results compared to outlet calibration strategy and provided more confidence. Transferring parameter values across spatial scales (i.e. from coarser resolution model to finer resolution model) needs additional fine tuning to produce realistic results.
Transferring parameters across temporal scales (i.e. from monthly to yearly and daily time-steps) performed well with a similar spatial resolution model. Furthermore, this study shows that relying solely on quantitative statistics without considering additional information can produce good but unrealistic simulations.


Renewed harmful algal blooms and hypoxia in Lake Erie have drawn significant attention to phosphorus loads, particularly increased dissolved reactive phosphorus (DRP) from highly agricultural watersheds. We use the Soil and Water Assessment Tool (SWAT) to model DRP in the agriculture-dominated Sandusky watershed for 1970-2010 to explore potential reasons for the recent increased DRP load from Lake Erie watersheds. We demonstrate that recent increased storm events, interacting with changes in fertilizer application timing and rate, as well as management practices that increase soil stratification and phosphorus accumulation at the soil surface, appear to drive the increasing DRP trend after the mid-1990s. This study is the first long-term, detailed analysis of DRP load estimation using SWAT.


Phosphorus in runoff from agricultural land is an important component of nonpoint-source pollution and can accelerate eutrophication of lakes and streams. Long-term land application of P as fertilizer and animal wastes has resulted in elevated levels of soil P in many locations in the USA. Problems with soils high in P are often aggravated by the proximity of many of these areas to P-sensitive water bodies, such as the Great Lakes, Chesapeake and Delaware Bays, Lake Okeechobee, and the Everglades. This paper provides a brief overview of the issues and options related to management of agricultural P that were discussed at a special symposium titled, “Agricultural Phosphorus and Eutrophication,” held at the November 1996 American Society of Agronomy annual meetings. Topics discussed at the symposium and reviewed here included the role of P in eutrophication; identification of P-sensitive water bodies; P transport mechanisms; chemical forms and fate of P; identification of P source areas; modeling of P transport; water quality criteria; and management of soil and manure P, off-farm P inputs, and P transport processes.


Integrated, quantitative expressions of anthropogenic stress over large geographic regions can be valuable tools in environmental research and management. Despite the fundamental appeal of a regional approach, development of regional stress measures remains one of the most important current challenges in environmental science. Using publicly available, pre-existing spatial datasets, we developed a geographic information system database of 86
variables related to five classes of anthropogenic stress in the U.S. Great Lakes basin: agriculture, atmospheric deposition, human population, land cover, and point source pollution. The original variables were quantified by a variety of data types over a broad range of spatial and classification resolutions. We summarized the original data for 762 watershed-based units that comprise the U.S. portion of the basin and then used principal components analysis to develop overall stress measures within each stress category. We developed a cumulative stress index by combining the first principal component from each of the five stress categories. Maps of the stress measures illustrate strong spatial patterns across the basin, with the greatest amount of stress occurring on the western shore of Lake Michigan, southwest Lake Erie, and southeastern Lake Ontario. We found strong relationships between the stress measures and characteristics of bird communities, fish communities, and water chemistry measurements from the coastal region. The stress measures are taken to represent the major threats to coastal ecosystems in the U.S. Great Lakes. Such regional-scale efforts are critical for understanding relationships between human disturbance and ecosystem response, and can be used to guide environmental decision-making at both regional and local scales.

Approximately 80% of the land area draining into the western Lake Erie Basin is in Ohio, much of which is agricultural. Therefore, the potential for agricultural phosphorus (P) loading from Ohio is a concern for the water quality of western basin rivers, embayments and open water. This work demonstrates soil P relationships across Ohio soils and its implications for potential revisions of Ohio P risk assessment tools. The objectives were, using a selection of soils representative of soils across Ohio, (i) to determine if soil survey classification (series) could be an indicator of hydrous oxide content and, (ii) to determine if agronomic soil test P (STP) Mehlich 3 (M3-P), Bray P, or alternative measures of soil P saturation (Psat) were comparable to oxalate Psat for predicting P solubility, and therefore, useful for Ohio P risk assessment tools. Results showed no significant difference (. P>. 0.01) in soil hydrous oxide content when grouped by soil series. However, significant (. P<. 0.01) inflection points, reflecting a rapid increase in P solubility, were identified for oxalate P saturation (11.8%), M3-P saturation (12.4%), M3-P extractable P (181. mg/kg), and Bray-P extractable P (122. mg/kg). This suggests a separate pre- and post-inflection point consideration of STP may be appropriate for revised Ohio P risk assessment tools to better reflect increased post-inflection offsite P transport risk and thereby be sufficiently protective of water quality. Identifying fields with high offsite P transport risk is critical to implementing management decisions to reduce P transport risk to receiving waters including Lake Erie.


Phosphorus (P) runoff from agricultural land continues to receive attention due to a widespread lack of reduction in losses combined with a series of high profile P-induced harmful algal blooms. Many widely adopted conservation practices (CPs), aimed at reducing P loss, target particulate P (PP) through reductions in erosion or entrapment of P within the terrestrial landscape. However, there is increasing evidence that in time, these CPs may in fact increase dissolved P (DP) losses. We reviewed the effectiveness of current CPs promoted in the U.S., the results from long-term in-stream monitoring following implementation of conservation schemes and field studies investigating P loss from buffer zones designed to trap PP. These studies showed that different CPs are required to target different forms of P loss and the tendency for farmers to implement strategies targeting PP over DP resulted in an increase in dissolved reactive P export post-implementation of 37–250 % in three of the five catchment monitoring studies. Buffer zones, such as grass and vegetative filter strips, managed riparian zones and wetlands were found to accumulate labile forms of soil P over time and, in some studies, became significant sources of both inorganic and organic DP. Furthermore, often overlooked microbial processes appear to play a key role in P release. Consequently, to improve the effectiveness of future conservation schemes, practices need to specifically target DP losses in addition to PP and recognize that CPs trapping P within the landscape are at risk of becoming legacy P sources.


Nonpoint source pollution from agricultural land uses continues to pose one of the most significant threats to water quality in the US, with measurable impacts across local, regional, and national scales. The impact and the influence of targeted conservation efforts are directly related to the degree to which farmers are familiar with and trust the entities providing the information and/or outreach. Recent research suggests that farmers consistently rank independent and retail-affiliated crop advisers as among the most trusted and influential sources for agronomic information, but little is understood about whether farmers are willing to receive advice from crop advisers on the use of practices that conserve soil and water, and, if so, whether crop advisers will be perceived as influential. We present survey data from farmers (n = 1461) in Michigan’s Saginaw Bay (Lake Huron) watershed to explore these questions. Results suggest that farmers view crop advisers as trustworthy sources of information about conservation, and influential on management practices that have large conservation implications. We discuss these results, along with perceived barriers and opportunities to crop advisers partnering with traditional conservation agencies to enhance the impact of voluntary conservation programs.

Nitrate (NO$_3$-N) concentrations in offshore waters of Lake Ontario increased by approximately 60% between the 1970s and 2000s, although the drivers are unclear. Here, we show that NO$_3$-N concentrations also increased significantly in at least one season at 13 of 15 large southern Ontario tributaries (8.4 to 2779km$^2$) that drain into Lake Ontario and have no known upstream wastewater treatment plants. Average NO$_3$-N concentrations more than doubled between the 1970s and 2000s at some streams. Only the two most urbanized streams did not show any increase in NO$_3$-N and NO$_3$-N declined at the most urbanized catchment in this study (Sheridan Creek; 92% urban). Agriculture is the predominant form of human activity at the 13 watersheds where NO$_3$-N increased, accounting for 51–71% of total land cover. Both the total area of agricultural land and the type of agriculture have changed dramatically in southern Ontario; and these shifts could alter nutrient transfer to waterways. Specifically, shifts in agriculture towards more N-demanding annual row crops like corn could result in higher NO$_3$-N leakage to streams, and the impact of this form of land use change on nutrient export requires further investigation. Overall, these results suggest that changes in tributary loading may have contributed to recent observations of increasing NO$_3$-N levels in offshore waters of Lake Ontario.


There is growing evidence that addressing nonpoint source pollution within intensely agricultural regions of the Great Lakes will require innovative solutions to achieve meaningful ecological outcomes. Recognizing this, a broad coalition of partners is collaborating across Michigan’s Saginaw Bay watershed to develop and test innovative approaches to achieve the vision of Strategic Agricultural Conservation. The strategy focuses on using science, technology, and new ways of incentivizing practices and delivering services to producers to address challenges and barriers to Strategic Agricultural Conservation. It uses science to model relations between conservation actions, water quality and fish community health, allowing the coalition to establish realistic ecological outcomes and both short and long-term implementation goals at a variety of scales. It uses a decision tool and pay-for-performance methods to strategically target conservation practices and increase their efficiency. It uses nontraditional partners to help increase the ability to engage landowners and streamlined the application process to help increase landowner participation. Finally, it uses secure, privacy respecting, methods to track practices and progress towards short and long-term goals. Herein we present three case studies that demonstrate the practical application of this strategy including developing and testing new innovative conservation programs across the Saginaw Bay watershed. The success of this work will ultimately be determined by a variety of factors that affect conservation at landscape scales. However, what is clear is that without the science and complementary decision tool, this collaborative adaptive management approach would be impossible to implement across such a large geography.

Since the early 1970s, pollution abatement efforts have recognized nonpoint sources and, particularly, agriculture, as major causes of pollution in the Lake Erie region. The first objective of this research is to summarize federal and state agricultural pollution abatement programs that encouraged farmers to adopt conservation practices. Next, the economic impacts of changes in farming practices are reviewed. Statistical analyses of farm-level accounting data and a farm simulation model are used to investigate the economic effects of conservation practices in the region. Finally, simulated farm pollutant emissions in 1985 and 1995 are compared to actual pollutant loadings. This comparison offers evidence that improvements in water quality are attributable to changes in farming practices, (e.g., conservation tillage adoption).

This paper summarizes research that investigates the effects of alternative farming practices on the performance of Lake Erie basin farms. First, data from a representative panel of about 100 farmers is analyzed to determine how conservation tillage, rotations, and other factors affected farms’ economic returns during 1987-1992. Statistical analysis of these data is unable to demonstrate that there is any significant relationship between farming system (i.e., tillage and rotation) variables and farm profitability. Next, a farm-level bioeconomic simulation model is used to analyze the effects of conservation tillage adoption on farm profitability, farm size, and pollutant emissions. Findings are that tillage system, farm size, and crop selection are determined jointly and may substantially improve economic performance of farms. Conservation tillage enables farms to be larger and more specialized, and as a result, farm profitability improves. Statistical analysis of farm panel data is unable to show the effect of tillage on profitability because it neglects to account for endogeneity of variables (or joint effects of tillage, size, crop selection, and performance) in production decisions.

40. Forster, D. L., & Rausch, J. N. (2002). Evaluating agricultural nonpoint-source pollution programs, in two Lake Erie tributaries. *Journal of Environmental Quality, 31*(1), 24–31. During the past three decades, numerous government programs have encouraged Lake Erie basin farmers to adopt practices that reduce water pollution. The first section of this paper summarizes these state and federal government agricultural pollution abatement programs in watersheds of two prominent Lake Erie tributaries, the Maumee River and Sandusky River. Expenditures are summarized for each program, total expenditures in each county are estimated, and cost effectiveness of program expenditures (i.e., cost per metric ton of soil saved) are analyzed. Farmers received nearly dollar sign143 million as incentive payments to implement agricultural nonpoint source pollution abatement programs in the Maumee and Sandusky River watersheds from 1987 to 1997. About 95% of these funds was from federal sources. On average, these payments totaled about dollar sign7000 per farm or about dollar sign30 per farm acre (annualized equivalent of dollar sign2 per acre) within the watersheds. Our analysis raises questions about how efficiently these incentive payments were allocated.
The majority of Agricultural Conservation Program (ACP) funds appear to have been spent on less cost-effective practices. Also, geographic areas with relatively low (high) soil erosion rates received relatively large (small) funding. Source: BIOSIS

Agriculture’s contributions to Lake Erie water quality problems have been a concern for the past three decades. This research investigates the relationship between changes in water quality and changes in farming practices in two Lake Erie tributaries. Using the Erosion Productivity Impact Calculator (EPIC), simulations of pollutant emissions from farms in the Maumee and Sandusky River basins were conducted with 1985 and 1995 land use and cropping patterns. This information was compared with unit area loads derived from detailed water quality data collected at integrator stations near the mouths of the two rivers. The comparison showed large differences between the two data sets that cannot be explained by errors of load estimation, errors in application of the EPIC model, or differences between the modeled and monitored parameters. Rather, discrepancies in results are likely due to the fact that EPIC does not model in-stream delivery losses, and the observed loads are affected by these losses. However, EPIC simulations are generally accurate in predicting the direction of change of unit area loads of water quality parameters.

Agricultural production has been identified as a major source of groundwater and sediment pollution in the western Lake Erie Basin of Ohio. In order to anticipate the effects of potential conservation policies, we employed a bioeconomic model to examine the relationship between alternative tillage practices and environmental and economic impacts in the western Lake Erie Basin of Ohio. Our results indicated that the effects of conservation tillage were mixed. Favorable impacts for the region’s environment and economy were: a.) soil erosion decreased and future soil productivity improved, b.) several potential pollutants (e.g., sediment, organic nitrogen, and total phosphorus loadings) decreased, and c.) farm profitability improved. But these positive effects were somewhat offset by unintended consequences such as: (a) some potential pollutants (e.g., nitrates and herbicides) increased, (b) crop mix and input usage changed, and (c) average farm size increased resulting in fewer farms in the region.

Evaluation of USDA conservation programs are required as part of the Conservation Effects Assessment Project (CEAP). The Agricultural Policy/Environmental eXtender (APEX) model was applied to the St. Joseph River watershed, one of CEAP’s benchmark watersheds. Using a previously calibrated and validated APEX model, the simulation of
various conservation practices (single and combined) was conducted at the field scale. Seven variables [runoff, sediment, total phosphorus (TP), dissolved reactive phosphorus (DRP), soluble nitrogen (SN), tile flow, and soluble nitrogen in tile (SN-Tile)], were compared between the simulated practices. The field-scale outputs were extrapolated to the areas encompassed by the different conservation practices at the watershed scale. The speculative estimations are presented as percentage reductions compared to the baseline scenario. When single conservation practices were implemented, reductions were 39% for sediment, 7% for TP, and 24% for SN-Tile. In contrast, losses of DRP and SN increased by 5% and 57%, respectively. When the conservation practices were combined, percentage reductions increased for all variables. The total reductions for combined two and three practices were 68% and 91% for sediments, 35% and 74% for TP, 1% and 48% for DRP, -43% and 28% for SN, and 50% and 85% for SN-Tile. Negative reductions were due to the slightly higher DRP and SN loads in no-till, mulch-till, and conservation crop rotation practices, and their greater extent of incorporation at the watershed scale. Overall, the cumulative and combined effects of field conservation practices can help address the watershed’s excess nutrient and sediment concerns and improve water quality.


The evaluation of agricultural practices through monitoring and modeling is necessary for the development of more effective conservation programs and policies. No-till and reduced-till are both agricultural conservation practices widely promoted for their proven ability to conserve water and reduce soil erosion. These conservation practices were used to evaluate the APEX (Agricultural Policy/Environmental Extender) model. Data from two tile-drained corn-soybean rotation fields located within the St. Joseph River watershed in northeast Indiana were collected and compared. Observed daily surface and subsurface tile flow, sediment load, and nutrient transport values were described and analyzed using a Wilcoxon signed-rank test. Among the nutrient variables examined, we compared soluble phosphorus (SP), total phosphorus (TP), soluble nitrogen (SN), and soluble nitrogen in tile (SN-tile). The results agree with previous findings identifying lower sediment and nutrient transport values in no-till compared to reduced-till (except for SP during the corn year). However, significantly lower values were only observed for sediment and SN-tile losses in the no-till system. The monitored variables were also used for calibration and validation of the APEX model. APEX calibration/validation evaluation scores were satisfactory for surface runoff for both tillage management simulations (R2 = 0.87/0.76 and NSE = 0.65/0.76 for no-till, and R2= 0.76/0.74 and NSE = 0.74/0.74 for reduced-till, in addition to other statistical analyses). Model performances in simulating sediment load, nutrient variables, and tile flow were relatively lower, yet satisfactory overall. APEX was an efficient tool for simulating most of the variables examined. However, the model presents limitations in simulating tile flow, and consequently nitrogen loss, from tile-drained systems.


Conservation tillage is encouraged in southwestern Ontario by concern for soil erosion and
compaction. The contribution of agriculture to eutrophication of the Great Lakes by P is also at issue. Soil loss and ortho-P transport were measured from a conventional and two conservation tillage treatments (zero and ridge tillage) from January 1988 to 30 Sept. 1990 to evaluate their impact on meeting Great Lakes water quality objectives for P. Sediment concentration from the poorly drained, Brookston clay loam (clayey, mixed, mesic Typic Haplaquolls), cropped to corn (Zea mays L.) was 2.1 times larger in surface runoff than tile discharge (0.20 g L(-1)) but tile discharge contributed 44 to 65% of the soil loss probably from preferential flow. Conservation tillage reduced average soil loss 49% from conventional tillage (899 kg ha(-1)). Conservation tillage increased ortho-P concentrations in runoff 2.2 times from conventional tillage (0.25 mg L(-1)). Orthophosphate transport decreased in the order zero>ridge>conventional tillage. Average ortho-P loss was 1.7 to 2.7 times greater from conservation than conventional tillage Q59 g ha(-1) yr(-1)). Subsurface drainage accounted for 55 to 68% of the ortho-P transported. Transport of total soluble P and total P (sum of sediment-attached P and soluble P, only measured in 1990) increased 2.2 and 2.0 times, respectively, with conservation than conventional tillage. Dissolved P accounted for 84 to 93% of the P transported from the three tillage treatments. Sediment-attached P constituted 7 to 16% of total P loss. Conservation tillage effectively reduced soil erosion but increased P loss. Source: WOS


To reduce the intensity and frequency of harmful algal blooms in western Lake Erie, it has been recommended to reduce the phosphorus load, contributed by the Maumee River watershed (MRW) in northwest Ohio. As the largest contributor of phosphorus to Lake Erie, the dominantly agricultural MRW in northwest Ohio has been recommended to reduce phosphorus loads by 40%. To achieve such reductions, three agricultural nutrient management practices, (1) fertilizer placement within the soil, (2) adjusted seasonal timing of fertilizer application, and (3) adjusted date of fertilizer application to drier days have been recommended. To determine the potential phosphorus load reduction from implementing these three management practices, a SWAT model of the MRW was developed to evaluate the effectiveness of each practice for reducing SRP and total phosphorus (TP) load to the lake. Management scenarios were modeled with variations of the three practices from 2007 to 2012, and compared to historical data. Overall, maximum fertilizer placement had the greatest potential to influence SRP and TP loads; reducing spring SRP and TP loading by 42% and 27%, respectively compared to baseline levels. Seasonal fertilizer application timing also impacted spring SRP and TP loads, but to a lesser degree. Changing the date of application from wetter days to drier days across the watershed did not significantly affect SRP or TP loads, but this result is likely due to limitations of the SWAT simulation. These results indicate that maximizing fertilizer placement has a great potential to reduce TP and
SRP runoff from the MRW.


