April 2010

Ohio Environmental Protection Agency

Division of Surface Water

Ohio Lake Erie Phosphorus Task Force Final Report

Ted Strickland, Governor
Lee Fisher, Lt. Governor
Chris Korleski, Director

Acknowledgements

The Ohio Lake Erie Phosphorus Task Force was comprised of the following members:

- Ohio Farm Bureau Federation – Larry Antosch
- Heidelberg University, National Center for Water Quality Research – Dave Baker, Jack Kramer and R. Peter Richards
- Ohio State University, Environment and Natural Resources – Nick Basta, Libby Dayton
- Ohio State University, College of Biological Sciences – David Culver
- Ohio State University Sea Grant – Jeff Reutter
- Ohio State University Extension – Robert Mullen
- U.S. EPA, Great Lakes National Program Office – Paul Bertram
- University of Toledo – Thomas Bridgeman
- U.S. Geological Survey – Dan Button
- Natural Resource Conservation Service – Steve Davis, Mark Scarpitti
- Ohio Department of Agriculture – Kevin Elder
- U.S. Department of Agriculture, Agriculture Research Service – Norm Fausey
- Conservation Action Project and Henry County SWCD – Todd Hesterman
- Northeast Ohio Regional Sewer District – Seth Hothem
- Ohio Department of Natural Resources, Soil and Water – John Kessler
- Ohio Department of Natural Resources, Wildlife – Roger Knight
- Case Western Reserve University – Gerald Matisoff
- Ohio Lake Erie Office – Chris Riddle
- Ohio Academy of Science/Ohio Fractured Flow Work Group– Julie Weatherington-Rice
- Ohio Environmental Protection Agency, Surface Water – Gail Hesse (Chair), Julie Letterhos and Rick Wilson

Observers

- Eric Partee, Little Miami Inc.
- Joe Logan, Ohio Environmental Council
- Ron Wyss

The Task Force would like to thank all the invited presenters who shared their expertise with the group. Presenters included: Amy Jo Klei, Erin Sherer, Robert Miltner, Randy Bournique and Trinka Mount from Ohio EPA; Dan Mecklenburg and Kirk Hines from ODNR; Kevin King from USDA, Agricultural Research Service; Chris Wible from The Scotts Miracle-Gro Company; Joe DePinto from Limnotech; Robert Bonnett from the Northeast Ohio Regional Sewer District; Jim Stafford and Mike Monnin from NRCS; and John Crumrine from Heidelberg University.

The Task Force would like to thank Bob Heitzman of Ohio EPA for maintaining the Phosphorus Task Force Web site. All presentations, minutes, handouts and other information, including an executive summary of this report, can be found at: *www.epa.ohio.gov/dsw/lakeerie/ptaskforce/index.aspx*.

Finally, the Task Force would like to thank Ohio EPA Director Chris Korleski for sponsoring and supporting the work of the Task Force.

Table of Contents

Appendices

Acronyms

AGNPS	Agricultural Nonpoint Source Pollution Model
ARS	Agricultural Research Service
BMP	Best Management Practice
CAFO	Concentrated Animal Feeding Operation
CAP	Conservation Action Project
CCA	Certified Crop Advisor
CNMP	Comprehensive Nutrient Management Plan
CPPE	Conservation Physical Practice Effects
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
CSO	Combined Sewer Overflow
CSP	Conservation Stewardship Program
DAP	Diammonium Phosphate
DRP	Dissolved Reactive Phosphorus
DSWC	Ohio Department of Natural Resources Division of Soil & Water Conservation
EMC	Event Mean Concentration
EQIP	Environmental Quality Incentives Program
FOTG	Field Office Technical Guide of the USDA NRCS
FWMC	Flow-Weighted Mean Concentration
FSA	Farm Service Agency
GLNPO	Great Lakes National Program Office
GLRI	Great Lakes Restoration Initiative
GLWQA	Great Lakes Water Quality Agreement
GPD	Gallons per Day
HABs	Harmful Algal Blooms
HSTS	Home Sewage Treatment System
HUC	Hydrologic Unit Code
IJC	International Joint Commission
LEB	Lake Erie Basin
LEWMS	Lake Erie Wastewater Management Study
MGD	Million Gallons per Day

MMP	Manure Management Plan or Manure Management Planner
MOU	Memorandum of Understanding
MS4	Municipal Separate Storm Sewer System
MT	Metric Tonnes
MTA	Metric Tonnes per Year
NASS	National Agricultural Statistics Service
NLCD	National Land Cover Data
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service
NURP	National Urban Runoff Program
ODA	Ohio Department of Agriculture
ODNR	Ohio Department of Natural Resources
OEPA	Ohio Environmental Protection Agency
OLICA	Ohio Land Improvement Contractors of America
OSU	The Ohio State University
P	Phosphorus
PCS	Permit Compliance System
PLUARG	Pollution from Land Use Activities Reference Group
PPM	Parts per Million
PWS	Public Water Supply
RDP	Runoff Dissolved Phosphorus (same as DRP)
STP	Soil Test Phosphorus
STRAP	Soil Test Risk Assessment Procedure
SWAT	Soil and Water Assessment Tool (Model)
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSP	Technical Service Provider
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WQ	Water Quality
WWTP	Wastewater Treatment Plant

Glossary

Agricultural Nonpoint Source Model (AGNPS)
A distributed event-based model that simulates surface runoff and sediment and nutrient transport, primarily used for agricultural watersheds

Buffer Strip
An area that is seeded to grass that can be used for filtering pollutants and provide wildlife habitat. They are also called filter strips, filtered areas, field borders, conservation cover and herbaceous riparian cover (shady habitat)

Conservation Tillage/Mulch Tillage
Tillage that breaks up the soil but leaves at least 30% of crop residue from the previous year on the soil surface

Controlled Traffic
Using the same wheel track for field operations to limit soil compaction

Conventional Tillage
Uses moldboard plowing or other intensive tillage that buries all previous year's residue and destroys the natural soil structure

Cover Crops
Used between crop cycles to reduce compaction, recycle nutrients, reduce erosion, improve soil tilth and structure, and fix nitrogen

Diagenesis
The physical and chemical changes occurring in sediments during and after the period of deposition up until the time of consolidation

Flow-weighted Mean Concentration
The sample concentration weighted by both the time and the flow that accompanied it. The FWMC represents the total load for the time period divided by the total discharge for the time period

Interstadial
A warmer subdivision within a glacial stage marking a temporary retreat of the ice

Lateral splitting
The practice of laying additional drainage tiles parallel to existing tiles to create closer spacing and better drainage. Lateral tiles drain into mains

Macropores
Cavities in the soil created by such agents as plant roots, soil cracks or soil fauna such as earthworms. Macropores increase the hydraulic conductivity of the soil, allowing water to infiltrate faster or for shallow groundwater to flow faster.

Manure brokering

Practice of buying/selling excess manure from livestock operations. In the context of this report, it may lead to manure being removed from the watershed where it was created or imported to a watershed where it was not created.

No-Till/Strip-Till/Direct Seed

Planting in the crop residue of the previous year with no soil disturbance

P Index

Modeling tool to assess the risk for runoff of phosphorus from the landscape to a water body

Producer

Farmer

Ridge-Till

Use of specialized equipment builds a ridge where seeds are planted. The ridge is drier and warmer and promotes earlier germination

Rotational Tillage

Practice that alternates no-till with conventional tillage

RTK auto steer

Uses GPS that is programmed to steer the tractor into a particular traffic pattern

Soil and Water Assessment Tool (SWAT)

A river basin scale model developed to quantify the impact of land management practices in large, complex watersheds

Sub-surface mains

The collector tile of sub-surface drainage systems that may consist of a number of connected underground pipes (tiles)

Tile Drainage

Series of underground tiles that are installed on poorly drained soils to improve soil quality and water infiltration, reduce compaction, improve crop yields, and potentially provide a system to control the amount of surface runoff

Tri-State

This refers to the partnership of the university agricultural research departments that set agricultural standards in the tri-state area of Michigan, Ohio and Indiana. The three schools are Michigan State University, the Ohio State University and Purdue University

Water Year

Covers the period from October to September

List of Figures

List of Tables

Section 1 — Introduction

Lake Erie in the 1960s and 1970s was highly eutrophic and subject to extensive algal blooms. The widespread adoption of phosphorus control programs reversed the highly eutrophic conditions and eliminated the algal blooms in Lake Erie by the 1980s. However, in the mid 1990s, blue-green algal blooms began to reappear in the western basin. A particularly massive bloom of *Microcystis aeruginosa* occurred in 2003. In 2006, the benthic mat-forming blue-green alga (cyanobacterium) *Lyngbya wollei* began growing profusely in Maumee Bay and washing up along the shoreline. Both *Microcystis* and *Lyngbya* produce toxins that can be potentially harmful to humans, animals and aquatic life via ingestion or contact. They are some of the species associated with harmful algal blooms (HABs) occurring in many areas around the country. Many shoreline areas around Lake Erie are again experiencing nuisance growths of the green filamentous algae *Cladophora*. Hypoxia/anoxia in the central basin hypolimnion is expanding both spatially and temporally. The increasingly eutrophic conditions may also be impacting the fishery. Walleye and yellow perch populations have been showing long term declining trends since the 1990s, and there has not been a good hatch of walleye since 2003. Coincidental to the increasing degradation of the lake, Heidelberg University's tributary monitoring program noted an increasing trend in dissolved reactive phosphorus (DRP) loads, also beginning in the mid 1990s, despite the fact that total phosphorus loads were not increasing. The increasing DRP was of particular concern because it is almost 100% bioavailable to support algal growth.