This review focuses on recent advances in understanding the origins, abiotic and biotic cycling, and measurement of inositol phosphates (IPx) in manures and soils. With up to eight orthophosphates bound to inositol via ester linkages, this class of compounds has the potential to be unavailable to enzymatic hydrolysis when sorbed or in complex with soil metals, limiting the release of phosphorus (P) for uptake by plants. However, hydrolysis of IPx by microbial phytases in aquatic environments could result in a potent source of the eutrophication agent orthophosphate. This review discusses the forms and stereoisomers of IPx that have been identified in environmental samples. Next, it discusses the various techniques used to identify IPx, including extraction and concentration, separation techniques such as electrophoresis, spectroscopic methods such as phosphorus-31 nuclear magnetic resonance spectroscopy (31P-NMR), mass spectrometry and X-ray absorption near-edge structure (XANES), and enzymatic techniques, such as enzyme hydrolysis (EH). Recent advances in knowledge about abiotic and biotic factors controlling the cycling of IPx in soil, manure and water are summarised, including soil characteristics affecting IPx sorption, transportation processes, and the microbial production and degradation of IPx. Finally, areas for future research focus are discussed.


Increasing concerns regarding water quality in the Great Lakes region are mainly due to changes in urban and agricultural landscapes. Both point and non-point sources contribute pollution to Great Lakes surface waters. Best management practices (BMPs) are a common tool used to reduce both point and non-point source pollution and improve water quality. Meanwhile, identification of critical source areas of pollution and placement of BMPs plays an important role in pollution reduction. The goal of this study is to evaluate the performance of different targeting methods in 1) identifying priority areas (high, medium, and low) based on various factors such as pollutant concentration, load, and yield, 2) comparing pollutant (sediment, total nitrogen-TN, and total phosphorus-TP) reduction in priority areas defined by all targeting methods, 3) determine the BMP relative sensitivity index among all targeting methods. Ten BMPs were implemented in the Saginaw River Watershed using the Soil and Water Assessment Tool (SWAT) model following identification of priority areas. Each targeting method selected distinct high priority areas based on the methodology of implementation. The concentration based targeting method was most effective at reduction of TN and TP, likely because it selected the greatest area of high priority for BMP implementation. The subbasin load targeting method was most effective at reducing sediment because it tended to select large, highly agricultural subbasins for BMP implementation. When implementing BMPs, native grass and terraces were generally the most effective, while conservation tillage and residue management had limited effectiveness. The BMP relative sensitivity index revealed that most combinations of targeting methods and priority areas resulted in a proportional decrease in pollutant load
from the subbasin level and watershed outlet. However, the concentration and yield methods were more effective at subbasin reduction, while the stream load method was more effective at reducing pollutants at the watershed outlet. The results of this study indicate that emphasis should be placed on selection of the proper targeting method and BMP to meet the needs and goals of a BMP implementation project because different targeting methods produce varying results. Published by Elsevier Ltd. Source: WOS


Evaluating the potential effects of changes in climate on conservation practices can help inform strategies to protect freshwater biodiversity that are robust, even as conditions change. Here we apply a climate change “test” to a framework for estimating the amount of agricultural conservation practices needed to achieve desired fish conservation outcomes for four watersheds in the Saginaw Bay region of Michigan, USA. We developed three climate scenarios from global climate model outputs (high emissions scenario, “2080s” timeframe) to provide insight on potential impacts of a climate driver that represents a key uncertainty for this management system, the amount and timing of spring and summer precipitation. These scenarios were used as inputs to agricultural watershed models, which produced water quality outputs that we compared to thresholds in fish biodiversity metrics at the subwatershed scale. Our results suggest that impacts of climate change on evaporation rates and other aspects of hydrology will shift the relative importance of key stressors for fish (i.e., sediment loadings vs. nutrient concentrations) across these different watersheds, highlighting the need to design resilient implementation plans and policies. Overall, we found that changes in climate are likely to increase the need for agricultural conservation practices, but that increasing the implementation rate above current levels will likely remain a good investment under current and future climate conditions.


Harmful blooms of cyanobacteria (CyanoHABs) have increased globally and cyanotoxins associated with some CyanoHAB species pose serious health risks for animals and humans. CyanoHABs are sensitive to supply rates of both nitrogen and phosphorus, but sensitivity may vary among species (e.g., between diazotrophic and non-diazotrophic species) and a range of physiographic and environmental factors. A sustainable approach to manage CyanoHABs is therefore to limit the supply of nitrogen and phosphorus from catchments to receiving waters. Alternative approaches of within-lake treatment have increased risks and
large capital and operational expenditure. The need to manage catchment nutrient loads will intensify with climate change, due to expected increases in nutrient remineralization rates, alteration in hydrological regimes, and increases in lake water temperature and density stratification. Many CyanoHAB species have physiological features that enable them to benefit from the effects of climate change, including positive buoyancy or buoyancy control, high replication rates at elevated water temperature, and nutrient uptake strategies adapted for the intermittency of nutrient supply with greater hydrological variability expected in the future. Greater attention needs to be focused on nonpoint sources of nutrients, including source control, particularly maintaining nitrogen and phosphorus in agricultural soils at or below agronomic optimum levels, and enhancing natural attenuation processes in water and solute transport pathways. Efforts to achieve effective catchment management and avert the dire ecological, human health and economic consequences of CyanoHABs must be intensified in an era of anthropogenically driven environmental change arising from increasing human population, climate change and agricultural intensification.


Phosphorus (P) applied to croplands in excess of crop requirements has resulted in large-scale accumulation of P in soils worldwide, leading to freshwater eutrophication from river runoff that may extend well into the future. However, several studies have reported declines in surplus P inputs to the land in recent decades. To quantify trends in P loading to Lake Erie (LE) watersheds, we estimated net anthropogenic phosphorus inputs (NAPI) to 18 LE watersheds for agricultural census years from 1935 to 2007. NAPI quantifies anthropogenic inputs of P from fertilizer use, atmospheric deposition and detergents, as well as the net exchange in P related to trade in food and feed. Over this 70-year period, NAPI increased to peak values in the 1970s and subsequently declined in 2007 to a level last experienced in 1935. This rise and fall was the result of two trends: a dramatic increase in fertilizer use, which peaked in the 1970s and then declined to about two-thirds of maximum values; and a steady increase in P exported as crops destined for animal feed and energy production. During 1974–2007, riverine phosphorus loads fluctuated, and were correlated with inter-annual variation in water discharge. However, riverine P export did not show consistent temporal trends, nor correlate with temporal trends in NAPI or fertilizer use. The fraction of P inputs exported by rivers appeared to increase sharply after the 1990s, but the cause is unknown. Thus estimates of phosphorus inputs to watersheds provide insight into changing source quantities but may be weak predictors of riverine export.


The Grand River watershed (GRW) is an important agricultural area in Southern Ontario. Land use has been modified by various human endeavors, altering hydrology and increasing export of sediment and nutrients. The objective of this study was to predict spatial and temporal patterns of hydrology, and export of sediment and nutrients from the GRW to Lake Erie using the Soil and Water Assessment Tool (SWAT) model. The Sequential Uncertainty Fititting (SUFI2) program was used to calibrate and validate stream flow for years 2001-
2010. Calibration and validation of the SWAT model for monthly stream flow at York indicated good model performance ($R^2$, NSE, and PBIAS = 0.64, 0.63 and 7.1 for calibration (2001-2005); = 0.82, 0.74 and 0.2, for validation (2006-2010)). The model was applied to predict sediment and nutrient export from the GRW into Lake Erie. Predicted loading at Dunnville (near the mouth) was $2.3 \times 10^5$ tonnes y$^{-1}$ total suspended sediment, $7.9 \times 10^3$ tonnes y$^{-1}$ TN, and $2.3 \times 10^2$ tonnes y$^{-1}$ TP. This SWAT model can now be used to investigate the relative effects of best management practices, and to forecast effects of climate change, on sustainable water management, hydrology, and sediment and nutrient export to Lake Erie.


Harmful algal blooms in Lake Erie have been increasing in severity over the past two decades, prompting new phosphorus loading target recommendations. We explore long-term drivers of phytoplankton blooms by leveraging new estimates of historical bloom extent from Landsat 5 covering 1984–2001 together with existing data covering 2002–2015. We find that a linear combination of springtime and long-term cumulative dissolved reactive phosphorus (DRP) loading explains a high proportion of interannual variability in maximum summertime bloom extent for 1984–2015 ($R^2 = 0.75$). This finding suggests that the impacts of internal loading are potentially greater than previously understood, and that the hypothesized recent increased susceptibility to blooms may be attributable to high decadal-scale cumulative loading. Based on this combined loading model, achieving mild bloom conditions in Lake Erie (defined in recent studies as bloom areas below 600 km$^2$ nine years out of ten) would require DRP loads to be reduced by 58% relative to the 2001–2015 average (equivalent to annual DRP loading of 240 MT and April to July DRP loading of 78 MT). Reaping the full benefits of load reductions may therefore take up to a decade due to the effects of historical loading.


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.


Widespread adoption of agricultural conservation measures in Lake Erie’s Maumee River watershed may be required to reduce phosphorus loading that drives harmful algal blooms and hypoxia. We engaged agricultural and conservation stakeholders through a survey and workshops to determine which conservation practices to evaluate. We investigated feasible and desirable conservation practices using the Soil and Water Assessment Tool calibrated for streamflow, sediment, and nutrient loading near the Maumee River outlet. We found subsurface placement of phosphorus applications to be the individual practice most influential on March-July dissolved reactive phosphorus (DRP) loading from row croplands. Perennial cover crops and vegetated filter strips were most effective for reducing seasonal total phosphorus (TP) loading. We found that practices effective for reducing TP and DRP load were not always mutually beneficial, culminating in trade-offs among multiple Lake Erie phosphorus management goals. Adoption of practices at levels considered feasible to stakeholders led to nearly reaching TP targets for western Lake Erie on average years; however, adoption of practices at a rate that goes beyond what is currently considered feasible will likely be required to reach the DRP target.


Both abiotic and biotic explanations have been proposed to explain recent recurrent nuisance/harmful algal blooms in the western basin and central basin of Lake Erie. We used two long-term (> 10. years) datasets to test (1) whether Lake Erie total phytoplankton biomass and cyanobacterial biomass changed over time and (2) whether phytoplankton abundance was influenced by soluble reactive phosphorus or nitrate loading from agriculturally-dominated tributaries (Maumee and Sandusky rivers). We found that whereas total phytoplankton biomass decreased in Lake Erie’s western basin from 1970 to 1987, it increased starting in the mid-1990s. Total phytoplankton and cyanobacterial seasonal (May-October) arithmetic mean wet-weight biomasses each significantly increased with increased
water-year total soluble reactive phosphorus load from the Maumee River and the sum of soluble reactive phosphorus load from the Maumee and Sandusky rivers, but not for the Sandusky River alone during 1996-2006. During this same time period, neither total phytoplankton nor cyanobacterial biomass was correlated with nitrate load. Consequently, recently increased tributary soluble reactive phosphorus loads from the Maumee River likely contributed greatly to increased western basin and (central basin) cyanobacterial biomass and more frequent occurrence of harmful algal blooms. Managers thus must incorporate the form of and source location from which nutrients are delivered to lakes into their management plans, rather than solely considering total (both in terms of form and amount) nutrient load to the whole lake. Further, future studies need to address the relative contributions of not only external loads, but also sources of internal loading.


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


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.


Phosphorus (P) transport from agricultural fields continues to be a focal point for addressing harmful algal blooms and nuisance algae in freshwater systems throughout the world. In humid, poorly drained regions, attention has turned to P delivery through subsurface tile drainage. However, research on the contributions of tile drainage to watershed-scale P losses is limited. The objective of this study was to evaluate long-term P movement through tile drainage and its manifestation at the watershed outlet. Discharge data and associated P concentrations were collected for 8 yr (2005–2012) from six tile drains and from the watershed outlet of a headwater watershed within the Upper Big Walnut Creek watershed in central Ohio. Results showed that tile drainage accounted for 47% of the discharge, 48% of the dissolved P, and 40% of the total P exported from the watershed. Average annual total P loss from the watershed was 0.98 kg ha−1, and annual total P loss from the six tile drains was 0.48 kg ha−1. Phosphorus loads in tile and watershed discharge tended to be greater in the winter, spring, and fall, whereas P concentrations were greatest in the summer. Over the 8-yr study, P transported in tile drains represented <2% of typical application rates in this watershed, but >90% of all measured concentrations exceeded recommended levels (0.03 mg L−1) for minimizing harmful algal blooms and nuisance algae. Thus, the results of this study show that in systematically tile-drained headwater watersheds, the amount of P delivered to surface waters via tile drains cannot be dismissed. Given the amount of P loss relative to typical application rates, development and implementation of best management practices (BMPs) must jointly consider economic and environmental benefits. Specifically, implementation of BMPs should focus on late fall, winter, and early spring seasons when most P loading occurs.

The Western Lake Erie Basin (WLEB) was inundated with precipitation during June and July 2015 (two to three times greater than historical averages), which led to significant nutrient loading and the largest in-lake algal bloom on record. Using discharge and concentration data from three spatial scales (0.18-16,000 km²), we contrast the patterns in nitrate (NO₃-N) and dissolved reactive phosphorus (DRP) concentration dynamics and discuss potential management implications. Across all scales, NO₃-N concentration steadily declined with each subsequent rainfall event as it was flushed from the system. In contrast, DRP concentration persisted, even on soils at or below agronomic P levels, suggesting that legacy P significantly contributes to nutrient loads in the WLEB. These findings highlight the need to revisit current P fertility recommendations and soil testing procedures to increase P fertilizer use efficiency and to more holistically account for legacy P.


Agricultural phosphorus (P) loss has been linked to the eutrophication of surface water bodies throughout the world. As a result, minimizing offsite P transport has become a priority in many rural watersheds. In the US Midwest and other subsurface tile-drained regions, there is a critical need to identify nutrient management practices that decrease P loss in both surface and subsurface discharge. An edge-of-field (EOF) network monitoring 38 agricultural fields was established in northwest Ohio, United States, to quantify the impacts of prevailing and novel crop production and conservation management practices on surface and subsurface P concentrations and loads. In this study, we evaluate nutrient management practices across these fields with varying characteristics in order to identify a suite of management practices within the 4R nutrient management framework (right source, right rate, right time, and right place) that reduce agricultural P loss in artificially drained landscapes. EOF monitoring data indicate that applying organic fertilizers at P-based rates, soil testing and following recommended application rates, avoiding fertilizer application during wet periods of the year (e.g., winter and early spring) and prior to large precipitation events, and placing fertilizer below the surface are all practices that result in decreased P loss. Findings also highlight the importance of field hydrology on surface and subsurface P transport and suggest that water management practices may also be effective at decreasing P loss. While the effectiveness of the nutrient management practices evaluated in this study will likely vary across fields with different characteristics, implementation of these practices should be considered a directionally correct (i.e., will reduce nutrient loss) approach for addressing excess P loss from artificially drained landscapes.


Phosphorus (P) loss from agricultural fields and watersheds has been an important water quality issue for decades because of the critical role P plays in eutrophication. Historically, most research has focused on P losses by surface runoff and erosion because subsurface P losses were often deemed to be negligible. Perceptions of subsurface P transport, however,
have evolved, and considerable work has been conducted to better understand the magnitude and importance of subsurface P transport and to identify practices and treatments that decrease subsurface P loads to surface waters. The objectives of this paper were (i) to critically review research on P transport in subsurface drainage, (ii) to determine factors that control P losses, and (iii) to identify gaps in the current scientific understanding of the role of subsurface drainage in P transport. Factors that affect subsurface P transport are discussed within the framework of intensively drained agricultural settings. These factors include soil characteristics (e.g., preferential flow, P sorption capacity, and redox conditions), drainage design (e.g., tile spacing, tile depth, and the installation of surface inlets), prevailing conditions and management (e.g., soil-test P levels, tillage, cropping system, and the source, rate, placement, and timing of P application), and hydrologic and climatic variables (e.g., baseflow, event flow, and seasonal differences). Structural, treatment, and management approaches to mitigate subsurface P transport—such as practices that disconnect flow pathways between surface soils and tile drains, drainage water management, in-stream or end-of-tile treatments, and ditch design and management—are also discussed. The review concludes by identifying gaps in the current understanding of P transport in subsurface drains and suggesting areas where future research is needed.


Phosphorus (P) losses in agricultural drainage waters, both surface and subsurface, are among the most difficult form of nonpoint source pollution to mitigate. This special collection of papers on P in drainage waters documents the range of field conditions leading to P loss in drainage water, the potential for drainage and nutrient management practices to control drainage losses of P, and the ability of models to represent P loss to drainage systems. A review of P in tile drainage and case studies from North America, Europe, and New Zealand highlight the potential for artificial drainage to exacerbate watershed loads of dissolved and particulate P via rapid, bypass flow and shorter flow path distances. Trade-offs are identified in association with drainage intensification, tillage, cover crops, and manure management. While P in drainage waters tends to be tied to surface sources of P (soil, amendments or vegetation) that are in highest concentration, legacy sources of P may occur at deeper depths or other points along drainage flow paths. Most startling, none of the major fate-and-transport models used to predict management impacts on watershed P losses simulate the dominant processes of P loss to drainage waters. Because P losses to drainage waters can be so difficult to manage and to model, major investment are needed (i) in systems that can provide necessary drainage for agronomic production while detaining peak flows and promoting P retention and (ii) in models that can adequately describe P loss to drainage waters.


The persistent problem of eutrophication, the biological enrichment of surface waters, has produced a vast literature on soil phosphorus (P) effects on runoff water quality. This paper considers the mechanisms controlling soil P transfers from agricultural soils to runoff
waters, and the management of these transfers. Historical emphases on soil conservation and control of sediment delivery to surface waters have demonstrated that comprehensive strategies to mitigate sediment-bound P transfer can produce long-term water quality improvements at a watershed scale. Less responsive are dissolved P releases from soils that have historically received P applications in excess of crop requirements. While halting further P applications to such soils may prevent dissolved P losses from growing, the desorption of P from soils that is derived from historical inputs, termed here as “legacy P”, can persist for long periods of time. Articulating the role of legacy P in delaying the response of watersheds to remedial programs requires more work, delivering the difficult message that yesterday’s sinks of P may be today’s sources. Even legacy sources of P that occur in low concentration relative to agronomic requirement can support significant loads of P in runoff under the right hydrologic conditions. Strategies that take advantage of the capacity of soils to buffer dissolved P losses, such as periodic tillage to diminish severe vertical stratification of P in no-till soils, offer short-term solutions to mitigating P losses. In some cases, more aggressive strategies are required to mitigate both short-term and legacy P losses.

This review provides a critical overview of conservation practices that are aimed at improving water quality by retaining phosphorus (P) downstream of runoff genesis. The review is structured around specific downstream practices that are prevalent in various parts of the United States. Specific practices that we discuss include the use of controlled drainage, chemical treatment of waters and soils, receiving ditch management, and wetlands. The review also focuses on the specific hydrology and biogeochemistry associated with each of those practices. The practices are structured sequentially along flowpaths as you move through the landscape, from the edge-of-field, to adjacent aquatic systems, and ultimately to downstream P retention. Often practices are region specific based on geology, cropping practices, and specific P related problems and thus require a right practice, and right place mentality to management. Each practice has fundamental P transport and retention processes by systems that can be optimized by management with the goal of reducing downstream P loading after P has left agricultural fields. The management of P requires a system-wide assessment of the stability of P in different biogeochemical forms (particulate vs. dissolved, organic vs. inorganic), in different storage pools (soil, sediment, streams etc.), and under varying biogeochemical and hydrological conditions that act to convert P from one form to another and promote its retention in or transport out of different landscape components. There is significant potential of hierarchically placing practices in the agricultural landscape and enhancing the associated P mitigation. But an understanding is needed of short- and long-term P retention mechanisms within a certain practice and incorporating maintenance schedules if necessary to improve P retention times and minimize exceeding retention capacity.

Crop residue left after harvest plays an important role in controlling against soil erosion and in increasing soil organic matter content of agricultural soils. Crop residue management is a practice of great importance in southwestern Ontario, where soil management practices have an effect on Great Lakes water quality. The use of remote sensing data to measure and monitor crop residue can be fast and efficient. However, remote sensing–based studies need calibration and validation using field observations. The objective of this study was to determine the optimal number of ground-truthing field measurements (i.e., digital photographs) required to estimate residue levels. To do so, we compared the residue estimates derived from digital photographs with those derived from the standard line-transect method. Residue was measured from 18 fields located in southern Ontario, and data collected included percentage of crop residue using line-transect and photographic grid methods. Results were analyzed using linear regression, correlation tests, ANOVA, and means tests. Analyses were also conducted to retrospectively determine the minimum number of line transects or digital photos required to estimate crop residue cover at specified levels of power. Results showed that (1) percentage of crop residue estimates derived from using digital photographs were strongly correlated ($r = 0.91$, $p < 0.001$, $R^2 = 0.83$, and $n = 90$) to those derived from using line transects; (2) counting 50 to 100 points per digital photograph was sufficient to accurately estimate the percentage of residue cover; and (3) there was greater variability in the results for soybean (Glycine max [L.] Merr.) than for corn (Zea mays L.), with the highest variability for medium-level soybean residue. Overall, the digital photograph method to estimate percentage of residue was found to be a suitable alternative to the line-transect method, which is more time consuming and labor intensive. Determining the optimal numbers of measurements to estimate crop residue cover is important to those wishing to use digital photo capture methods to record, archive, and measure residue for remote sensing calibration and validation or for handheld mobile device applications.


Agricultural watersheds have been identified as a source of nutrients to surface water bodies, contributing to the degradation of water quality. Reduced till (RT) management practices have been employed to reduce the potential for particulate P loss in surface runoff, but may increase the transfer of dissolved reactive phosphorus (DRP) into tile drains. It is unclear if RT increases P losses in tile drainage when nutrient management strategies are used and fertilizers are applied in the subsurface. It is also unclear how these management strategies perform year round, including during the snowmelt period. The objectives of this study are to quantify year round losses of runoff, DRP and total phosphorus (TP) losses from drainage tiles beneath annual disk till (AT) and reduced till (RT) plots, and, to investigate the role of seasonality (particularly winter snowmelt) on runoff and P losses. Results indicate that both runoff and P-export were episodic across all plots and most annual losses occurred during a few key events under heavy precipitation or snowmelt events. Runoff and P losses through drainage tiles were primarily observed between October and May, with most losses occurring in March during snowmelt. Tillage practices did not affect
DRP or TP concentrations or loads in tile drainage. This study has highlighted the importance of the non-growing season (particularly winter) in annual P loss, and has demonstrated that the cumulative Best Management Practices (BMPs) used at the study sites may be an effective way to reduce P losses in tile drain effluent.


Excessive application of crop nutrients has been identified as a threat to surface water quality in many jurisdictions. The Western Basin of Lake Erie Collaborative Agreement commits the governments of Michigan, Ohio and Ontario to reduce phosphorus entering the Lake Erie’s western basin by 40% by 2025/2026 from 2008 levels by, among other things, reducing fertilizer use in agriculture. The International Joint Commission (2014) estimates that agriculture accounts for 44% of total phosphorus loadings to Lake Erie. Our study uses a unique micro level data set of 16 farms over 6 years that allows us to examine 397 individual nutrient application choices at the field and farm level. If efforts to reduce excessive application of nutrients are to be successful at aggregate level, they need to be informed by an understanding of how farmers make nutrient application decisions within existing production systems. The study aims to enhance our understanding by determining whether farmers applying nutrients to maximize yields, to maximize net returns or to meet environmental targets, and whether over-application depends on factors such as farm size, crop type, manure use, and type of nutrient. We compare actual nutrient application rates with site specific rates intended to minimize excess nutrient application and we regress nutrient application levels against potential explanatory variables including farm size, crop rotation practices, and application of livestock. The data were collected from farmers in the Gully Creek watershed in Ontario. We found that excess nutrient applications, as a percentage of the total nutrient applications, are much higher for phosphorus than for nitrogen and higher for wheat than for corn. While most of the farmers in the study are not required to comply with provincial nutrient management regulations, many of them apply fertilizer at rates close to that recommended by those regulations and some at rates significantly less. While most farms are applying fertilizer, particularly nitrogen, at rates close to the minimum crop requirements, nevertheless, a few farms apply much more phosphorous than recommended. Policy and research efforts should be directed toward targeting these individuals that appear to be the primary contributor to the nutrient loading issue.


Nutrient loading from the Maumee River watershed is a significant reason for the harmful algal blooms (HABs) problem in Lake Erie. The nutrient loading from urban areas needs to be reduced with the installation of green infrastructure (GI) practices. The Long-Term Hydrologic Impact Assessment-Low Impact Development 2.1 (L-THIA-LID 2.1) model was used to explore the influences of land use (LU) and climate change on water quantity and quality in Spy Run Creek watershed (SRCW) (part of Maumee River watershed), decide whether and where excess phosphorus loading existed, identify critical areas to understand where the greatest amount of runoff/pollutants originated, and optimally implement GI practices to obtain maximum environmental benefits with the lowest costs. Both LU/climate changes increased runoff/pollutants generated from the watershed. Areas with the highest runoff/pollutant amount per area, or critical areas, differed for various environmental concerns, land uses (LUs), and climates. Compared to optimization considering all areas, optimization conducted only in critical areas can provide similar cost-effective results with decreased computational time for low levels of runoff/pollutant reductions, but critical area optimization results were not as cost-effective for higher levels of runoff/pollutant reductions. Runoff/pollutants for 2011/2050 LUs/climates could be reduced to amounts of 2001 LU/climate by installation of GI practices with annual expenditures of $0.34 to $2.05 million. The optimization scenarios that were able to obtain the 2001 runoff level in 2011/2050, can also reduce all pollutants to 2001 levels in this watershed.

The Grand River is the largest river in Southern Ontario feeding Lake Erie with water, sediment, and nutrients. Understanding the watershed hydrological processes is crucial to support decision making on reducing non-point source pollution from the watershed into Lake Erie. In this study, the Soil and Water Assessment Tool (SWAT) was adapted to Canadian conditions and applied to the Grand River watershed in Southern Ontario to simulate hydrologic processes based on available geospatial, climate, management, flow, and water quality data. The SWAT was calibrated based on flow, sediment, and nutrient concentrations at eight flow gauging stations and seven water quality stations. The calibrated model was then applied to evaluate the potential effects of Best Management Practices (BMPs) including nutrient management, buffer strip, cover crop, and wetland restoration on water quantity and water quality in the watershed. The evaluated results showed that the BMPs of nutrient management and wetland restoration have more significant impacts on nutrient reduction at the watershed outlet to Lake Erie based on the BMP implementation and extent that were applied in this study. The SWAT modeling, findings, challenges, and recommendations for future research in the Grand River watershed are also discussed in this paper.

Extension has a long history of conducting educational programs for agricultural producers on a wide array of issues, including water quality. In Ohio, the focus of these educational efforts has grown to include best management practices for nutrient management. The need for education in nutrient management began in earnest in the 1970s due to the presence of harmful algal blooms (HAB) in the Western Lake Erie Basin. International actions taken during that time all but eliminated the HABs from the lake until they made a resurgence in the 1990s. Twenty years later, the HAB threat in Lake Erie is still present and has major implications for commerce, tourism, and human and environmental health. The HAB threat has spurred outcries from the general public, resulting in the creation of new laws by the Ohio Legislature, and an expanded and enhanced focus area for Ohio State University Extension (OSUE) programming. In this paper, we describe the conditions that have led to the development of the HAB in Lake Erie, the legislative action that has been taken in attempts to curb the problem, and the educational programs developed by OSUE in partnership with state agencies, non-government organizations, and other interested parties to address these water quality issues with Ohio agricultural producers and the general public. [ABSTRACT FROM AUTHOR]


Over the past few decades, there has been a nationwide trend away from small livestock farms and toward large Concentrated Animal Feeding Operations (CAFOs). This shift results in concentrated manure production and introduces potential problems associated with its disposal. We analyzed data from 13 permitted CAFOs in southeastern Michigan, including 1187 occurrences of manure application from 12 of the CAFOs with available field-level data. CAFOs applied excess manure nutrients to cropland by applying to fields with soil phosphorus test levels >50 ppm (42% of all cases), applying to soybeans (7% of all cases), over-estimating crop yields in calculating plant nutrient requirements (67% of all cases), and applying beyond what is allowed by state permits (26% of all cases). This represents significant potential for redistribution of manure nutrients. The total amount of manure from all instances of over-application could be redistributed to fertilize over 4775 ha (11,800 acres) per year. Significant barriers to redistribution of manure exist, however, including cost, land availability, crop and soil need, transport logistics, and farmers’ reluctance to use manure instead of inorganic fertilizer due to its variable composition. These findings are relevant to the harmful algal bloom and hypoxia issues in Lake Erie, which are driven by excess nutrients, and can be used to better inform science, modeling, and policy in the region.


Information about the loads of total and soluble reactive phosphorus entering Lake Erie is required in order to support commitments made under Annex 4 of the Great Lakes Water Quality Agreement. For these purposes, annual (water year) total phosphorus loads to Lake Erie are updated (2003–2013) and soluble reactive loads are reported on a lakewide basis for the first time (2009–2013). Complete documentation including input data and error estimates are provided. The results confirm previously documented long-term declining TP loads and show how these are driven by early and recent improvements in point source discharges, but are confounded by recent increases in nonpoint source loads that may in turn be due to increasing trends in precipitation and river discharge. The record since 2009 for SRP indicates high interannual variability and no discernible change in loadings over time. Recent TP loads are dominated by nonpoint sources (71%), with lower contributions from point sources (19%) and the balance comprising atmospheric deposition and loads from the upstream Great Lakes. Approximately one-half (49%) of the load of SRP is contributed from nonpoint sources, approximately 39% comprises point sources, and atmospheric deposition and upstream loads comprise 6% each. Loads are highest to the western basin for TP and highest to the Huron–Erie corridor for SRP. U.S. sources account for a majority (>80%) of the phosphorus loads entering the lake. Recommendations for improvements to the study approach are made including the identification of monitoring gaps and the testing of assumptions that require independent verification.


Artificial subsurface drainage provides an avenue for the rapid transfer of phosphorus (P) from agricultural fields to surface waters. This is of particular interest in eastern Wisconsin, where there is a concentrated population of dairy farms and high clay content soils prone to macropore development. Through collaboration with private landowners, surface and tile drainage was measured and analyzed for dissolved reactive P (DRP) and total P (TP) losses at four field sites in eastern Wisconsin between 2005 and 2009. These sites, which received frequent manure applications, represent a range of crop management practices which include: two chisel plowed corn fields (CP1, CP2), a no-till corn–soybean field (NT), and a grazed pasture (GP). Subsurface drainage was the dominant pathway of water loss at each site accounting for 66–96% of total water discharge. Average annual flow-weighted (FW) TP concentrations were 0.88, 0.57, 0.21, and 1.32mgL−1 for sites CP1, CP2, NT, and GP, respectively. Low TP concentrations at the NT site were due to tile drain interception of groundwater flow where large volumes of tile drainage water diluted the FW-TP concentrations. Subsurface pathways contributed between 17% and 41% of the TP loss across sites. On a drainage event basis, total drainage explained between 36% and 72% of the event DRP loads across CP1, CP2, and GP; there was no relationship between event drainflow and event DRP load at the NT site. Manure applications did not consistently increase P concentrations in drainflow, but annual FW-P concentrations were greater in years receiving manure applications compared to years without manure application. Based on these field measures, P losses from tile drainage must be integrated into field level P budgets and P loss calculations on heavily manured soils, while also acknowledging the
unique drainage patterns observed in eastern Wisconsin.


Six small, predominantly agricultural (> 70%) watersheds in the Conesus Lake catchment of New York State, USA, were selected to test the impact of Best Management Practices (BMPs) on mitigation of nonpoint nutrient sources and soil loss from farms to downstream aquatic systems. Over a 5-year period, intensive stream water monitoring and analysis of covariance provided estimates of marginal means of concentration and loading for each year weighted by covariate discharge. Significant reductions in total phosphorus, soluble reactive phosphorus, nitrate, total Kjeldahl nitrogen, and total suspended solids concentration and flux occurred by the second year and third year of implementation. At Graywood Gully, where Whole Farm Planning was practiced and a myriad of structural and cultural BMPs were introduced, we observed the greatest percent reduction (average = 55.8%) and the largest number of significant reductions in analytes (4 out of 5). Both structural and cultural BMPs were observed to have profound effects on nutrient and soil losses. Where fields were left fallow or planted in a vegetative type crop, reductions, especially in nitrate, were observed. Where structural implementation occurred, reductions in total fractions were particularly evident. Where both were applied, major reductions in nutrients and soil occurred. After 5 years of management, nonevent and event concentrations of total suspended solids in streams draining agricultural watersheds were not significantly different from those in a relatively “pristine/reference” watershed. This was not the case for nutrients. © 2009 Elsevier Inc. All rights reserved.


Developing reference criteria for nutrient conditions on streams can be difficult especially in heavily farmed or urbanized regions where most of the landscape has been impacted by human development. SWAT (soil water assessment tool) simulations permit the removal of the anthropogenic impacted land use, allowing the simulation of natural conditions and a prediction of reference conditions. A Genesee River watershed simulation was developed to determine the nutrient and sediment contributions of subbasins of the Genesee River under the current human-impacted conditions and contrasted against natural conditions. Nutrient boundary values estimated for Genesee basin small wadeable streams (34.3μgP/L) were nearly identical to those calculated by others for small, wadeable streams (30.7μgP/L). For large streams, the simulation-based boundary total phosphorus (TP) value (75.8μgP/L) of the Genesee River was high compared to other observations in New York State (30μgP/L). Causes in the variability in large stream reference values include inappropriate use of regional reference conditions, stream bank erosion, basin geology, soil type, and catchment area. When river bank stabilization was added to the simulation, a 34.3% reduction in phosphorus loading was observed, resulting in a boundary value of ~54μgP/L. This reduction in the simulated sediment load suggested that the Genesee River has a higher
natural sediment and TP load than most streams in NYS. SWAT is an effective tool for simulations of small streams and may be an effective method in determining reference conditions for large rivers.


An assessment of sediment and phosphorus concentrations and load, identification of phosphorus allocation and sources, and the effectiveness of management practices on the main stem (Upper Genesee River, Lower Genesee River) and on the four major Genesee tributaries (Canaseraga, Honeoye, Black, and Oatka Creeks) were conducted. The P load allocation analysis indicated that 60% of the total phosphorus load to Lake Ontario was due to anthropogenic sources and that only 40% was due to natural sources. With a P load of 412,505 kg P/yr, the Genesee River carries the second highest load, after the Niagara River, to Lake Ontario. Such a large P load of anthropogenic origin suggested that a managed reduction in P loss from the Genesee watershed is possible. SWAT was employed to test the effectiveness of best management practices (BMPs) on land use and to determine the minimum potential phosphorus concentration expected in the subcatchments. Simulations of BMPs on both point and nonpoint sources indicated that phosphorus could effectively be maintained within the watershed and out of Lake Ontario, where elevated phosphorus stimulates algae production and is implicated in beach closings in the Rochester Embayment AOC. Using our most effective simulated scenario of grassed waterways and upgrading of wastewater treatment plants to tertiary treatment, a 32.9% (135,714 kg P/yr) reduction in P loading to the nearshore of Lake Ontario was predicted. With this reduction in P, concentrations of 65 μg P/L, which is within the debated target goal of 65 μg TP/L in NYS, were also predicted.


Soil cores and suspended sediments were collected within the Old Woman Creek, Ohio (OWC) watershed following a thunderstorm and analyzed for 7Be, 137Cs, and 210Pb activities to compare the effects of till vs. no-till management on soil erosion and sediment yield. The upper reaches of the watershed draining tilled agricultural fields were disproportionately responsible for the majority of the suspended sediment load compared with lower in the watershed (2.0-7.0 metric tons/km² [Mg/km²] vs. 1.2-2.6 Mg/km²). About 6 to 10 times more sediment was derived from the subbasins that are predominantly tilled (6.8-12.4 Mg/km²) compared with the subbasins undergoing no-till practices (0.5-1.1 Mg/km²). In undisturbed soils the 210Pb activities decreased with movement toward the bottom of the cores to the constant supported 210Pb value at a depth of about 10 cm. There was a subsurface maximum in 137Cs activity within the top 10 cm. In contrast, the 210Pb and 137Cs distributions in soils that are currently or were previously tilled were nearly homogeneous with depth, reflecting continuing or previous mixing by plowing. The
activities of 210Pb and 7Be were linearly correlated and were higher in suspended sediments derived from no-till subbasins than those derived from tilled subbasins, indicating that the soil surface is the source of suspended sediment. This study demonstrates that no-till farming results in decreases in soil erosion and decreases in suspended sediment discharges and that those eroded sediments have a radionuclide signature corresponding to the tillage practice and the depth of erosion.


In 2011, Lake Erie experienced the largest harmful algal bloom in its recorded history, with a peak intensity over three times greater than any previously observed bloom. Here we show that long-term trends in agricultural practices are consistent with increasing phosphorus loading to the western basin of the lake, and that these trends, coupled with meteorological conditions in spring 2011, produced record-breaking nutrient loads. An extended period of weak lake circulation then led to abnormally long residence times that incubated the bloom, and warm and quiescent conditions after bloom onset allowed algae to remain near the top of the water column and prevented flushing of nutrients from the system. We further find that all of these factors are consistent with expected future conditions. If a scientifically guided management plan to mitigate these impacts is not implemented, we can therefore expect this bloom to be a harbinger of future blooms in Lake Erie.