In January 2007, in consultation with Heidelberg University, Ohio EPA convened the Ohio Lake Erie Phosphorus Task Force. The goals of the Task Force were: to identify and evaluate potential point and nonpoint sources of phosphorus to Ohio tributaries; determine what practices may have changed since 1995 that could increase DRP loads; examine various aspects of agriculture that might influence the increase in DRP loads; review the possible/probable relationships of the increased DRP loads to the eutrophication problems that have returned to Lake Erie (particularly the western basin); consider the impacts of zebra and quagga mussels in altering the internal cycling of phosphorus in the lake itself; determine if these issues were unique to Lake Erie or occurring on a broader basis; identify research and monitoring needs; and recommend management actions that could be implemented to alleviate current conditions. The Task Force included representatives from state and federal agencies, Lake Erie researchers, soil scientists, agricultural program representatives and wastewater treatment plant personnel. Experts in a variety of disciplines were invited to provide presentations and additional insight into issues beyond the expertise of Task Force members.

This report presents the findings of the Task Force along with recommendations for future management actions for Ohio. A lakewide approach to phosphorus management is currently being pursued as a priority under the Lake Erie Lakewide Management Plan (LaMP). The Task Force has had input into identifying research and monitoring programs currently being funded by the Ohio Lake Erie Protection Fund and U.S. EPA Great Lakes National Program Office to better understand the reasons for the increasing trend in DRP and the connection to the return of blue-green algal blooms and the degradation of the lake.

An executive summary for this report
is available online at
www.epa.ohio.gov/dsw/lakeerie/ptaskforce/index.aspx.

Section 2 — Background

2.1 — An Overview of Historical Phosphorus Control Programs for Lake Erie

In the 1960s excessive growth of the blue-green algae (cyanobacteria) A*nabaena* and *Aphanizomenon,* along with *Microcystis aeruginosa* covered the western basin in late summer and early fall. These blooms caused taste and odor problems in drinking water supplies, stressed the aquatic community and fouled beaches. Extensive growth of the filamentous green alga *Cladophora glomerata* covered shorelines and hard substrates in shallower waters. The decomposition of this excessive algal growth contributed to widespread oxygen depletion in the deeper waters of the central basin. Total phosphorus loads in excess of 25,000 metric tonnes/year were identified as the major cause of the excessive algal growth. The United States and Canada signed the Great Lakes Water Quality Agreement (GLWQA) in 1972 to begin a bi-national effort to reduce phosphorus loads and the degradation of the Great Lakes.

The Federal Clean Water Act of 1972 authorized the U.S. Army Corps of Engineers to conduct the Lake Erie Wastewater Management Study (LEWMS) to set the course for the restoration of the lake (U.S. Army Corps of Engineers 1975). The Corps initiated detailed monitoring programs to accurately determine the total amounts of phosphorus entering the lake, as well as the relative importance of wastewater treatment plant (WWTP) effluents (point sources) versus land runoff (nonpoint sources). Similar monitoring programs were initiated throughout the Great Lakes as part of the International Joint Commission’s Pollution from Land Use Activities Reference Group (PLUARG) studies (International Joint Commission 1978, 1980). Initial programs to reduce phosphorus loading focused on limiting the discharge from WWTPs and eliminating phosphorus in laundry detergents. These sources produced dissolved phosphorus that was nearly 100% bioavailable.

The LEWMS and PLUARG programs used the general approach for quantifying nonpoint source phosphorus contributions that is summarized in Figure 1. The total watershed phosphorus export is measured at the most downstream gauging/monitoring station. The point source inputs upstream of this station are subtracted from the total watershed measurement to get an estimate of the nonpoint source component of the total load. This approach assumes that 100% of the point source phosphorus load entering streams is delivered to the monitoring station, while in reality, this phosphorus is largely assimilated by stream bed materials and biota before it reaches the monitoring station. During subsequent flood events, portions of this material may be re-suspended and deposited on flood plains or washed out into the lake. The procedure shown in Figure 1 thus results in over-estimation of point source contributions to total watershed export and under-estimation of the nonpoint source contributions, but by largely unknown amounts.

In the late 1970s, modeling studies of the relationships among total phosphorus (TP) loading to the lake, concentrations in the lake, algal population densities, and oxygen depletion rates in the central basin led to the establishment of a TP target load for Lake Erie of 11,000 metric tonnes per year (MTA). The models predicted the achievement of this goal would alleviate the problems associated with excessive algal growth. This target was incorporated in the GLWQA. To meet these targets, the GLWQA set a TP limit of 1 mg/L in the effluent from major WWTPs discharging more than 1 million gallons per day (MGD). Further, although not included in the GLWQA, corresponding TP concentration targets were set at 15 µg/L for the western basin and 10 µg/L for the central and eastern basins.