Sediment and nutrient exports were evaluated in a small agriculture-dominated watershed that drains into Rondeau Bay, on the northern shore of Lake Erie in Southwestern Ontario, Canada. The following hypothesis was tested: the quantity and quality of suspended sediment yields in agricultural settings controls nutrient transfer from surface runoff. Stream discharge and water quality were monitored at three locations along a tributary reach within the Rondeau Bay basin during the 2013 growing-harvest season (May-October). Water samples were analyzed in the laboratory for suspended sediment concentration, particle size, and sediment-assisted nitrogen and phosphorus content. Estimated total sediment yield over the 6-month monitoring period was ~50t (0.13tha⁻¹). A mid-season change in contributing sediment sources was inferred based on the observations of suspended sediment transfer and particle size following a ~92mm rainfall event. This extreme runoff event marked a change in the discharge-suspended sediment response seen in the catchment, which included a July-September abrupt decrease in suspended sediment concentration and a coincident increase in fine-grained particle abundance. Clockwise event hysteresis suggested adjacent and/or likely channel derived sediment sources. Finally, there was a positive relationship between suspended sediment concentration and phosphorus (R²=0.86, n=63) and orthophosphate (R²=0.75, n=63). Estimated nutrient concentrations exceeded provincial load guidelines, which suggests that present land management efforts to minimize nutrient loading via surface runoff require further evaluation. This research concludes that agricultural-based nutrient loading into Lake Erie is sediment-assisted and that this sediment potentially derives from in-channel and tile drain sources. The findings have important implications for future soil loss and thus nutrient loading from agricultural settings, especially during extreme events.

90. Monteith, T. J., Baise, M. P., & Sullivan, R. A. (1981). Environmental and economic implications of conservation tillage practices in the Great Lakes Basin. Great Lakes Environmental Planning Study (Gelps) Contribution. Conservation tillage requires less fuel, labour and equipment than conventional tillage. However, these savings are offset by increased usage of herbicides and pesticides and increased training. With adequate technical assistance many farms in the Great Lakes basin will support some form of conservation tillage. Yields with reduced tillage depend on the soil type and the climate. In general, no-till farming will be most successful on well-drained soils in the southern regions of the basin while till-plant and chisel-plow can be applied over much of the cropland in the basin. Soil loss occurring with present agricultural practices in the Great Lakes drainage basin was compared with the expected loss associated with the adoption of various levels of conservation tillage. The analysis indicates that cropland erosion can be reduced by between 8% (with till-plant implemented over 20% of the cropland area) and 65% (with chisel-plow and no-till implemented on appropriate soils over the total cropland area). This represents a 6 to 50 million mt/yr reduction in erosion. The maximum reduction in total phosphorus loading to Great Lakes tributaries from cropland runoff was estimated to be about 55%. A 40% reduction could be achieved in biologically available phosphorus, if no-till farming was implemented on all soils that would support it and chisel-plow was adopted on all remaining cropland. Problems due to reduced soil temperature, reduced efficiency of nitrogen fertilization, increased soil density and groundwater pollution by pesticides may occur. Source: CAB
Trends in climatic variables, streamflow, agricultural practices, and loads of nutrients and suspended solids were estimated for 1976-1995 in the Maumee and Sandusky watersheds, two large agricultural basins draining to Lake Erie. To understand the contributions that various factors may have made to the trends in loads, earlier results of models linking loads to explanatory variables were combined with estimated trends in those variables. The study period was characterized by increases in temperature, wintertime precipitation and streamflow, conservation farming, and loads of nitrate and total suspended solids; decreases in snowfall and snow cover, fertilizer, manure from livestock, and loads of soluble reactive phosphorus; and relatively steady exports of total phosphorus. After removing the effects of trends in streamflow, nitrate loads increased much less while total suspended solids and total phosphorus loads declined. The analysis suggests that the nitrate increases were due largely to climatic factors, particularly increases in winter streamflow, decreases in snowfall and snow cover, and declining annual precipitation. Decreases in soluble reactive phosphorus were associated with changes in agricultural practices, particularly declines in fertilizer deliveries and head of livestock.

Export of agricultural nutrients and sediment to lakes and oceans is of great environmental concern in many agricultural watersheds. Recent years have seen efforts to reduce loads through agricultural practices such as conservation tillage, efficient fertilizer application, and reservation of erodible areas. Monitoring the efficacy of such efforts is complicated by the fact they take place against a varying climatic and hydrologic background. In this study, statistical analysis was used to identify those climatic, hydrologic, and agricultural variables that best explained variations in nitrate, phosphorus, and total suspended solids over the period 1976-95 in two large agricultural watersheds that feed Lake Erie, those of the Maumee and Sandusky Rivers (Ohio, USA). The dominant variable was stream discharge; after curvefits to remove its influence, the residual loads were tested via stepwise linear regression to reveal the most significant explanatory variables. Loads of nitrate, total suspended solids, and total phosphorus tended to decrease when previous months were wet, except in the summer, and to decrease when snow cover was extensive. It is speculated that stores of nitrate in the soil were lost during wet periods through increased crop uptake and/or leaching. Nitrogen fertilizer application in the Maumee watershed decreased following dry periods, but not enough to decrease stream loads. Soluble reactive phosphorus loads were negatively correlated to conservation tillage and reserves, and positively correlated to fertilizer and manure sources. Results for total phosphorus were similar to those for total suspended solids, on which most transported phosphorus is adsorbed. Source: CAB

Pay-for-performance (PFP) is a relatively new approach to agricultural conservation that attaches an incentive payment to quantified reductions in nutrient runoff from a participating farm. Similar to a payment for ecosystem services approach, PFP lends itself to providing incentives for the most beneficial practices at the field level. To date, PFP conservation in the U.S. has only been applied in small pilot programs. Because monitoring conservation performance for each field enrolled in a program would be cost-prohibitive, field-level modeling can provide cost-effective estimates of anticipated improvements in nutrient runoff. We developed a PFP system that uses a unique application of one of the leading agricultural models, the USDA’s Soil and Water Assessment Tool, to evaluate the nutrient load reductions of potential farm practice changes based on field-level agronomic and management data. The initial phase of the project focused on simulating individual fields in the River Raisin watershed in southeastern Michigan. Here we present development of the modeling approach and results from the pilot year, 2015-2016. These results stress that (1) there is variability in practice effectiveness both within and between farms, and thus there is not one “best practice” for all farms, (2) conservation decisions are made most effectively at the scale of the farm field rather than the sub-watershed or watershed level, and (3) detailed, field-level management information is needed to accurately model and manage on-farm nutrient loadings.


The recent resurgence of hypoxia and harmful algal blooms in Lake Erie, driven substantially by phosphorus loads from agriculture, have led the United States and Canada to begin developing plans to meet new phosphorus load targets. To provide insight into which agricultural management options could help reach these targets, we tested alternative agricultural-land-use and land-management scenarios on phosphorus loads to Lake Erie. These scenarios highlight certain constraints on phosphorus load reductions from changes in the Maumee River Watershed (MRW), which contributes roughly half of the phosphorus load to the lake’s western basin. We evaluate the effects on phosphorus loads under nutrient management strategies, reduction of fertilizer applications, employing vegetative buffers, and implementing widespread cover crops and alternative cropping changes. Results indicate that even if fertilizer application ceased, it may take years to see desired decreases in phosphorus loads, especially if we experience greater spring precipitation or snowmelt. Scenarios also indicate that widespread conversions to perennial crops that may be used for biofuel production are capable of substantially reducing phosphorus loads. This work demonstrates that a combination of legacy phosphorus, land management, land use, and climate should all be considered when seeking phosphorus-loading solutions.

cost of a ton of soil erosion reduction varies across site characteristics in a watershed, including field shape and size, tillage method, and soil type. Data from the Maumee River Basin in NW Ohio, USA were used in the study. The methods are used to show how watershed managers may target funds to high and low cost sites and regions within a watershed. The results suggest that the costs of reducing soil erosion with riparian buffers are lower when buffers are applied to conventionally tilled fields, and that the costs of buffers are comparable to the costs of no-till. The relationship between buffer size, drainage area size, and effectiveness is explored. The paper shows how riparian buffers with low effectiveness can be cheaper to install than riparian buffers with high effectiveness.


In this first worldwide synthesis of in situ and satellite-derived lake data, we find that lake summer surface water temperatures rose rapidly (global mean = 0.34°C decade−1) between 1985 and 2009. Our analyses show that surface water warming rates are dependent on combinations of climate and local characteristics, rather than just lake location, leading to the counterintuitive result that regional consistency in lake warming is the exception, rather than the rule. The most rapidly warming lakes are widely geographically distributed, and their warming is associated with interactions among different climatic factors—from seasonally ice-covered lakes in areas where temperature and solar radiation are increasing while cloud cover is diminishing (0.72°C decade−1) to ice-free lakes experiencing increases in air temperature and solar radiation (0.53°C decade−1). The pervasive and rapid warming observed here signals the urgent need to incorporate climate impacts into vulnerability assessments and adaptation efforts for lakes.


Bloom-forming harmful cyanobacteria (CyanoHABs) are harmful from environmental, ecological and human health perspectives by outcompeting beneficial phytoplankton, creating low oxygen conditions (hypoxia, anoxia), and by producing cyanotoxins. Cyanobacterial genera exhibit optimal growth rates and bloom potentials at relatively high water temperatures; hence, global warming plays a key role in their expansion and persistence. CyanoHABs are regulated by synergistic effects of nutrient (nitrogen:N and phosphorus:P) supplies, light, temperature, vertical stratification, water residence times, and biotic interactions. In most instances, nutrient control strategies should focus on reducing
both N and P inputs. Strategies based on physical, chemical (nutrient) and biological manipulations can be effective in reducing CyanoHABs; however, these strategies are largely confined to relatively small systems, and some are prone to ecological and environmental drawbacks, including enhancing release of cyanotoxins, disruption of planktonic and benthic communities and fisheries habitat. All strategies should consider and be adaptive to climatic variability and change in order to be effective for long-term control of CyanoHABs. Rising temperatures and greater hydrologic variability will increase growth rates and alter critical nutrient thresholds for CyanoHAB development; thus, nutrient reductions for bloom control may need to be more aggressively pursued in response to climatic changes globally.

Cyanobacteria are the Earth’s oldest oxygenic photoautotrophs and have had major impacts on shaping its biosphere. Their long evolutionary history (≈ 3.5 by) has enabled them to adapt to geochemical and climatic changes, and more recently anthropogenic modifications of aquatic environments, including nutrient over-enrichment (eutrophication), water diversions, withdrawals, and salinization. Many cyanobacterial genera exhibit optimal growth rates and bloom potentials at relatively high water temperatures; hence global warming plays a key role in their expansion and persistence. Bloom-forming cyanobacterial taxa can be harmful from environmental, organismal, and human health perspectives by outcompeting beneficial phytoplankton, depleting oxygen upon bloom senescence, and producing a variety of toxic secondary metabolites (e.g., cyanotoxins). How environmental factors impact cyanotoxin production is the subject of ongoing research, but nutrient (N, P and trace metals) supply rates, light, temperature, oxidative stressors, interactions with other biota (bacteria, viruses and animal grazers), and most likely, the combined effects of these factors are all involved. Accordingly, strategies aimed at controlling and mitigating harmful blooms have focused on manipulating these dynamic factors. The applicability and feasibility of various controls and management approaches is discussed for natural waters and drinking water supplies. Strategies based on physical, chemical, and biological manipulations of specific factors show promise; however, a key underlying approach that should be considered in almost all instances is nutrient (both N and P) input reductions; which have been shown to effectively reduce cyanobacterial biomass, and therefore limit health risks and frequencies of hypoxic events.

Cost-effectively mitigating agricultural nutrient export requires an understanding of the biophysical characteristics of cropland as well as the behavioral and economic factors that drive land management decisions. Conservation auctions informed by models that simulate environmental outcomes have the potential to allocate conservation payments cost-effectively by funding practices that provide high predicted environmental benefits per dollar spent. This research tested two forms of conservation auctions. First, experimental
auctions were used to analyze farmer preferences for different types of financial incentives for voluntary conservation, including direct payments, insurance, tax credits, and stewardship certification benefits. Second, conservation auctions were conducted in two Ohio counties to evaluate performance under real-world conditions. Supporting both types of auctions, the Soil and Water Assessment Tool (SWAT) predicted reductions in phosphorus exported as a function of the type of conservation practice and farm location. Results of the experimental auctions showed direct payments and tax credits to be the most cost-effective incentives to mitigate phosphorus export. The real auctions yielded two important lessons: 1) participation was very low, due to perceived transaction costs of participation—especially on rented fields and for group bids, and 2) the cost-effectiveness ranking of bids was highly sensitive to the parameters for soluble reactive phosphorus concentrations in the SWAT model. Future socio-economic research into payment for environmental services programs should seek cost-effective mechanisms with lower transaction costs for participants. Future biophysical research should strengthen our understanding of the factors governing soluble reactive phosphorus movement, so that models like SWAT can be more reliably parameterized.


Financial incentives are commonly used to promote voluntary adoption of agricultural best management practices (BMPs), but little is known about farmer preferences among alternative incentives. Using experimental procurement auctions, we evaluate how different conservation incentives affect farmer willingness to adopt BMPs that reduce phosphorus (P) runoff, a major driver of harmful algal blooms in Lake Erie. We rank incentives (e.g., payment, BMP insurance, tax credit, and certification price premium) by the cost per pound of P runoff reduction. Payments and tax credits that target high impact areas of the watershed are more cost-effective than untargeted price premiums for product certification. Farmers demand higher payments for contracts offering BMP insurance (i.e., protection against yield loss from BMP use) due to uncertainty about how the program will be implemented and the reliability of indemnities, as well as anticipated transaction costs associated with the program. Understanding farmer preferences for different types of conservation incentives is critical to design agri-environmental programs that engage more farmers and cost-effectively enhance ecosystem services.


The US Midwest is expected to experience higher intensity rainfall events along with an increased chance of drought during the mid- and late 21st century under projected future climate scenarios. Development of strategies to mitigate the impact of these projected changes on agricultural production and environmental quality is important for ensuring agricultural resiliency to future climate. This study used the DRAINMOD hydrologic model to simulate subsurface drainage discharge at a field site in the headwaters of the Western
Lake Erie Basin using future climate patterns projected by 20 general circulation models. Despite projected increases in rainfall, by the late twenty-first century, subsurface discharge was projected to decrease 7% and 11% under representative concentration pathway (RCP) 4.5 and RCP 8.5, respectively. Reductions in subsurface discharge were attributed to increased temperature and evapotranspiration. The performance of controlled drainage was not projected to change on an annual basis throughout the next century. The benefits of controlled drainage systems as an agricultural best management practice were still evident under the projected climate change of the next century. The role of controlled drainage as a means to potentially retain more crop available water in the soil profile could become critically important under future climate conditions.


Field observations that quantify agricultural phosphorus (P) losses are critical for the development of P reduction strategies across the Eastern Corn Belt region of North America. Within this region, surface water bodies including Lake Erie are sensitive to non-point P loadings. It is therefore imperative to quantify the impact of agricultural crop production on surface and subsurface water quality. This study characterized discharge, P concentrations, and P loads in surface runoff and subsurface drainage from 38 edge-of-field research sites in Ohio. Over the four-year study period, 31 ± 16% (mean ± one standard deviation) of annual precipitation became subsurface discharge while 7 ± 8% became surface discharge. Subsurface discharge accounted for 81 ± 23% of annual discharge, 71 ± 26% of annual dissolved reactive phosphorus (DRP) load, and 69 ± 27% of annual total phosphorus (TP) load. A P balance was also developed using management and loading data from the study sites. Under prevailing management practices, P removal (i.e., surface losses, subsurface losses, crop uptake) was greater than P input (i.e., atmospheric deposition, fertilizer application) on 60% of fields. Even so, further reduction of edge-of-field P losses will likely be necessary to meet watershed-scale P load recommendations. Findings suggest that balancing P inputs with crop uptake may not be sufficient to reduce edge-of-field losses due to a combination of legacy P and high-intensity rainfall events. Implementation of management practices targeting P-source will be needed in conjunction with practices at the edge-of-field targeting P-transport in order to meet recommended P loading targets in the Eastern Corn Belt region.


Phosphorus (P) mobilization in agricultural landscapes is regulated by both hydrologic (transport) and biogeochemical (supply) processes interacting within soils; however, the
dominance of these controls can vary spatially and temporally. In this study, we analyzed a 5-yr dataset of stormflow events across nine agricultural fields in the lower Great Lakes region of Ontario, Canada, to determine if edge-of-field surface runoff and tile drainage losses (total and dissolved reactive P) were limited by transport mechanisms or P supply. Field sites ranged from clay loam, silt loam, to sandy loam textures. Findings indicate that biogeochemical processes (P supply) were more important for tile drain P loading patterns (i.e., variable flow-weighted mean concentrations ([Cf]) across a range of flow regimes) relative to surface runoff, which trended toward a more chemostatic or transport-limited response. At two sites with the same soil texture, higher tile [Cf] and greater transport limitations were apparent at the site with higher soil available P (STP); however, STP did not significantly correlate with tile [Cf] or P loading patterns across the nine sites. This may reflect that the fields were all within a narrow STP range and were not elevated in STP concentrations (Olsen-P, ≤25 mg kg⁻¹). For the study sites where STP was maintained at reasonable concentrations, hydrology was less of a driving factor for tile P loadings, and thus management strategies that limit P supply may be an effective way to reduce P losses from fields (e.g., timing of fertilizer application).


Implementing agricultural best management practices (BMPs) is influenced by a balance of desired environmental outcomes, economic feasibility, and stakeholder familiarity, the latter taken to be related to BMP acceptability. To explore this balance, we developed a multi-objective decision support system for allocating BMP type and placement by coupling the Soil and Water Assessment Tool with a nondominated sorted genetic algorithm that minimizes total phosphorus (TP) yields from agricultural hydrologic response units (HRUs) and costs, while using stakeholder BMP familiarity as a constraint; conventional tillage, no tillage, nutrient management, riparian buffers, and contour cropping were explored. Using constraints representing current conditions, the optimization resulted in 59.6 to 81.0% reduction in agricultural TP yield from HRUs at costs ranging between US $0.8 and US $5.3 million. The constrained optimization tended to select mostly single BMPs or at most two BMPs for a given HRU due to these BMPs having higher acceptability to stakeholders. In contrast, the unconstrained case, representing full familiarity, selected 2- and 3-BMP applications. There was little difference in costs between the constrained and unconstrained cases below an 80% TP yield reduction; however, significant differences were found at larger reductions, supporting the value of stakeholder education and extension efforts.

Editor’s note: This paper is part of the featured series on SWAT Applications for Emerging Hydrologic and Water Quality Challenges. See the February 2017 issue for the introduction and background to the series.