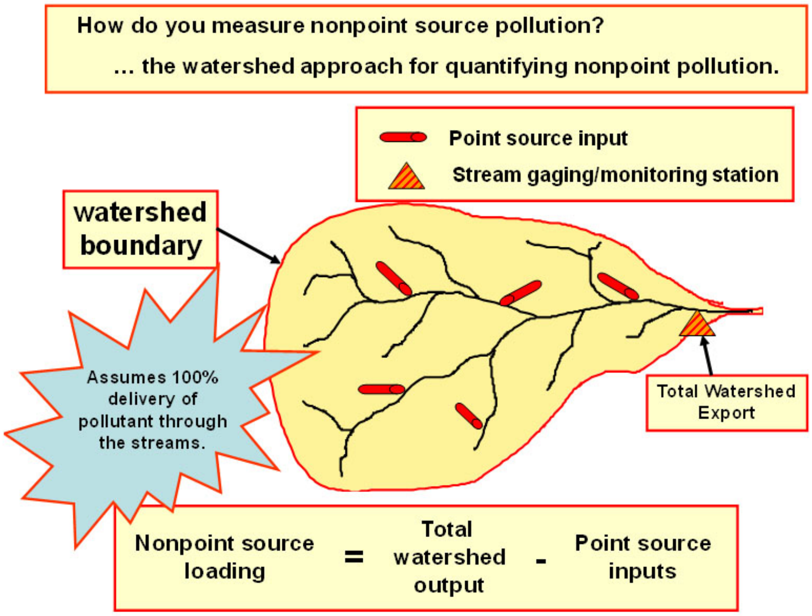


Figure 1 — Conceptual diagram for the procedures used by the IJC to calculate the contributions of phosphorus to the Great Lakes from nonpoint sources. (Graphic produced by David Baker, Heidelberg University)

By 1980, with many of the major WWTPs meeting the 1 mg/L TP limit, agricultural nonpoint sources became the major contributor of phosphorus to Lake Erie (Figure 2). To consistently reach the target load, agricultural nonpoint source loads to the Lake would need to be reduced. Since 75 to 90% of the agricultural phosphorus load was attached to sediment particles, the use of no-till and reduced till conservation practices were promoted (US Army Corps of Engineers, 1979). These measures became the dominant cropping practices in Northwest Ohio through the late 1980s and early 1990s, especially for soybean and wheat production. Increasing use of streamside buffers and set-aside programs for highly erodible land under the Ohio Lake Erie Conservation Reserve Enhancement Program also contributed to reductions in the sediment and associated particulate phosphorus load.

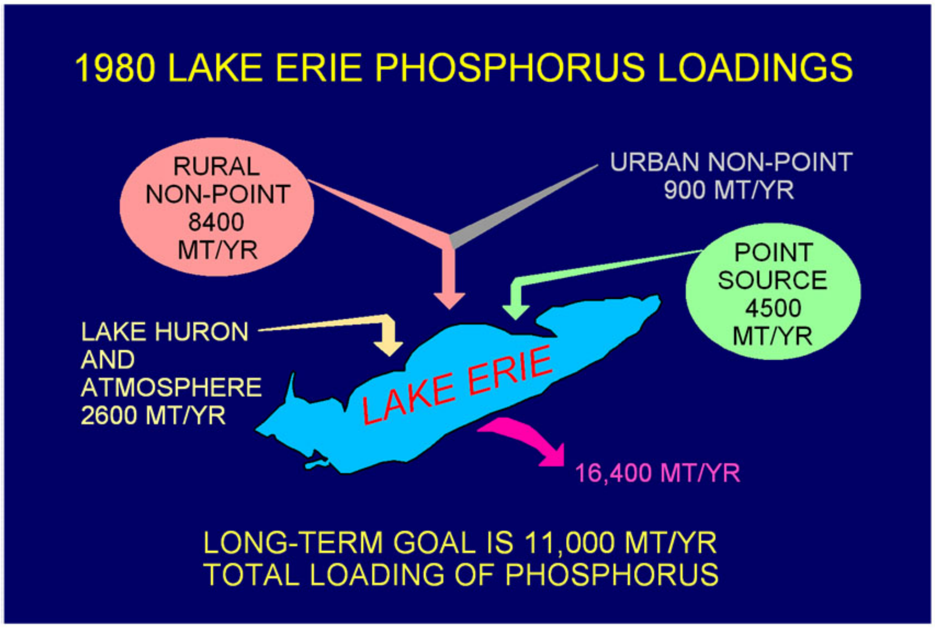


Figure 2 — 1980 mass balance of phosphorus loading to Lake Erie. (U. S. Army Corps of Engineers, 1983)

Figures 3, 4 and 5 show the trends in annual phosphorus loads to Lake Erie. Figure 3 represents the contributions from all sources. Figure 4 depicts the large and rapid reductions in point source loads that occurred in the 1970s as major WWTPs in both the United States and Canada came into compliance with phosphorus effluent limitations of 1 mg/L. Figure 5 shows the large year-to-year variability in the nonpoint source contributions to Lake Erie, reflecting weather-induced (precipitation) influence on river discharges and associated sediment and nutrient loads.