Most phosphorus (P) modeling studies of water quality have focused on surface runoff losses. However, a growing number of experimental studies have shown that P losses can occur in drainage water from artificially drained fields. In this review, we assess the
applicability of nine models to predict this type of P loss. A model of P movement in artificially drained systems will likely need to account for the partitioning of water and P into runoff, macropore flow, and matrix flow. Within the soil profile, sorption and desorption of dissolved P and filtering of particulate P will be important. Eight models are reviewed (ADAPT, APEX, DRAINMOD, HSPF, HYDRUS, ICECREAMDB, PLEASE, and SWAT) along with P Indexes. Few of the models are designed to address P loss in drainage waters. Although the SWAT model has been used extensively for modeling P loss in runoff and includes tile drain flow, P losses are not simulated in tile drain flow. ADAPT, HSPF, and most P Indexes do not simulate flow to tiles or drains. DRAINMOD simulates drains but does not simulate P. The ICECREAMDB model from Sweden is an exception in that it is designed specifically for P losses in drainage water. This model seems to be a promising, parsimonious approach in simulating critical processes, but it needs to be tested. Field experiments using a nested, paired research design are needed to improve P models for artificially drained fields. Regardless of the model used, it is imperative that uncertainty in model predictions be assessed.

Richards, R. Peter, Ibrahim Alameddine, J. David Allan, David B. Baker, Nathan S. Bosch, Remegio Confesor, Joseph V. DePinto, David M. Dolan, Jeffrey M. Reutter, and Donald Scavia, 2012. Discussion—“Nutrient Inputs to the Laurentian Great Lakes by Source and Watershed Estimated Using SPARROW Watershed Models” by Dale M. Robertson and David A. Saad. Journal of the American Water Resources Association (JAWRA) 1-10. DOI: 10.1111/jawr.12006 Abstract: Results from the Upper Midwest Major River Basin (MRB3) SPARROW model and underlying Fluxmaster load estimates were compared with detailed data available in the Lake Erie and Ohio River watersheds. Fluxmaster and SPARROW estimates of tributary loads tend to be biased low for total phosphorus and high for total nitrogen. These and other limitations of the application led to an overestimation of the relative contribution of point sources vs. nonpoint sources of phosphorus to eutrophication conditions in Lake Erie, when compared with direct estimates for data-rich Ohio tributaries. These limitations include the use of a decade-old reference point (2002), lack of modeling of dissolved phosphorus, lack of inclusion of inputs from the Canadian Lake Erie watersheds and from Lake Huron, and the choice to summarize results for the entire United States Lake Erie watershed, as opposed to the key Western and Central Basin watersheds that drive Lake Erie’s eutrophication processes. Although the MRB3 SPARROW model helps to meet a critical need by modeling unmonitored watersheds and ranking rivers by their estimated relative contributions, we recommend caution in use of the MRB3 SPARROW model for Lake Erie management, and argue that the management of agricultural nonpoint sources should continue to be the primary focus for the Western and Central Basins of Lake Erie.

Data series for tributaries, the Maumee, Sandusky, and Cuyahoga Rivers, and for Honey Creek, were examined for trends in nutrients and suspended solids. Mean daily flows and two forms of weighted mean concentrations were compiled at monthly intervals, and studied using parametric and non-parametric techniques of trend detection. Total and soluble reactive phosphorus, suspended sediment, and nitrate-plus-nitrite were examined. Flow and suspended sediment generally showed statistically non-significant minor trends. Total and soluble phosphorus both showed downward trends, statistically significant for most data series, of 5 to 40 μg/L per year. Nitrate-plus-nitrite showed usually statistically significant increases of 10 to 140 μg/L per year, except for the Cuyahoga data, which showed a statistically significant downward trend of about 70 μg/L per year.


Trends in water quality in four northwest Ohio rivers over the period 1975-1995 were identified using datasets of daily concentrations containing 4500 to 6800 observations per river during the study period. Concentrations were log-transformed prior to analysis, and adjusted for flow using a locally weighted scatterplot smoother (LOWESS) fit between log(concentration) and log(flow). Seasonality was modeled using one- and two-cycle sinusoidal oscillations and monthly additive constants. Substantial decreases in total and soluble reactive phosphorus were documented at all stations. Smaller but highly significant decreases in total Kjeldahl nitrogen were documented at all stations, and significant decreases in total suspended solids were documented at three of the four stations. Nitrate did not show significant trends at the two stations draining major watersheds, and showed significant trends in opposite directions at the two stations on smaller watersheds. Comparisons using nonparametric, nonlinear trend fits (LOWESS) suggest that changes in fertilizer and manure application rates are the most important cause of trends in phosphorus and total Kjeldahl nitrogen; point sources are insufficient to account for the phosphorus trends. The conflicting trends for nitrate are enigmatic, but may reflect diverging land use in the two smaller watersheds.


Sediment is an important pollutant for Lake Erie and its tributaries, both as a carrier of other substances, particularly phosphorus, and as a pollutant in its own right. Environmental managers have called for major reductions in sediment and phosphorus loadings from Lake Erie tributaries. In this study, thirty-year datasets (Water Years 1975-2004) with daily resolution are analyzed to identify and interpret trends in suspended sediment and particulate phosphorus concentrations and loads in two major US tributaries to Lake Erie. The Maumee and Sandusky Rivers in agricultural northwest Ohio show continual decreases in concentrations and loads throughout this period. The greatest decreases are observed in summer and fall and under low flow conditions, whereas the smallest decreases are observed in the spring and under high flow conditions. Analysis of concentration-flow
relationships indicates that these changes are not due to weather but reflect the successful use of agricultural practices to reduce erosion and prevent sediment loss. Opportunities for further reductions in suspended sediment and particulate phosphorus loads and concentrations lie in better management of sediment losses during winter and spring.


During water year 2007 (October 1, 2006, through September 30, 2007), the Maumee River and Sandusky River in northern Ohio transported the largest, or nearly the largest, loads of several water quality constituents that have been observed in 33 years of monitoring. Discharge, total phosphorus, dissolved reactive phosphorus, total Kjeldahl nitrogen, and chloride all recorded 33-year maximum loads, while the loads for nitrate ranked 5th (Sandusky) and 8th (Maumee) out of 33. Loads of particulate phosphorus ranked 2nd (Sandusky) and 4th (Maumee), and those for suspended solids ranked 10th (Sandusky) and 9th (Maumee). This is partly a consequence of total rainfall, which was the largest observed at the Tiffin weather station (Sandusky watershed) and nearly the largest at the Toledo station (Maumee watershed) during this period. It also results from other aspects of the weather in interaction with agricultural practices, notably a warm, wet fall and early winter. Longer-term trends were also significant factors for some parameters. The weather was the major factor responsible for these large loads. Regardless of cause, these loads represent a substantial loss of resources from agricultural fields in the watersheds. This loss could have been reduced by better management. Losses of sediment and phosphorus from these watersheds are higher than average for Midwestern agricultural watersheds, and losses of nitrogen are slightly above average. Based on winter 2008 fertilizer prices from local fertilizer dealers, replacing the nutrients lost from these watersheds in water year 2007 would cost more than $80,000,000 or $166 ha(-1) ($67 ac(-1)) for every field in the watershed receiving fertilizer in a given year. Source: WOS


County-level agricultural statistics were aggregated at the watershed level to provide estimates of trends in land use and agricultural management in the Maumee and Sandusky River watersheds during the period 1975-1995. Average farm size increased by 40% or more, but the number of farms decreased by nearly 40%; the total land area in agriculture also decreased, but only by about 7%. Conservation tillage increased from virtually nothing to nearly 50% of cropland in corn (Zea mays L.) and soybean [Glycine max (L.) Merr.]; most of the change is due to adoption of no-till soybean. The Conservation Reserve Program has enrolled more than 75 000 hectares, but this represents less than 5% of total farmland. The great majority of land classified as highly erodible has been placed under treatment during the study period. Cropland in soybean has increased; land in wheat (Triticum aestivum L.) and hay has decreased. Cropland in corn has decreased in the Maumee watershed and increased slightly in the Sandusky watershed. Average per-hectare yields of corn, soybean, wheat, and hay have increased by 10 to 40%. Fertilizer phosphorus sales increased until about 1980 and have declined significantly since then; fertilizer nitrogen follows a similar but less pronounced pattern. The decreases are more substantial in the
Maumee watershed than in the Sandusky. Manure use for fertilizer has also declined significantly. Source: WOS

115. Richards, R. P., Calhoun, F. G., & Matisoff, G. (2002). The Lake Erie agricultural systems for environmental quality project: An introduction. *Journal of Environmental Quality*. In the last part of the twentieth century, recognition became widespread of the important effect of agricultural runoff on the health of aquatic ecosystems in the Lake Erie basin and elsewhere. Because of the efforts to remediate Lake Erie, the “dead lake” among the Laurentian Great Lakes, a number of research and demonstration projects were undertaken in the Lake Erie basin to evaluate and foster adoption of conservation tillage and other farming techniques that would reduce runoff while maintaining productivity. In addition, intensive water quality studies of long duration were begun on major tributaries to Lake Erie during this time. The Lake Erie Agricultural Systems for Environmental Quality (LEASEQ) project examined governmental programs, changes in agriculture, and changes in water and soil quality during the period 1975-1995, and sought to evaluate the linkages among these factors. The study area is characterized by extensive agricultural land use of soils developed from glacial materials deposited on Paleozoic sedimentary bedrock, mostly limestone. Tile drainage is extensive, particularly in slow-draining clay-rich lacustrine soils in the lower reaches of the watersheds. This paper introduces the study area, its geology, geography, soils, and agricultural history. In addition, we provide an overview of the LEASEQ concept and introduce the 11 other papers in this series, which provide a detailed exposition of the results of our studies.

116. Richards, R. P., & Grabow, G. L. (2003). Detecting reductions in sediment loads associated with Ohio’s conservation reserve enhancement program. *Journal of the American Water Resources Association, 39*(5), 1261–1268. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-0242407060&partnerID=tZOtx3y1 Small systematic changes in loads or concentrations of water quality constituents are difficult to detect against the background of short term fluctuations (“noise”) that result from weather and climate effects. Minimum Detectable Change Analysis (MDCA) uses prior knowledge of a water quality constituent to determine how much change must occur (e.g., from implementation of conservation practices) for the change to be statistically significant. In this paper we use MDCA to determine whether the goal of the Ohio Lake Erie Conservation Reserve Enhancement Program (CREP), to reduce sediment loads by an average of 6 percent over 10 years, represents a large enough change to be detected. We conclude that this amount of change is unlikely to be detected as statistically significant, even with the high frequency sampling program planned for evaluating it. The minimum detectable change ranges from about 7 to 9 percent for three different rivers.

Nutrient input to the Laurentian Great Lakes continues to cause problems with eutrophication. To reduce the extent and severity of these problems, target nutrient loads were established and Total Maximum Daily Loads are being developed for many tributaries.
Without detailed loading information it is difficult to determine if the targets are being met and how to prioritize rehabilitation efforts. To help address these issues, SPAtially Referenced Regressions On Watershed attributes (SPARROW) models were developed for estimating loads and sources of phosphorus (P) and nitrogen (N) from the United States (U.S.) portion of the Great Lakes, Upper Mississippi, Ohio, and Red River Basins. Results indicated that recent U.S. loadings to Lakes Michigan and Ontario are similar to those in the 1980s, whereas loadings to Lakes Superior, Huron, and Erie decreased. Highest loads were from tributaries with the largest watersheds, whereas highest yields were from areas with intense agriculture and large point sources of nutrients. Tributaries were ranked based on their relative loads and yields to each lake. Input from agricultural areas was a significant source of nutrients, contributing $\sim 33-44\%$ of the P and $\sim 33-58\%$ of the N, except for areas around Superior with little agriculture. Point sources were also significant, contributing $\sim 14-44\%$ of the P and $13-34\%$ of the N. Watersheds around Lake Erie contributed nutrients at the highest rate (similar to intensively farmed areas in the Midwest) because they have the largest nutrient inputs and highest delivery ratio.


The role of groundwater in delivering nutrients (nitrogen and phosphorus) to the Great Lakes and their tributaries is not well understood. Consequently, this potentially important non-point source is poorly managed and often neglected. Evaluating nutrient inputs from groundwater requires knowledge of the (i) sources of groundwater nutrient contamination, (ii) physical groundwater discharge flow paths, and (iii) geochemical processes occurring along these flow paths that control the ultimate loading of nutrients to surface waters. Although groundwater quality in the Great Lakes Basin (GLB) is generally good, nutrient concentrations in aquifers can become elevated by a range of agricultural and non-agricultural activities. Nutrients can be delivered from groundwater to the Great Lakes by indirect discharge into tributaries or direct discharge into the lakes. The factors affecting these discharge pathways and their contributions to nutrient loading are distinct. The discharge of nutrients from groundwater to surface water is strongly regulated by zones of high reactivity that exist close to the sediment–water interface (i.e., riparian zone, hyporheic zone). Understanding the functioning of these zones for the landscape and hydrogeological conditions in the GLB is essential for evaluating nutrient loading to the Great Lakes and their tributaries as well as maximizing the benefits these zones can provide for water quality management. The paper concludes with a discussion of key knowledge gaps, challenges, and future research priorities that need to be addressed to evaluate and better manage this complex nutrient input to the Great Lakes and their tributaries.


Legacy phosphorus (P) that has accumulated in soils from past inputs of fertilizers and manures is a large secondary global source of P that could substitute manufactured fertilizers, help preserve critical reserves of finite phosphate rock to ensure future food and
bioenergy supply, and gradually improve water quality. We explore the issues and management options to better utilize legacy soil P and conclude that it represents a valuable and largely accessible P resource. The future value and period over which legacy soil P can be accessed depends on the amount present and its distribution, its availability to crops and rates of drawdown determined by the cropping system. Full exploitation of legacy P requires a transition to a more holistic system approach to nutrient management based on technological advances in precision farming, plant breeding and microbial engineering together with a greater reliance on recovered and recycled P. We propose the term “agro-engineering” to encompass this integrated approach. Smaller targeted applications of fertilizer P may still be needed to optimize crop yields where legacy soil P cannot fully meet crop demands. Farm profitability margins, the need to recycle animal manures and the extent of local eutrophication problems will dictate when, where and how quickly legacy P is best exploited. Based on our analysis, we outline the stages and drivers in a transition to the full utilization of legacy soil P as part of more sustainable regional and global nutrient management.


A 1-dimensional, linked hydrodynamic and eutrophication model was developed and calibrated with 19 years of observations (1987-2005) for the summer stratification period in the central basin of Lake Erie, corroborated by comparison with observed process rates and areal hypoxic extents, and confirmed with observations from the 1960s and 1970s. The model effectively captures observations of both vertical and temporal trends in dissolved oxygen, as well as temporal trends in chlorophyll-a, phosphorus, zooplankton biomass, and several key processes. The model was used to develop a relationship between external phosphorus load and hypolimnion oxygen conditions, and then to establish load-response envelopes that account for inter-annual variability in physical conditions driven by variation in meteorological drivers. The curves provide a valuable tool for reassessing phosphorus loading targets with respect to reducing hypoxia in Lake Erie.


A draft literature review prepared for the International Joint Commission’s Lake Erie Ecosystem Priority, IJC Great Lakes Regional Office, Windsor, ON (2013)


123. Scavia, D., David Allan, J., Arend, K. K., Bartell, S., Beletsky, D., Bosch, N. S., … Zhou, Y. (2014). Assessing and addressing the re-eutrophication of Lake Erie: Central basin
Relieving phosphorus loading is a key management tool for controlling Lake Erie eutrophication. During the 1960s and 1970s, increased phosphorus inputs degraded water quality and reduced central basin hypolimnetic oxygen levels which, in turn, eliminated thermal habitat vital to cold-water organisms and contributed to the extirpation of important benthic macroinvertebrate prey species for fishes. In response to load reductions initiated in 1972, Lake Erie responded quickly with reduced water-column phosphorus concentrations, phytoplankton biomass, and bottom-water hypoxia (dissolved oxygen <2mg/l). Since the mid-1990s, cyanobacteria blooms increased and extensive hypoxia and benthic algae returned. We synthesize recent research leading to guidance for addressing this re-eutrophication, with particular emphasis on central basin hypoxia. We document recent trends in key eutrophication-related properties, assess their likely ecological impacts, and develop load response curves to guide revised hypoxia-based loading targets called for in the 2012 Great Lakes Water Quality Agreement. Reducing central basin hypoxic area to levels observed in the early 1990s (ca. 2000km2) requires cutting total phosphorus loads by 46% from the 2003-2011 average or reducing dissolved reactive phosphorus loads by 78% from the 2005-2011 average. Reductions to these levels are also protective of fish habitat. We provide potential approaches for achieving those new loading targets, and suggest that recent load reduction recommendations focused on western basin cyanobacteria blooms may not be sufficient to reduce central basin hypoxia to 2000km2. © 2014 Elsevier B.V.


In response to water quality changes in the Great Lakes since implementing the 1978 Amendment to the Great Lakes Water Quality Agreement, the US and Canada renegotiated the agreement in 2012, requiring the governments to review and revise phosphorus (P) load targets, starting with Lake Erie. In response, the governments supported a multi-model team to evaluate the existing objectives and P load targets for Lake Erie and provide the information needed to update those targets. Herein, we describe the process and resulting advice provided to the binational process. The collective modeling effort concluded that avoiding severe Western Basin (WB) cyanobacteria blooms requires: 1) focusing on reducing total P loading from the Maumee River, with an emphasis on high-flow events during March–July, 2) focusing on dissolved reactive P load alone will not be sufficient because there is significant bioavailable P in the particulate phosphorus portion of the load, and 3) loading from the Detroit River is not a driver of cyanobacteria blooms. Reducing Central Basin (CB) hypoxia requires a CB + WB load reduction greater than what is needed to reach the WB cyanobacteria biomass goal. Achieving Cladophora thresholds will be challenging without site-specific load reductions, and more research is needed.


In response to degraded water quality, federal policy makers in the US and Canada called for a 40% reduction in phosphorus (P) loads to Lake Erie, and state and provincial policy
makers in the Great Lakes region set a load-reduction target for the year 2025. Here, we configured five separate SWAT (US Department of Agriculture’s Soil and Water Assessment Tool) models to assess load reduction strategies for the agriculturally dominated Maumee River watershed, the largest P source contributing to toxic algal blooms in Lake Erie. Although several potential pathways may achieve the target loads, our results show that any successful pathway will require large-scale implementation of multiple practices. For example, one successful pathway involved targeting 50% of row cropland that has the highest P loss in the watershed with a combination of three practices: subsurface application of P fertilizers, planting cereal rye as a winter cover crop, and installing buffer strips. Achieving these levels of implementation will require local, state/provincial, and federal agencies to collaborate with the private sector to set shared implementation goals and to demand innovation and honest assessments of water quality-related programs, policies, and partnerships.