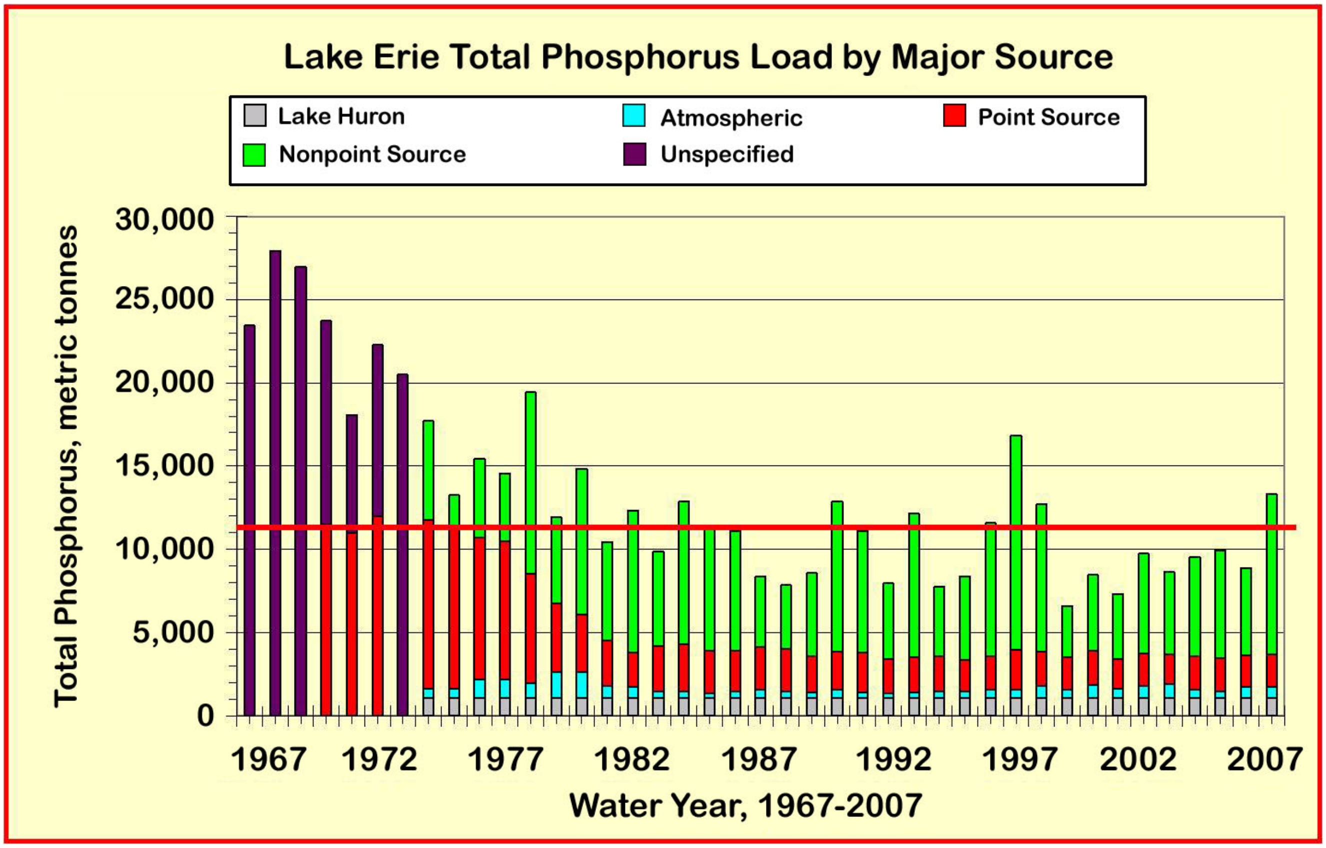


Figure 3— Annual loading of total phosphorus to Lake Erie, 1967 – 2007.
(Historical data from David Rockwell, U.S.EPA and David Dolan, University of Wisconsin Green Bay. Data from 2002-2007 are based on personal communication from David Dolan to David Baker, Heidelberg University. Graph prepared by David Baker)

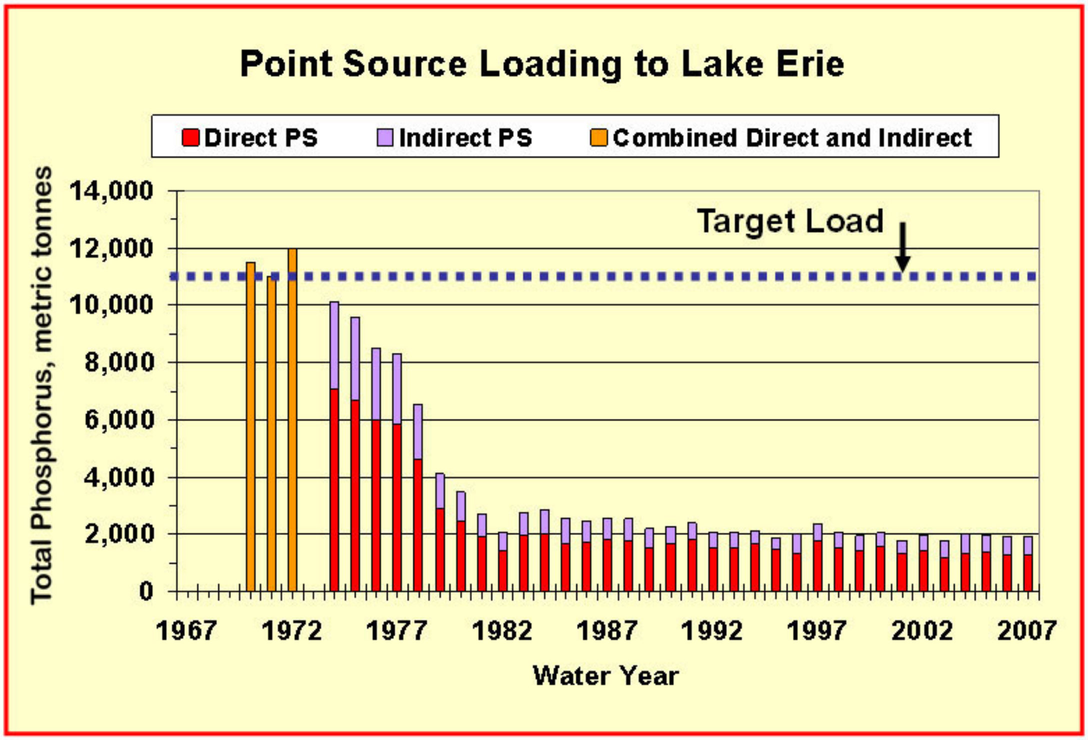


Figure 4— Point source loads to Lake Erie highlighting the large and rapid reductions from wastewater treatment plants in the 1970s. (Subset of data from Figure 3 prepared by David Baker, Heidelberg University)

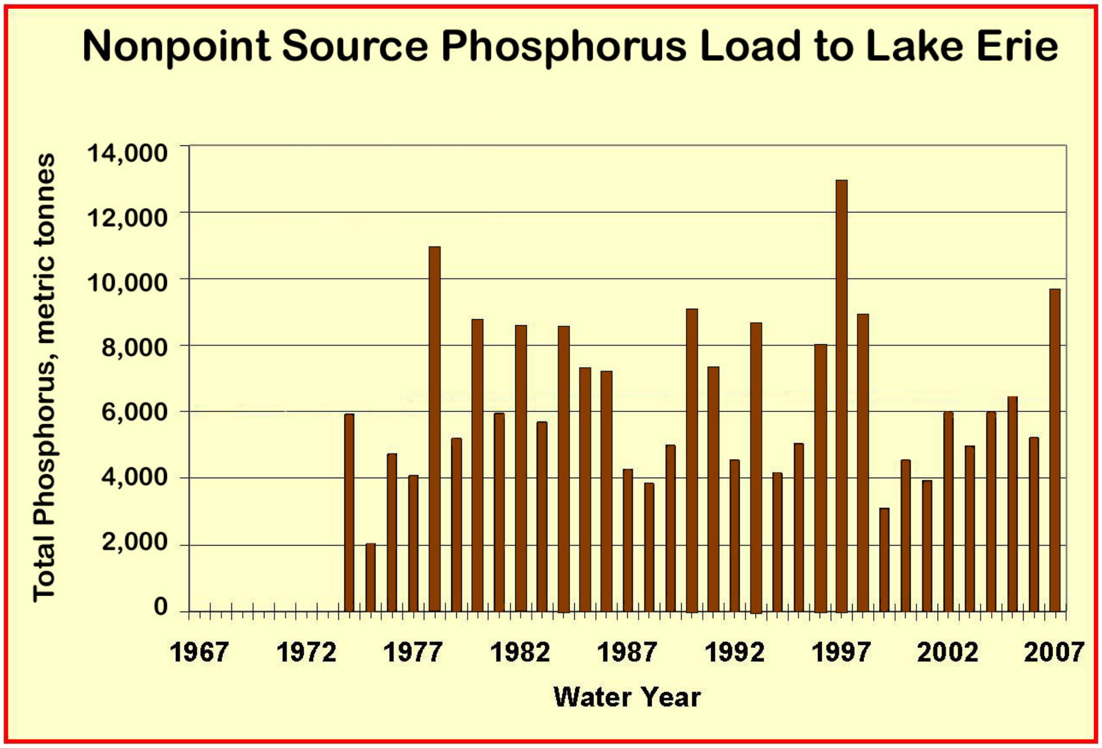


Figure 5— Nonpoint source loads of TP to Lake Erie reflecting weather-induced variability. (Subset of data from Figure 3, Prepared by David Baker, Heidelberg University)

The data shown in Figure 3 reveal that the target load of 11,000 metric tonnes was first reached in 1981. Since that time, the target load has been achieved in most years, with the exceptions limited to years of high precipitation. Conditions in Lake Erie improved dramatically up until the mid 1990s, when problems associated with eutrophication began to reappear.

In 1995, *Microcystis aeruginosa* blooms began to occur in the western basin and recurred with varying intensity through 2002. In August 2003, a massive bloom of *Microcystis* formed in the western basin and persisted for nearly a month. Blooms also occurred in 2004, 2005, and 2006, with particularly extensive blooms in 2007 and 2008. The 2009 bloom extended into the central basin. Not only did surface scums impair recreation and aesthetics, they caused taste and odor problems at water supplies. Elevated concentrations of the toxin microcystin threatened water supplies and at times created potentially harmful exposures to animals, wildlife, fish and humans (NOAA, 2009). In 2006, a benthic mat-forming blue-green alga tentatively identified as the cyanobacterium *Lyngbya wollei* emerged in Maumee Bay and began coating the shoreline in thick foul-smelling mats. The filamentous green alga *Cladophora* once again grew profusely along shorelines and the lake bottom where there was hard substrate. Oxygen depletion rates in the central basin were also increasing.