Major advances in the scientific understanding and management of eutrophication have been made since the late 1960s. The control of point sources of phosphorus reduced algal blooms in many lakes. Diffuse nutrient sources from land use changes and urbanization in the catchments of lakes have proved possible to control but require many years of restoration efforts. The importance of water residence time to eutrophication has been recognized. Changes in aquatic communities contribute to eutrophication via the trophic cascade, nutrient stoichiometry, and transport of nutrients from benthic to pelagic regions. Overexploitation of piscivorous fishes appears to be a particularly common amplifier of eutrophication. Internal nutrient loading can be controlled by reducing external loading, although the full response of lakes may take decades. In the years ahead, climate warming will aggravate eutrophication in lakes receiving point sources of nutrients, as a result of increasing water residence times. Decreased silica supplies from dwindling inflows may increasingly favor the replacement of diatoms by nitrogen-fixing Cyanobacteria. Increases in transport of nitrogen by rivers to estuaries and coastal oceans have followed increased use of nitrogen in agriculture and increasing emissions to the atmosphere. Our understanding of eutrophication and its management has evolved from simple control of nutrient sources to recognition that it is often a cumulative effects problem that will require protection and restoration of many features of a lake’s community and its catchment. © 2006, by the American Society of Limnology and Oceanography, Inc.


As human populations increase and land-use intensifies, toxic and unsightly nuisance blooms of algae are becoming larger and more frequent in freshwater lakes. In most cases, the blooms are predominantly blue-green algae (Cyanobacteria), which are favored by low ratios of nitrogen to phosphorus. In the past half century, aquatic scientists have devoted much effort to understanding the causes of such blooms and how they can be prevented or reduced. Here we review the evidence, finding that numerous long-term studies of lake
ecosystems in Europe and North America show that controlling algal blooms and other symptoms of eutrophication depends on reducing inputs of a single nutrient: phosphorus. In contrast, small-scale experiments of short duration, where nutrients are added rather than removed, often give spurious and confusing results that bear little relevance to solving the problem of cyanobacteria blooms in lakes.


Severe environmental and health impacts have been experienced in the Western Lake Erie Basin (WLEB) because of eutrophication and associated proliferation of harmful algae blooms. Efforts to improve water quality within the WLEB have been on-going for several decades. However, water quality improvements in the basin have not been realized as anticipated. In this study, factors affecting water quality within the WLEB were evaluated with a view to differentiating their impacts and informing further assessments in the basin. Over the long-term (1966–2015) and basin-wide, total annual precipitation increased significantly by about 2.4 mm/year while mean monthly streamflows also increased during the same period although the increase was not significant (p = 0.36). There was, however, a significant increase in spring streamflows during this period (p = 0.003). Patterns in water quality parameters showed significant reductions in total suspended solids (TSS) (p < 0.001) and total phosphorus (TP) (p = 0.018) while soluble reactive phosphorus (SRP) increased significantly (p < 0.001), and in particular from about 1995. Results of near-term (2005–2015) analysis showed a non-significant (p = 0.262) reduction in TSS concentrations of about 0.25 mg/L/year. TP concentrations did not vary substantially during the same period while a 0.11 mg/L/year increase in nitrate and a 0.001 mg/L/year increase in SRP were observed, with increases in nitrates being significant (p = 0.013). TP and SRP concentrations, however, remained high within the basin with daily values ranging between 0.03 and 1.84 mg/L and less than 0.002–0.52 mg/L, respectively. Basin-wide, both spring precipitation and spring streamflows increased significantly during the period 2005–2015 (p < 0.001). Overall, no substantial changes in land use were observed, suggesting that water quality responses might be attributable to management. Based on recent data, corn acreage in the basin and fertilizer applied to corn increased by 33% and 10% respectively. Combined Sewer Overflows (CSOs) and impoundments were also important factors due to their prevalence in the basin. Based on the analysis, changes in agricultural management, increase in spring precipitation, CSOs, legacy phosphorus, and the presence of dams were thought to present constraints to water quality improvements despite conservation efforts within the basin.


We evaluated the recent ecological history of Lake Erie from diatoms and geochemistry in sediment cores. Two major transition points in the ecology of the western basin (WB; 1985 and 2008) and central basin (CB; 1935 and 1982) were defined. Changes in abundance of diatom eutrophic indicators and geochemical markers were interpreted as a degradation in water quality after 1935 due to the effects of increased population, agriculture, and
industrialization until abatement measures were enacted in the 1970s and 1980s. Diatom indicators suggested modest recovery from eutrophic conditions in Lake Erie, however diatom-inferred total phosphorus suggested that despite abatement efforts total phosphorus was not reduced below pre-impact levels. The effects on diatoms of increased temperature and dissolved silica also became apparent in the 1980s, and in the WB recent shifts were likely caused by increased pollution and recent climatic warming. Based on stratigraphic changes since 1985, the diatom trajectory suggests the phytoplankton of Lake Erie will likely remain in a state of flux for the near future due to a variety of countervailing impacts including unknown effects of mitigation efforts, legacy pollution, climate change, and changing upstream conditions. © 2017 International Association for Great Lakes Research.

Economic costs, water quantity/quality benefits, and cost effectiveness of agricultural best management practices (BMPs) at a watershed scale are increasingly examined using integrated economic-hydrologic models. However, these models are typically complex and not user-friendly for examining the effects of various BMP scenarios. In this study, an open source geographic information system (GIS)-based decision support system (DSS), named the watershed evaluation of BMPs (WEBs), was developed for creating BMP scenarios and simulating economic costs and water quantity/quality benefits at farm field, subbasin, and watershed scales. This DSS or WEBs interface integrated a farm economic model, the Soil and Water Assessment Tool (SWAT), and an optimization model within Whitebox Geospatial Analysis Tools (GAT), an open source GIS software. The DSS was applied to the 14.3-km2 Gully Creek watershed, a coastal watershed in southern Ontario, Canada that drains directly into Lake Huron. BMPs that were evaluated included conservation tillage, nutrient management, cover crop, and water and sediment control basins. In addition to assessing economic costs, water quantity/quality benefits, and cost effectiveness of BMPs, the DSS can be also used to examine prioritized BMP types/locations and corresponding economic and water quantity/quality tradeoffs in the study watershed based on environmental targets or budget constraints. Further developments of the DSS including interface transfer to other watersheds are also discussed.

The water quality response to implementation of conservation measures across watersheds has been slower and smaller than expected. This has led many to question the efficacy of these measures and to call for stricter land and nutrient management strategies. In many cases, this limited response has been due to the legacies of past management activities, where sinks and stores of P along the land–freshwater continuum mask the effects of reductions in edge-of-field losses of P. Accounting for legacy P along this continuum is important to correctly apportion sources and to develop successful watershed remediation. In this study, we examined the drivers of legacy P at the watershed scale, specifically in
relation to the physical cascades and biogeochemical spirals of P along the continuum from soils to rivers and lakes and via surface and subsurface flow pathways. Terrestrial P legacies encompass prior nutrient and land management activities that have built up soil P to levels that exceed crop requirements and modified the connectivity between terrestrial P sources and fluvial transport. River and lake P legacies encompass a range of processes that control retention and remobilization of P, and these are linked to water and sediment residence times. We provide case studies that highlight the major processes and varying timescales across which legacy P continues to contribute P to receiving waters and undermine restoration efforts, and we discuss how these P legacies could be managed in future conservation programs.


The accelerated eutrophication of most freshwaters is limited by P inputs. Nonpoint sources of P in agricultural runoff now contribute a greater portion of freshwater inputs, due to easier identification and recent control of point sources. Although P management is an integral part of profitable agrisystems, continued inputs of fertilizer and manure P in excess of crop requirements have led to a build-up of soil P levels, which are of environmental rather than agronomic concern, particularly in areas of intensive crop and livestock production. Thus, the main issues facing the establishment of economically and environmentally sound P management systems are the identification of soil P levels that are of environmental concern; targeting specific controls for different water quality objectives within watersheds; and balancing economic with environmental values. In developing effective options, we have brought together agricultural and limnological expertise to prioritize watershed management practices and remedial strategies to mitigate nonpoint-source impacts of agricultural P. Options include runoff and erosion control and P-source management, based on eutrophic rather than agronomic considerations. Current soil test P methods may screen soils on which the aquatic bioavailability of P should be estimated. Landowner options to more efficiently utilize manure P include basing application rates on soil vulnerability to P loss in runoff, manure analysis, and programs encouraging manure movement to a greater hectareage. Targeting source areas may be achieved by use of indices to rank soil vulnerability to P loss in runoff and lake sensitivity to P inputs.


Agriculture, particularly livestock agriculture, is receiving increasing public scrutiny due to non-point source phosphorus (P) pollution and eutrophication. Much of today’s situation may be attributed to system level trends in specialization and intensification that result in excess P entering livestock farms. Balancing P at the farm gate represents a necessary step for long-term soil and water quality protection. Remedial P management combines source and transport control that confront critical areas of P export in surface and subsurface runoff from agricultural landscapes. Source management seeks to immobilize P in the environment through such strategies as reducing soluble P in manure, targeting P application to soils with
high retention capacities, and managing soil P. Transport controls employ an understanding of loss or transfer mechanisms to avoid P application on areas with a high transport potential. Also, the potential for P transport can be reduced by implementation of conservation practices such as reduced tillage, terracing, and stream buffers. However, implementation of agricultural management strategies that minimize P export must consider the cost effectiveness of alternative measures, as low practice adoption may limit or impede water quality benefits.


Phosphorus (P), an essential nutrient for crop and animal production, can accelerate freshwater eutrophication, now one of the most ubiquitous forms of water quality impairment in the developed world. Repeated outbreaks of harmful algal blooms (e.g., Cyanobacteria and *Pfiesteria*) have increased society’s awareness of eutrophication, and the need for solutions. Agriculture is regarded as an important source of P in the environment. Specifically, the concentration of specialized farming systems has led to a transfer of P from areas of grain production to animal production. This has created regional surpluses in P inputs (mineral fertilizer and feed) over outputs (crop and animal produce), built up soil P in excess of crop needs, and increased the loss of P from land to water. Recent research has shown that this loss of P in both surface runoff and subsurface flow originates primarily from small areas within watersheds during a few storms. These areas occur where high soil P, or P application in mineral fertilizer or manure, coincide with high runoff or erosion potential. We argue that the overall goal of efforts to reduce P loss to water should involve balancing P inputs and outputs at farm and watershed levels by optimizing animal feed rations and land application of P as mineral fertilizer and manure. Also, conservation practices should be targeted to relatively small but critical watershed areas for P export.


The impairment of surface water quality in the United States has been well documented, as has the potential for agriculture to contribute nutrients that accelerate this impairment. In response, widespread implementation of conservation strategies to reduce nutrient losses and mitigate impairment has occurred. This study reports and compares the outcomes of voluntary and litigated conservation and nutrient management strategies in watersheds of Lake Erie and northwest Arkansas, respectively. In the Maumee (MRW) and Sandusky River Watersheds (SRW) that drain into Lake Erie, voluntary strategies to reduce total phosphorus (P) loading from cropland were implemented in the mid-1980s. The strategies focused on reducing particulate P loading through erosion control programs, utilizing no-till and reduced-till management. As various subsidies became available, as well as improved planters and better herbicides, farmers rapidly adopted conservation tillage. Between 1975 and 1995, this led to a decline in fertilizer and manure application and increased conservation tillage acreage, which contributed to a reduction in total and dissolved P export. In the last 10 years, however, increased no-till acres with surface soil P stratification, fall and winter broadcasting of P fertilizer, and more extreme rainfall-runoff events have
contributed to an increase in dissolved P export. In the Eucha-Spavinaw Watershed (ESW), northwest Arkansas, litigation required a minimum of 33% of the poultry litter produced be exported out of ESW and the remaining land applications to be based on the risk of P runoff. Use of the Eucha-Spavinaw P Index (ESPI) has decreased the land application of poultry litter from an average 5.6 t ha⁻¹ (2.5 tn ac⁻¹) before litigation to 2.5 t ha⁻¹ (1.12 tn ac⁻¹) in 2009. This, combined with the fact that 70% to 80% of the produced litter was being transported out of ESW, has greatly reduced the risk of P loss in agricultural runoff. At 2009 fertilizer prices, the loss of P and nitrogen (N) from cropped acres in MRW and SRW was US$13 ha⁻¹ (US$5 ac⁻¹), and the value of P and N exported in litter from ESW was US$40 ha⁻¹ (US$16 ac⁻¹). While voluntary implementation of BMPs in Lake Erie watersheds decreased total P export, continued monitoring is needed to adaptively manage these BMPs to ensure their long-term effectiveness. Litigated BMP adoption in northwest Arkansas did reduce land application of litter but at a cost to beef grazing operations, which …


Conservation practices are implemented on farm fields in the USA through Farm Bill programs; however, there is a need for greater verification that these practices provide environmental benefits (e.g., water quality). This study was conducted to assess the impact of Farm Bill eligible conservation practices on soluble P (SP) and total P (TP) losses from four fields that were monitored between 2004 and 2013. No-tillage doubled SP loading compared to rotational tillage (e.g., tilled only before planting corn); however, no-tillage decreased TP loading by 69% compared to rotational tillage. Similarly, grassed waterways were shown to increase SP loads, but not TP loads. A corn-soybean-wheat-oat rotation reduced SP loads by 85% and TP loads by 83% compared to the standard corn-soybean rotation in the region. We can potentially attain TP water quality goals using these Farm Bill practices; however, additional strategies must be employed to meet these goals for SP.


Water quality experts have suggested that no-till induces phosphorus (P) stratification, which may exacerbate soluble P (SP) runoff from agricultural fields, contributing to eutrophication. Conservationists have been concerned about increased SP loading to Lake Erie, which has been partially blamed on adoption of no-till and the concomitant P stratification of no-till soils. This study was conducted to provide better insight into the potential link between P stratification from no-till soils and P losses via runoff with the objective of exploring P fertilization strategies on P stratification and P runoff from a corn (Zea mays L.)–soybean (Glycine max L.) rotation. Plots were established with nine treatments, including unfertilized, diammonium phosphate (DAP) applications, monoammonium phosphate (MAP) applications, surface applied, injecting fertilizer or tilling fertilizer in, and the use of cover crops. Fertilizer applications were made at 24.4 kg P ha⁻¹ (21.8 lb P ac⁻¹) every other year or at 9.6 kg P ha⁻¹ (8.7 lb P ac⁻¹) every year. Disking, which was intended to minimize P stratification, resulted in the greatest stratification, with significantly higher water SP and Mehlich 3 P in the 0 to 5 cm (0 to 2 in)
soil layer compared to the other treatments. There were no differences in SP or total P (TP) runoff from rainfall simulations between fertilizer source (MAP versus DAP) or fertilizer rate (annual versus biennial). The highest SP concentrations observed were from DAP applied to cover crops at the high application rate (24.4 kg P ha⁻¹ applied every other year). This may suggest cover crops are not the ideal practice to decrease SP losses from agricultural fields. Incorporation of fertilizer reduced SP but increased erosion and could potentially increase TP loss. Injecting liquid fertilizer (polyphosphate [Poly]) at the time of planting resulted in lower SP and TP loads than surface applied fertilizers. We encourage other researchers to confirm these results at the field-to-watershed scale to ensure there are not unintended consequences of adopting this fertilization strategy. Further, fertilizer dealers, crop consultants, and farmers should be encouraged to consider liquid fertilizer applications as one option to minimize P losses.


The midwestern United States offers some of the most productive agricultural soils in the world. Given the cool humid climate, much of the region would not be able to support agriculture without subsurface (tile) drainage because high water tables may damage crops and prevent machinery usage in fields at critical times. Although drainage is designed to remove excess soil water as quickly as possible, it can also rapidly transport agrochemicals, including phosphorus (P). This paper illustrates the potential importance of tile drainage for P transport throughout the midwestern United States. Surface runoff and tile drainage from fields in the St. Joseph River Watershed in northeastern Indiana have been monitored since 2008. Although the traditional concept of tile drainage has been that it slowly removes soil matrix flow, peak tile discharge occurred at the same time as peak surface runoff, which demonstrates a strong surface connection through macropore flow. On our research fields, 49% of soluble P and 48% of total P losses occurred via tile discharge. Edge-of-field soluble P and total P areal loads often exceeded watershed-scale areal loadings from the Maumee River, the primary source of nutrients to the western basin of Lake Erie, where algal blooms have been a pervasive problem for the last 10 yr. As farmers, researchers, and policymakers search for treatments to reduce P loading to surface waters, the present work demonstrates that treating only surface runoff may not be sufficient to reach the goal of 41% reduction in P loading for the Lake Erie Basin.


Increasing soluble phosphorus (SP) loads to Lake Erie occurring around the same time as the implementation of no-tillage in the watershed has led to speculation that this important
conservation practice is a primary cause of the SP loading. Thus, conservationists are interested in finding management practices that will minimize stratification of P, which may be common in no-tillage systems, while also minimizing erosion losses that result from conventional tillage practices. As no-tillage was marketed as a practice to decrease sediment and total P (TP) loads, it is important to examine adoption of future conservation practices for their impact on multiple resource concerns. This study was conducted to determine if a shallow vertical tillage practice was sufficient to minimize P, N and atrazine loading from long-term no-tillage fields in a corn-soybean rotation, while maintaining minimal erosion. Rainfall simulations (average intensity of 53mmh−1) were performed on no-tillage and vertical tillage plots (5×1m) sufficient to produce 30min of runoff. Runoff was collected every 2.5min, and analyzed for sediment and nutrients (NH4–N, NO3–N, total Kjehldahl N (TKN), SP and TP). Runoff was delayed by 17min using vertical tillage; however, the steady-state rate of runoff was significantly greater from vertical tillage compared to no-tillage. There were no significant differences for N from runoff (NH4–N, NO3–N, or TKN). There was a trend of slightly higher SP loads from vertical tillage than no-tillage. Total P losses were correlated with sediment, and were observed to be higher from vertical tillage than no-tillage. The primary advantage that vertical tillage has with respect to nutrient losses is in delaying runoff initiation, however this effect could be nullified in subsequent runoff events. If P loading to surface waters is the primary concern, it would appear from the data presented in this study that vertical tillage may not be an appropriate practice, and in fact may impose greater risks due to greater erosion and associated TP losses.


The size of the harmful algal blooms in western Lake Erie is strongly correlated with agricultural phosphorus (P) loading from tributaries. Despite farmers’ efforts to reduce sediment-bound P loadings and fertilize using current guidance, the media and public have singled them out as the culprit in Lake Erie re-eutrophication. In this paper, two farmer surveys were used to evaluate if farmers in the Lake Erie region follow P fertilizer recommendations, and we also review historic and current P management guidance provided by the scientific community and agricultural industry. The majority (56% to 80%) of farmers apply P fertilizers at or below the current fertility recommendations. Wholesale agronomic changes (e.g., no-tillage adoption, crop cultivar advances, and fertilizer application and formulation) have occurred since current fertilizer recommendations were developed. Although crop P uptake mechanisms have not changed, these agronomic changes have altered P cycling in soil and water. Based on these results, it is time that the scientific community and agricultural industry acknowledge that our current guidance may be contributing to eutrophication. We must ask whether or not we have (1) developed appropriate fertility guidance, (2) developed and recommended appropriate practices to protect water quality, (3) adequately considered “the law of unintended consequences” in conservation recommendations, and (4) focused too much on short-term economic outcomes while disregarding environmental quality. Improved understanding, reconsideration of traditional recommendations, and wider farmer adoption of the most effective practices are needed to develop a sustainable agricultural system in the Western Lake Erie Basin that
produces needed commodities while preserving ecosystem integrity.