It is important to note that shoreline algal problems are now more localized and there is a different assemblage of blue-green and green algae than in the past. This may suggest that different mechanisms are now in place and the phosphorus control measures needed may differ from controls used previously. This “re-eutrophication” of Lake Erie has occurred during a time in which total phosphorus loading has remained relatively constant (Figure 3). A variety of potential causes have been proposed, including: 1) increased internal loading of phosphorus (release of phosphorus from bottom sediments to the water column possibly mediated by zebra and/or quagga mussels); 2) underestimation of phosphorus inputs from sources such as urban storm water; 3) changes in overall nutrient balances in the lake and related adaptations of nutrient uptake mechanisms by algae and bacteria (including changes in dominant species); 4) changes in bioavailable phosphorus loading that do not parallel changes in total phosphorus loading; and 5) changes in weather/climate conditions affecting physical conditions in the lake (lake levels, temperatures, wind events, etc.).

Several large scale studies have been mounted to address these questions. These include the Lake Erie Trophic Status (LETS) collaborative study (Matisoff and Ciborowski, 2005) and the Ecological Forecasting Hypoxia Assessment in Lake Erie (ECOFORE 2006). Additional studies were initiated in 2009 as part of the joint Canadian–U.S. Lake Erie Intensive Monitoring Year and a set of related studies being funded by the U.S. EPA’s Great Lakes National Program Office and the Ohio Lake Erie Protection Fund.

2.2 — Current Phosphorus Loading Patterns to Lake Erie

For purposes of this analysis, the Lake Erie watershed is divided into three areas: 1) the connecting channel consisting of the St. Clair River, Lake St. Clair and the Detroit River; 2) the western basin from the mouth of the Detroit River to a line drawn from Point Pelee to Cedar Point; and 3) the combined central and eastern basins. The drainage area going into each of these components of the Lake Erie system is shown in Figure 6. Since the western basin receives the land drainage from both the connecting channel and its own watersheds, about 65% of the total drainage from the Lake Erie watershed enters the western basin. According to Bolsenga and Herdendorf (1993), the shoreline along the central and eastern basins make up 68% of the total Lake Erie shoreline, while the western basin contains 32% of the shoreline. Thus the amount of land area contributing pollutants to nearshore waters per mile of shoreline is much greater in the western basin than in the central and eastern basins.

Estimates of the distribution of external phosphorus load into each area are shown in Table 1 and Figure 6. The nonpoint source loads included in these estimates are based on extrapolation from the tributary loading program conducted by Heidelberg University. Comparable data are not available for Canadian tributaries. Nonpoint sources are responsible for about 60.8% of the total phosphorus load in comparison to about 20.7% for point sources (Table 1). The majority of the point source load to Lake Erie is derived from watersheds draining into the connecting channels while the majority of the nonpoint source load comes from watersheds draining into the western basin (Figure 6).