As animal manure is primarily disposed of on cropland and used as a beneficial soil amendment, the time available for disposal is limited by periods of crop growth as well as climate and soil conditions. Winter has historically been a convenient time for farmers to apply manure as the fields lay fallow and equipment can safely drive on frozen soil without fear of compacting soil or bogging down. However, it is widely recognized that applying manure to hard packed surfaces (such as frozen ground) can increase the risk for bulk runoff of manure as well as the nutrients and pathogens contained within, particularly during periods of high runoff such as spring thaw. At its heart, this is a risk management issue that needs detailed investigation of risk factors in order to assess potential dangers. The urgency for new science concerning winter manure application is increasing because of the potential links to an observed increase of cyanobacteria in the Great Lakes and other vulnerable water bodies. In order to address these issues under controlled conditions, a suite of laboratory studies investigating several parameters key to quantifying the fate associated with winter manure application events are underway, including Runoff relation to snow pack at thaw events for winter/fall manured soils, runoff relation to soil moisture content prior to thaw events for winter/fall manured soils, the effect of macropores, associated with no till management strategies, on nutrient movement during freeze-thaw events for winter/fall manured soils and nutrient movement at the root zone of cover crops under multiple freeze/thaw cycles for fall manured soils.

Cultural eutrophication has become the primary water quality issue for most of the freshwater and coastal marine ecosystems in the world. However, despite extensive research during the past four to five decades, many key questions in eutrophication science remain unanswered. Much is yet to be understood concerning the interactions that can occur between nutrients and ecosystem stability: whether they are stable or not, alternate states pose important complexities for the management of aquatic resources. Evidence is also mounting rapidly that nutrients strongly influence the fate and effects of other non-nutrient contaminants, including pathogens. In addition, it will be important to resolve ongoing debates about the optimal design of nutrient loading controls as a water quality management strategy for estuarine and coastal marine ecosystems. © 2009 Elsevier Ltd. All rights reserved.

This paper assesses the impact of nutrient prices on nutrient concentrations in agricultural
watersheds. Specifically, we find that the price elasticity of nutrient emissions from agricultural watersheds is -0.17 to -0.34, suggesting that a 10% increase in nitrogen or phosphorus prices faced by farmers would lead to up to a 3.4% reduction in nitrogen or phosphorus emissions from a watershed. While this sounds modest, it is about the same size as estimates of the price elasticity of nutrient demand by farmers, a relationship which also is very inelastic. Our results suggest that when prices for nutrients rise, there is a direct effect on nutrient emissions from watersheds. Given recent concerns about phosphorus in Lake Erie, we assess the potential implications of applying a phosphorus usage fee to reduce phosphorus emissions there. We find that a 25% increase in phosphorus prices would reduce nutrient outputs from the three Lake Erie watersheds we modelled by 6.5%, or 210t phosphorus per year, and cost about $6ha-1yr-1. These costs are similar to estimates of the costs of reducing phosphorus through waste water treatment plants, and less than the costs of other widely used agricultural best management practices like cover crops.


“How much conservation is enough?” is one of the most important and difficult questions to answer. In this work, we demonstrate an approach to specifically answer this question for conservation strategies designed to address nonpoint source pollution in agriculturally-dominated watersheds. We developed empirical models relating conservation investments and actions to measures of stream water quality and fish community health. Our results are consistent with other studies that demonstrate a need for extensive implementation of conservation practices in agricultural landscapes to see measurable improvements in ecological conditions. Our results also demonstrate the influence spatial grain can have on answering “how much conservation is enough?” Our coarse-grained analyses suggest that water quality in at the outlets of four watersheds could be improved to the point that water quality was no longer limiting the fish community with only about 18% of the agricultural lands treated with conservation practices and incentive payments totaling $7.7M. Yet, finer-grained subbasin analyses predict fish communities would still be limited in many tributaries of these watersheds even with ~50% of lands treated and incentive payments totaling ~$44M. Consequently, coarse-grained analyses could significantly underestimate scope of the solution needed to address these impacts to stream ecosystems. Finding balanced solutions to address agricultural nonpoint source pollution throughout the Great Lakes will require unprecedented collaboration from local to regional scales. Herein, we provide examples of how this work is supporting collaborative efforts to establish realistic ecological goals and associated performance measures and strategic implementation of practices throughout the Saginaw Bay drainage.


Cultural eutrophication of the Great Lakes resulted in actions to reduce phosphorus loading beginning in the 1970’s. Despite these measures, a resurgence of harmful algae blooms began in the 1990s. Non-point sources and changing agricultural practices are frequently
cited as contributing to this resurgence. We examined changes in total phosphorus concentrations ([TP]) and several other water quality parameters from April through November from 1979 to 2011 using 56 streams throughout Ontario, including agricultural, undeveloped, urban, and mixed-use watersheds. Growing season median [TP] was not significantly different among stream types, but decreased in 32 of the 56 sites; only one urban site increased. There were weak differences among land uses; mixed sites typically had the highest [TP] and steepest declines. Soluble reactive P concentration [SRP] decreased at 12 sites, and increased at one agricultural and three urban sites. Where trends were significant, suspended solids typically decreased, while [Cl–] and alkalinity typically increased. As adequate winter data were not available and there may have been changes in the seasonal distribution of high flow during the period we studied, the changes we observed in median growing season [TP] may not reflect changes in loading. However, seasonal discharge trends were not significant except for one site with a decreasing trend in spring discharge. Possible mechanisms for pervasive downward trends in TP include improved rural and urban land use practices, reduced acid precipitation, increased nitrogen availability in terrestrial ecosystems, and ongoing forest regrowth after initial clear-cutting.


The Laurentian Great Lakes are among the most prominent sources of fresh water in the world. Lake Erie’s infamous cyanobacterial blooms have, however, threatened the health of this valuable freshwater resource for decades. Toxic blooms dominated by the cyanobacterium *Microcystis aeruginosa* have most recently been one of primary ecological concerns for the lake. These toxic blooms impact the availability of potable water, as well as public health and revenues from the tourism and fishery industries. The socioeconomic effects of these blooms have spurred research efforts to pinpoint factors that drive bloom events. Despite decades of research and mitigation efforts, these blooms have expanded both in size and duration in recent years. However, through continued joint efforts between the Canadian and United States governments, scientists, and environmental managers, identification of the factors that drive bloom events is within reach. This review provides a summary of historical and contemporary research efforts in the realm of Lake Erie’s harmful cyanobacterial blooms, both in terms of experimental and management achievements and insufficiencies, as well as future directions on the horizon for the lake’s research community. © 2014 Elsevier B.V.


Agriculture has long been regarded as a major contributor to wildlife habitat despoliation, soil degradation, and downstream watercourse pollution. It would be possible to largely eliminate natural resource degeneration through judicious application of on-farm conservation practices. Farmers have little economic incentive to conserve because, according to previous research, most conservation techniques have been demonstrated to be unprofitable. The empirical research into three alternative types of conservation practices for this study confirms that two (conservation crops and riparian buffer strips) provide for net costs to farmers, and that the third (conservation soil tillage) is not profitable under all
circumstances. At the same time, the research shows that two out of the three sets of practices, namely riparian buffer strips and conservation tillage, can be economically beneficial to society as a whole. This raises the question of whether and to what extent society, as economic gainers, should offer compensation to farmers as economic losers. This study furthermore establishes that not all conservation practices that result in reduced soil erosion will lead to decreased sediment and phosphorus loadings into watercourses; that not all reduced sediment and phosphorus loadings lead to improved water quality; and that, even where an improvement to water quality in chemical, physical, biological and aesthetic terms can be obtained, the costs to society of achieving improvement may exceed the economic benefits. Such outcomes can readily promote disagreements between environmentalists and ecologists on the one hand and socio-economists on the other. (C) 1999 John Wiley & Sons, Ltd. Source: WOS


Cyanobacterial blooms in western Lake Erie have recently garnered widespread attention. Current evidence indicates that a major source of the nutrients that fuel these blooms is the Maumee River. We applied a seasonal trend decomposition technique to examine long-term and seasonal changes in Maumee River discharge and nutrient concentrations and loads. Our results indicate similar long-term increases in both regional precipitation and Maumee River discharge (1975-2013), although changes in the seasonal cycles are less pronounced. Total and dissolved phosphorus concentrations declined from the 1970s into the 1990s; since then, total phosphorus concentrations have been relatively stable, while dissolved phosphorus concentrations have increased. However, both total and dissolved phosphorus loads have increased since the 1990s because of the Maumee River discharge increases. Total nitrogen and nitrate concentrations and loads exhibited patterns that were almost the reverse of those of phosphorus, with increases into the 1990s and decreases since then. Seasonal changes in concentrations and loads were also apparent with increases since approximately 1990 in March phosphorus concentrations and loads. These documented changes in phosphorus, nitrogen, and suspended solids likely reflect changing land-use practices. Knowledge of these patterns should facilitate efforts to better manage ongoing eutrophication problems in western Lake Erie.


Nitrate (NO₃⁻) loss from intensively farmed cropland is a long-standing, recalcitrant environmental problem that contributes to surface and groundwater pollution and coastal zone hypoxia. Here nitrate leaching losses are reported from nine replicated cropped and unmanaged ecosystems in southwest Michigan, USA. Ecosystems include four annual corn-soybean-winter wheat rotations under conventional, no-till, reduced-input, and organic/biologically-based management, two perennial cropping systems that include alfalfa and hybrid poplar trees, and three unmanaged successional communities including an early successional community analogous to a cellulosic biofuel system as well as a mature
deciduous forest. The organic, alfalfa, and unmanaged systems received no synthetic, manure, or compost nitrogen. Measured nitrate concentrations were combined with modeled soil water drainage to provide estimates of nitrate lost by leaching over 11 years. Among annual crops, average nitrate losses differed significantly (p<0.05) and followed the order conventional (62.3±9.5kgN/ha -1yr -1)>no-till (41.3±3.0)>reduced-input (24.3±0.7)>organic (19.0±0.8) management. Among perennial and unmanaged ecosystems, nitrate loss followed the pattern alfalfa (12.8±1.8kgN/ha -1yr -1)>deciduous forest (11.0±4.2)>early successional (1.1±0.4)=mid-successional (0.9±0.4)>poplar (<0.01±0.007kgN/ha -1yr -1) systems. Findings suggest that nitrate loss in annual row crops could be significantly mitigated by the adoption of no-till, cover crops, and greater reliance on biologically based inputs, and in biofuel systems by the production of cellulosic rather than grain-based feedstocks. © 2011 Elsevier B.V.


Corn management practices, incorporating annual ryegrass intercrop, conservation tillage and water table management, were evaluated to reduce herbicide and NO-3 losses through surface runoff and tile drainage. The integrated management system being developed at Harrow in S.W. Ontario reduced herbicide input 50% by banding the chemical over the seed row. Runoff events close to herbicide application contained high concentrations of atrazine, metribuzin and metolachlor. However, the volume of runoff was low during the 1991 growing season, therefore herbicide loss was low (<2% of applied). The three herbicides rapidly dissipated in the soil so that subsequent runoff events transported little herbicide in the runoff water. The total quantity of de-ethyl atrazine loss was lower from soil saver than moldboard plow. No water table control or intercrop effects were found in 1991 for herbicide loss because of the drought. Tile drainage resulted in a greater volume of water and loss of NO-3 than with surface runoff. Consequently, over 97% of the total NO-3 loss occurred through tile drainage. The flow weighted NO-3 concentration in tile drainage water was 22.5 mg N L-1 for the drainage treatments and 15.1 mg N L-1 for the water table control treatments from Nov. 1, 1991 till April 30, 1992. During this time period, NO-3 loss through tile drainage was 57.8 kg N ha-1 from the drainage treatments and 36.3 kg N ha-1 from the water table control treatments. Therefore, the water table control treatment reduced the flow weighted NO-3 concentration in tile drainage water by 33% and total NO-3 loss by 37%. The water table control treatments combined with soil saver tillage resulted in lower concentrations and losses of NO-3 than with any other treatments.


Effectiveness of manure addition and closed-loop water recycling with controlled drainage/sub-irrigation on water quality and crop production were evaluated between 2008
and 2011. Over 50% of farm lands in the Great Lakes region are tile drained. However, the agronomic and environmental effectiveness of tile drainage (TD) options can differ with nutrient management. A study was conducted to determine the impacts of organic fertilizer (i.e. solid and liquid cattle manures) vs. inorganic fertilizer (IF) on crop productivity and nutrient movement under free drainage and water table control systems in a corn-soybean rotation. Four separate reservoirs and water recycling system were used to maintain desired water table control. All treatments were added with same amounts of P and crop available N, except for the P draw-down (PDD) where only N was added. Results from the first rotation cycle showed that the IF control and PDD had the greatest corn yields. The liquid cattle manure (LCM) had the lowest corn yields. The solid cattle manure (SCM) had much higher corn yields than LCM, but slightly lower value than IF control and PDD. It was noticed that there were no differences in soybean yields for all the treatments. However, the LCM organic fertilizer treatments had the lowest total cumulative nutrient loss. The PDD inorganic fertilizer treatments had the highest total nutrient loss followed by IF control inorganic treatments. The SCM organic fertilizer treatments had a similar high nutrient loss as IF control inorganic treatments. The controlled drainage with sub-irrigation recycling system reduced total cumulative nutrient loss by 24 to 37% relative to traditional free drainage system. This study must be continued to provide valuable knowledge for accessing the long-term cumulative effects of organic manure addition compare with inorganic fertilizer under traditional free drainage and innovative water table recycling management system on crop productivity and water quality.


Human activities have transformed the landscape and altered geochemical pathways through intensive land uses such as agriculture and urbanization. This study quantified the individual and cumulative influence of land-use drivers on nutrient concentrations for 29 Ontario tributaries flowing to Lake Erie and Lake Huron. For each watershed, measures of agriculture, urbanization and population served by municipal sewage treatment plants were quantified at multiple spatial scales; stream-water nutrients (nitrogen, N, and phosphorus, P) were sampled on 10 occasions between May and November 2012, and were also compiled from government records for concurrent (2012) and prior (2007, 2008, 2011) years. Application of ordinary least squares regression analysis showed that in 2012, concentrations of N and P (total as well as dissolved forms) were primarily driven by sewage treatment and urban activity, with agricultural activity as a secondary influence on variability. Evaluation of model predictive performance under scenarios of varying climate (wet, dry and “normal” conditions) and spatial coverage (i.e. broader than the original sampling sites) showed that stream nitrogen concentrations could be predicted, on average, 36–85% of the time; phosphorus forms were, however, not successfully predicted, likely due to differences in sampling frequency relative to runoff events. The finding that both urban and agricultural land-use activities influence nutrient concentrations in Canadian tributaries to lakes Erie and Huron underscores the need to reduce both point and non-point inputs in order to mitigate eutrophication of downstream lakes.

155. U.S. Department of Agriculture, N. R. C. S. (2016). *Effects of Conservation Practice Adoption on Cultivated Cropland Acres in Western Lake Erie Basin, 2003-06 and 2012*. Farmers maintained conservation practices, cropland acreage, and crop mixes despite higher commodity prices. Between the 2003-06 and the 2012 CEAP surveys, average corn prices nearly tripled, rising to $6.67 per bushel, and average soybean prices nearly doubled, rising to $13.24 per bushel. Despite these increases, cultivated cropland acreage and crop mixes did not change significantly between the two surveys. Average annual phosphorus application rates decreased from 21.5 pounds per acre in 2003-06 to 18.7 pounds in 2012. In addition, application methods that reduce the risk of phosphorus runoff and leaching losses increased from being in use on 45 percent of acres to being in use on 60 percent of acres, and edge-of-field trapping practices that reduce runoff losses, such as filter strips, increased from being in use on 18 percent of acres to being in use on 31 percent of acres. The cost of conservation practices in place represents a significant annual investment. Using NRCS conservation practice cost data, the costs of reported conservation practices were estimated for recognized NRCS practices, regardless of whether the practice was funded through federal or state programs, through local initiatives, or by producers. Practices reported in the CEAP-1 survey (2003-06), represented a $208 million annual investment in conservation; an average of 1.8 practices were applied per acre, at an average annual cost of $43.39 per acre. The 2012 CEAP survey indicates the regional investment in conservation increased by nearly $69 million since the CEAP-1 survey, to a total annual investment of $277 million. The average number of practices adopted per acre increased to 2.36, with an annual investment of $56.98 per acre. Voluntary conservation is making significant headway in reducing nutrient and sediment losses from farm fields. Compared to a scenario simulating the removal of all conservation practices in WLEB, conservation practices in use in 2012 reduce annual sediment losses by 81 percent (9.1 million tons per year), reduce total nitrogen losses by 36 percent (40.6 million pounds per year), and reduce total phosphorus losses by 75 percent (11.4 million pounds per year). In the 2012 conservation condition, harvested crops remove an average of 16.3 pounds of phosphorus per acre per year, which is 87 percent of the average phosphorus applied per acre annually (18.7 pounds). Simulations suggest average annual total phosphorus loss is 1.9 pounds per acre with 1.3 …


Phosphorus (P) export from agriculture fields is contributing to algal blooms within Lake Erie. Field data quantifying the magnitude, timing and pathways of P loss are required to
develop and test solutions. This study quantifies annual and seasonal losses of dissolved (DRP) and total (TP) phosphorus in surface runoff and tile drainage from three reduced tillage fields (October 2011 to April 2013). The non-growing season (NGS, October to April) was a critical period, with 83 to 97% of annual combined [surface + tile] runoff; 84 to 100% of DRP loss; 67 to 98% of TP loss occurring in this time. Annual export (May 2012 to April 2013) ranged from 0.332 to 0.419 kg TP/ha/yr and 0.034 to 0.096 kg DRP/ha/yr. Tile drainage contributed the majority of annual water export from fields (78 to 90%) whereas surface runoff contributed little (10 to 22%). Tiles exported 0.169 to 0.255 kg TP/ha/yr (40 to 77% of total TP load) and 0.017 to 0.023 kg DRP/ha/yr (19 to 67% of total DRP load). Thus, surface runoff, which primarily occurred during winter thaws, exported disproportionately more P relative to its contribution to flow. Phosphorus losses in tile drain effluent monitored over an additional NGS (October 2011 to April 2012) were elevated at two sites following the fall application of P. This study provides an improved understanding of edge-of-field P losses in humid, cold temperate regions that experience significant winter periods, and provides estimates of P loads from fields in which P conservation strategies are employed.


Since the mid-1990s, Lake Erie has experienced re-eutrophication symptoms including harmful algal blooms in the western basin and summer hypoxia in the Central Basin. The 2012 Protocol for the Great Lakes Water Quality Agreement (GLWQA) required phosphorus objectives and management recommendations to be set for all the Great Lakes, beginning with Lake Erie. To inform setting revised loading targets for the Lake Erie portion of the GLWQA, modeling was performed. The development and application of one of those models, the Western Lake Erie Ecosystem Model (WLEEM), is described here. WLEEM is a three dimensional, fine-scale, process-based model that links hydrodynamic, sediment transport, and in-lake biogeochemical and ecological processes. WLEEM was applied here to assess system sensitivity to a range of variables, and ultimately to develop a robust phosphorus load — cyanobacteria response relationship to determine a maximum load of total phosphorus from the Maumee River during the period of March–July that would produce a mild cyanobacteria bloom (< 7830 MT cyanobacteria biomass) in Western Lake Erie. The maximum total phosphorus load from the Maumee River for that period to produce a mild bloom was determined to be 890 metric tons. Given the natural variability of systems like this, tools like WLEEM used in a dynamic operational modeling mode, consistent tributary and lake monitoring, and ongoing research will be essential components of effective mitigation and science-based adaptive management of eutrophication in Lake Erie and other nutrient-impacted water bodies.


This study aims at understanding the impacts of projected climate change on the
For Research Purposes Only ........................................Not for Publication.

hydrological processes within the Maumee River watershed (16395 km²) lying in the Lake Erie Basin using soil and water assessment tool (SWAT). The model was calibrated and validated for a baseline time-period of 1995-2005. Downscaled ensemble projected temperature and precipitation data from three general circulation models (GCMs) was then used to assess future flow, sediment, and nutrient loading in the watershed for mid-century (2045-2055) and late-century (2089-2099) time periods. Compared to the baseline, a 2.9°C rise in the annual average temperature along with a 3.2% fall in the annual precipitation in the mid-century time-period is projected to reduce annual flow volumes, and suspended solids (SS), total phosphorus (TP), nitrate (NO₃) loads by 8.5, 10.4, 8.5, and 9.9%, respectively. Similarly, for the late-century a 4.3°C rise in the annual average temperature along with a 5.6% rise in the annual precipitation is projected to increase annual flow volumes, and SS, TP, NO₃ loads by 9.7, 19.6, 3.5, and 6.8%, respectively. Temporal shifts in climatic conditions were also projected for both the future time-periods with higher temperatures throughout the year along with wetter winters and drier summers. Implications of these changes would include the need for an increased focus on pollutant loadings for total maximum daily load guidelines and possible lengthening of crop growing cycles.


Biogeochemical and hydrological processes in riparian zones regulate contaminant movement to receiving waters and often mitigate the impact of upland sources of contaminants on water quality. These heterogeneous processes have recently been conceptualized as “hot spots and moments” of retention, degradation, or production. Nevertheless, studies investigating the importance of hot phenomena (spots and moments) in riparian zones have thus far largely focused on nitrogen (N) despite compelling evidence that a variety of elements, chemicals, and particulate contaminant cycles are subject to the influence of both biogeochemical and transport hot spots and moments. In addition to N, this review summarizes current knowledge for phosphorus, organic matter, pesticides, and mercury across riparian zones, identifies variables controlling the occurrence and magnitude of hot phenomena in riparian zones for these contaminants, and discusses the implications for riparian zone management of recognizing the importance of hot phenomena in annual solute budgets at the watershed scale. Examples are presented to show that biogeochemical process-driven hot spots and moments occur along the stream / riparian zone / upland interface for a wide variety of constituents. A basic understanding of the possible co-occurrence of hot spots and moments for a variety of contaminants in riparian systems will increase our understanding of the influence of riparian zones on water quality and guide management strategies to enhance nutrient or pollutant removal at the landscape scale. © 2010 American Water Resources Association.


Harmful algal blooms in the Western Lake Erie Basin (WLEB) can be considered a wicked
problem—there are conflicting interpretations of the problem and science, stakeholders have different values and goals, and there is no definitive solution. This paper provides an overview and lessons learned of how one set of diverse stakeholders worked together to initiate a voluntary 4R Nutrient Stewardship Certification Program to address the wicked problem in the WLEB. 4R Nutrient Stewardship (Right rate, Right time, Right place, and Right source) provides the foundation for a science-based framework that achieves sustainable plant nutrition management while considering the environment, society, and economics. The 4R Certification Program ensures a third-party auditor objectively evaluates the nutrient service providers’ implementation of the 41 criteria of the program that encompass education, recordkeeping, nutrient recommendations, and applications. While the environmental impact of 4R Certification Program adoption is being evaluated currently, implementing the 4Rs has been identified as a key step to improving water quality. In two years, the 4R Certification Program has influenced nearly 40% of WLEB’s farmland through the 30 4R certified providers. While any single organization could have created a nutrient management program, it would not have been as robust, as practical, or as accepted as the one created by the broad group of stakeholders involved with the WLEB 4R Advisory Committee. The rigor, structure, governance, and credibility of the 4R Certification Program make it a top candidate to act in other regions with wicked problems related to nutrient management.


The Soil and Water Assessment Tool with downscaled weather data generated using the MarkSim weather file generator was used to evaluate the impact of long-term conservation practice implementation on runoff, sediment, atrazine, nitrogen (N) and phosphorus (P) losses in an agricultural watershed located in northeastern Indiana. As part of the Conservation Effects Assessment Project, evaluation of these conservation practices is required to provide insight on how their implementation is benefiting the environment. The results indicate that individual conservation practices were effective in reducing a particular pollutant load, but combined practices were more effective in reducing multiple pollutant loads simultaneously. Of the individual best management practices (BMPs) assessed, no-till was the most effective in reducing multiple pollutant loads (reduced surface runoff by an average of 25%, sediment by 46%, atrazine by 46%, total N by 9%, soluble P by 16%, and total P by 29%). When BMPs were combined, pollutant load reductions were increased significantly (at α=0.05) for all pollutants, both under baseline and future climate scenarios. The reductions in runoff and pollutant loads for each decade of future climate ranged from 15 to 25% for surface runoff, 32–68% for sediment loss, 37–60% for atrazine loss, 5–13% for soluble N loss, 12–35% for total N loss, 9–41% for soluble P loss, and 33–60% for total P loss.


Forms (e.g., liquid and solid) of manure influence the risk of P loss after land application.
The objective of this study was to investigate the effects of P-based application of various forms of cattle manure (liquid, LCM; or solid, SCM) or inorganic P as triple superphosphate (IP) on soil P losses in tile drainage water. A 4-yr field experiment was conducted in a clay loam soil with a corn (Zea mays L.)-soybean [Glycine max (L.) Merr.] rotation in the Lake Erie basin. Over the 4 yr, the dissolved reactive P (DRP) flow-weighted mean concentration (FWMC) in tile drainage water was greater under SCM fertilization than under either IP or LCM fertilization. Despite its lower value on an annual basis, DRP FWMC rose dramatically immediately after LCM application. However, the differences in DRP FWMC did not result in detectable differences in DRP loads. Regarding particulate P and total P losses during the 4 yr, they were 68 and 47%, respectively, lower in the soils amended with SCM than in those with IP, whereas both values were similar between IP and LCM treatments. Overall, the P contained in solid cattle manure was less prone to P loss after land application. Accordingly, the present results can provide a basis for manure storage and application of best management practices designed to reduce P losses and improve crop growth.


Useful in evaluating best management practices and nutrient management planning, the prediction of phosphorus (P) transfer from agricultural lands to water bodies via surface runoff and tile drainage remains as a challenge, as few models can provide reasonably accurate P loss simulations. The EPIC (Environmental Policy Integrated Climate) model was firstly applied to simulate crop yields, surface runoff, tile drainage, and dissolved reactive P (DRP) losses under a corn-soybean rotation grown on a “cracking” Brookston clay loam soil (Vertisol) in the Lake Erie basin, Ontario, Canada. Different potential evapotranspiration and curve number equations were compared to determine the most suitable equations (Penman-Monteith equation and variable Daily Curve Number with soil moisture index) for this region. A crack flow coefficient was used to deal with inflow partitioned to cracks. A soil layer below tile drain with low saturated hydraulic conductivity was employed in simulating the experimental site, where most water was leaving the field through tile drain. Lateral subsurface flow was used to substitute for drainage. Annual simulations of crop grain yield, cumulative surface runoff, and cumulative drainage closely matched observed data. Over shorter periods (months), surface runoff (NSE = 0.78), tile drainage (NSE = 0.57), and relevant DRP loss (NSE > 0.5) simulations were satisfactory, except for two periods of DRP loss in surface runoff, where most DRP moved downward through lateral flow and deep percolation due to limitations in the crack flow coefficient.

For this vertic soil, EPIC generally simulated crop yields and flow volumes well, while DRP losses were only adequately simulated.


Lake Erie supplies drinking water to more than 11 million consumers, processes millions of gallons of wastewater, provides important species habitat and supports a substantial
industrial sector, with >$50 billion annual income to tourism, recreational boating, shipping, fisheries, and other industries. These and other key ecosystem services are currently threatened by an excess supply of nutrients, manifested in particular by increases in the magnitude and extent of harmful planktonic and benthic algal blooms (HABs) and hypoxia. Widespread concern for this important international waterbody has been manifested in a strong focus of scientific and public material on the subject, and commitments for Canada-US remedial actions in recent agreements among Federal, Provincial and State agencies. This review provides a retrospective synthesis of past and current nutrient inputs, impairments by planktonic and benthic HABs and hypoxia, modelling and Best Management Practices in the Lake Erie basin. The results demonstrate that phosphorus reduction is of primary importance, but the effects of climate, nitrogen and other factors should also be considered in the context of adaptive management. Actions to reduce nutrient levels by targeted Best Management Practices will likely need to be tailored for soil types, topography, and farming practices.


The Phosphorus (P) Index is a widely used tool for assessing the vulnerability of agricultural fields to P loss. This study is focused on the Ohio P Index, which was developed in the mid-1990s and has yet to be evaluated or revised. The objective of the study was to complete a stochastic sensitivity analysis of the Ohio P Index in order to determine the input variables to which the P Index score is most sensitive and identify variables for which future research and development are needed. Input variable probability distributions were created using the best available data from five agricultural watersheds in Ohio. Monte Carlo simulation was then used to generate 10,000 iterations of the P Index score based on the input variable probability distributions for each watershed. Results showed that three variables (connectivity to water, runoff class, soil-test P) explained 78% to 81% of the variance in the P Index score. Phosphorus application rate, P application method, soil erosion, and filter strip variables each explained <10% of the variability. Findings suggest that the structure of the Ohio P Index may not accurately account for the interrelationship between source and transport variables, and current input variable weightings may not provide any incentive for producers to modify management practices. Differences in input variable sensitivities among watersheds also suggest that a watershed P Index, rather than a statewide P Index, may yield better predictions of a field’s risk of P loss by placing an emphasis on variables and practices that are relevant in individual watersheds. To increase the predictive capability of the Ohio P Index, it is recommended that (1) the structure of the P Index be changed from additive to multiplicative, (2) input variable weights be re-evaluated to ensure that implementation of management practices is accurately reflected in the P Index score, and (3) additional input variables, including subsurface drainage, be considered for inclusion in the P Index.

Understanding the processes controlling nutrient delivery in headwater agricultural watersheds is essential for predicting and mitigating eutrophication and harmful algal blooms in receiving surface waters. The objective of this study was to elucidate nutrient transport pathways and examine key components driving nutrient delivery processes during storm events in four nested agricultural watersheds (298–19,341 ha) in the western Lake Erie basin with poorly drained soils and an extensive artificial drainage network typical of the Midwestern U.S. Concentration-discharge hysteresis patterns of nitrate-nitrogen (NO3-N), dissolved reactive phosphorus (DRP), and particulate phosphorus (PP) occurring during 47 storm events over a 6 year period (2004–2009) were evaluated. An assessment of the factors producing nutrient hysteresis was completed following a factor analysis on a suite of measured environmental variables representing the fluvial and wider watershed conditions prior to, and during the monitored storm events. Results showed the artificial drainage network (i.e., surface tile inlets and subsurface tile drains) in these watersheds was the primary flow pathway for nutrient delivery to streams, but nutrient behavior and export during storm events was regulated by the flow paths to and the intensity of the drainage network, the availability of nutrients, and the relative contributions of upland and in-stream nutrient sources. Potential sources and flow pathways for transport varied among NO3-N, PP, and DRP with results underscoring the challenge of mitigating nutrient loss in these watersheds. Conservation practices addressing both nutrient management and hydrologic connectivity will likely be required to decrease nutrient loss in artificially drained landscapes.


Significant reductions in phosphorous (P) inputs from cropland are needed to address the re-
eutrophication of Lake Erie. Previous studies aimed at addressing non-point source pollution have primarily analyzed the effectiveness of conservation practices (CPs) as land-management strategies. However, the effectiveness and efficiency of these practices have not been compared to those of possible land-use changes. We develop a spatially explicit integrated modeling approach that compares the effectiveness and economic efficiency of alternative spatially optimal land-use and -management strategies for P abatement in the Sandusky River watershed. Using the Soil and Water Assessment Tool and data on costs and profits from crop and forest production and urban development, we evaluated joint impacts on P reduction and economic-returns for optimized land-use changes and/or implementation of CPs in the watershed. Results showed a combination of both CPs and land-use changes are likely required to meet current abatement targets for dissolved reactive phosphorus. Additionally, the combination of these approaches can generate a positive, synergistic effect on economic efficiency in meeting key policy targets. This is largely because the combined strategy will establish CPs on the most productive cropland, while achieving greater nutrient reduction through land-use change away from corn-soybean rotations on less productive lands.


Beginning in the mid-1990s, re-eutrophication has reemerged as severe problems in Lake Erie. Controlling non-point source (NPS) nutrient pollution from cropland, especially dissolved reactive phosphorus (DRP), is the key to restore water quality in Lake Erie. To address NPS pollution, previous studies have analyzed the effectiveness of alternative spatially optimal land use and management strategies (represented as agricultural conservation practices (CPs)). However, few studies considered both strategies and have analyzed and compared their sensitivity to expected changes in temperature and precipitation due to climate change and increased greenhouse gas concentrations. In this study, we evaluated impacts of climatic change on the economic efficiency of these strategies for DRP abatement, using an integrated modeling approach that includes a watershed model, an economic valuation component, and a spatial optimization model. A series of climate projections representing relatively high greenhouse gas emission scenarios was developed for the western Lake Erie basin to drive the watershed model. We found that performance of solutions optimized for current climate was degraded significantly under projected future climate conditions. In terms of robustness of individual strategies, CPs alone were more robust to climate change than land use change alone or together with CPs, but relying on CPs alone fails to achieve a high (> 71%) DRP reduction target. A combination of CPs and land use changes was required to achieve policy goals for DRP reductions (targeted at ~ 78%). Our results point to the need for future spatial optimization studies and planning to consider adaptive capacity of conservation actions under a changing climate.

Complex watershed simulation models are powerful tools that can help scientists and policy-makers address challenging topics, such as land use management and water security. In the Western Lake Erie Basin (WLEB), complex hydrological models have been applied at various scales to help describe relationships between land use and water, nutrient, and sediment dynamics. This manuscript evaluated the capacity of the current Soil and Water Assessment Tool (SWAT) to predict hydrological and water quality processes within WLEB at the finest resolution watershed boundary unit (NHDPlus) along with the current conditions and conservation scenarios. The process based SWAT model was capable of the fine-scale computation and complex routing used in this project, as indicated by measured data at five gaging stations. The level of detail required for fine-scale spatial simulation made the use of both hard and soft data necessary in model calibration, alongside other model adaptations. Limitations to the model’s predictive capacity were due to a paucity of data in the region at the NHDPlus scale rather than due to SWAT functionality. Results of treatment scenarios demonstrate variable effects of structural practices and nutrient management on sediment and nutrient loss dynamics. Targeting treatment to acres with critical outstanding conservation needs provides the largest return on investment in terms of nutrient loss reduction per dollar spent, relative to treating acres with lower inherent nutrient loss vulnerabilities. Importantly, this research raises considerations about use of models to guide land management decisions at very fine spatial scales. Decision makers using these results should be aware of data limitations that hinder fine-scale model interpretation.


Integrating multiple practices for mitigation of phosphorus (P) loss from soils may enhance the reduction efficiency, but this has not been studied as much as individual ones. A four-year study was conducted to determine the effects of cover crop (CC) (CC vs. no CC, NCC) and drainage water management (DWM) (controlled drainage with sub-irrigation, CDS, vs. regular free tile drainage, RFD) and their interaction on P loss through both surface runoff (SR) and tile drainage (TD) water in a clay loam soil of the Lake Erie region. Cover crop reduced SR flow volume by 32% relative to NCC, regardless of DWM treatment. In contrast, CC increased TD flow volume by 57 and 9.4% with CDS and RFD, respectively, compared to the corresponding DWM treatment with NCC. The total (SR + TD) field water discharge volumes were comparable amongst all the treatments. Cover crop reduced flow-weighted mean (FWM) concentrations of particulate P (PP) by 26% and total P (TP) by 12% in SR, while it didn’t affect the FWM dissolved reactive P (DRP) concentration, regardless of DWM treatments. Compared with RFD, CDS reduced FWM DRP concentration in TD water by 19%, while CC reduced FWM PP and TP concentrations in TD by 21 and 17%, respectively. Total (SR + TD) soil TP loss was the least with CDS-CC followed by RFD-CC, CDS-NCC, and RFD-NCC. Compared with RFD-NCC, currently popular practice in the region, total TP loss was reduced by 23% with CDS-CC. The CDS-CC system can be an effective practice to ultimately mitigate soil P loading to water resource.

Phosphorus loadings from the Maumee River watershed have significantly compromised the Lake Erie ecosystem, as evidenced by the most severe harmful algal bloom in Lake Erie in 2015 and the shut-down of Toledo drinking water supply in 2014. Despite government payments for adoption of voluntary conservation practices, excess nutrient runoff from agricultural production remains a substantial challenge. The right timing of nutrient application is a critical best management practice (BMP). Using a unique survey of 2540 farmer respondents in the Maumee River watershed, this paper analyzes how socio-psychological, socio-demographic, and field-based spatial characteristics impact farmers’ adoption of timing-related best practices for nutrient management, including delaying broadcast application before a storm event, avoiding winter application of nutrients, and avoiding fall application of nutrients. Results reveal three unique classes of farmers for each of the timing-related management decisions. While the significance of most farmer and field characteristics varies across the three BMP adoption decisions, perceived efficacy—the belief that the particular practice will actually reduce dissolved phosphorus runoff from farm fields—is positively correlated with a higher likelihood of adopting each of the BMPs across almost all classes of farmers. For example, results from the ordered logit model suggest that a 20% increase in perceived efficacy would result in the likelihood of actual adoption of delaying broadcast from 35% to 48%. An implication is that policies and outreach efforts aimed at increasing farmers’ perceived efficacy of practices could lead to higher adoption levels, but the effectiveness may vary across different classes of farmers.

# # #

Compiled by J.R. Makuch
5/11/18