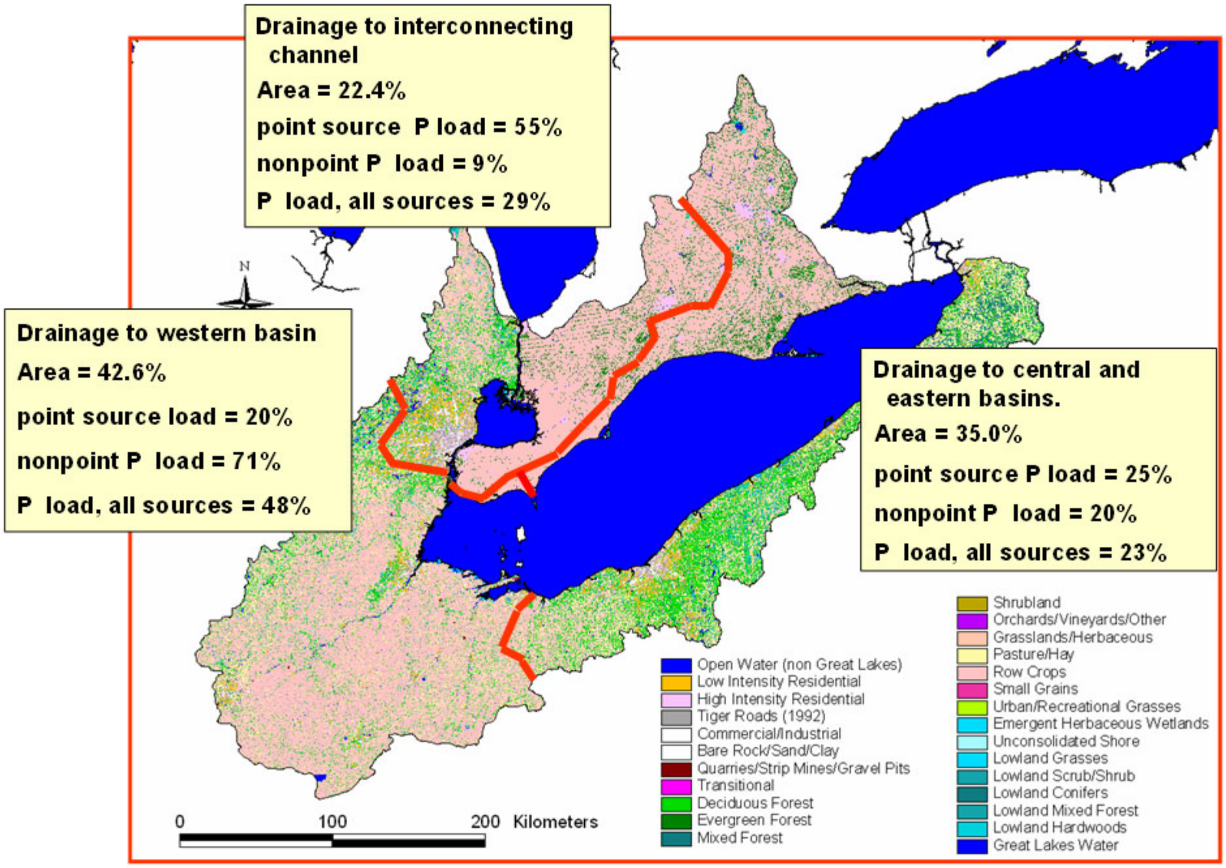


Figure 6— Land areas draining into the three major sub-basins of Lake Erie, along with the corresponding contributions of total phosphorus. (Base map provided by Thomas Hollenhorst, University of Minnesota, Duluth, with phosphorus load allocations calculated by David Baker using data provided by David Dolan, University of Wisconsin, Green Bay and Heidelberg University)

Ohio contributes about 34% of the point source load to Lake Erie (Figure 7), most of which is discharged to the central basin. Ohio is the major contributor to the nonpoint source phosphorus load entering the western basin. Ohio contains 80% of the land area of the watersheds draining directly into the western basin-Sandusky Bay area, excluding the watersheds draining into the connecting channels. While about 27% of the Maumee River watershed lies outside of Ohio in either Michigan or Indiana, these states provide only about 19% of the combined Maumee to Sandusky drainage area. Ontario has minimal land area that drains directly into the western basin (Figure 6). Since the unit area phosphorus load from the Ohio tributaries to the western basin is about twice as high as those of the Michigan tributaries, it is clear that Ohio is responsible for a large proportion of the total nonpoint source load into the western basin, and hence into all of Lake Erie. Overall, Ohio’s land area makes up about 55% of the US drainage to the lake and about 39% of the total US-Canadian drainage to the lake.

Table 1— Approximate distribution of phosphorus entering each component of the Lake Erie system from various external phosphorus sources, 1998 - 2005. (MTA – Metric tonnes/year)

External Phosphorus Source	Connecting Channel MTA	Western Basin MTA	Central/Eastern Basin MTA	Total Loads MTA	Percent of Total
Nonpoint	522	3,987	1,094	5,604	60.8%
Point	1,051	388	469	1,908	20.7%
Upper Lakes	1,080	0	0	1,080	11.7%
Atmospheric		80	548	628	6.8%
Total	2,653	4,455	2,111	9,220	100%
Percent of total	**29%**	**48%**	**23%**	**100%**	

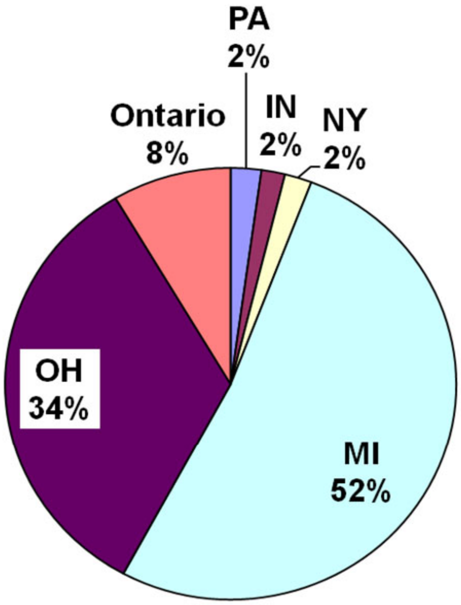


Figure 7 — Percent of total phosphorus point source load to Lake Erie by political jurisdiction, 2004. (Graph by David Baker, Heidelberg University based on data provided by David Dolan, University of Wisconsin, Green Bay)

The phosphorus concentrations in the tributaries entering Lake Erie also vary. The flow-weighted mean concentrations of TP and, where available, DRP are shown in Figure 8 for the mouth of the Detroit River, as well as for five Lake Erie tributaries monitored by Heidelberg University. Flow-weighted concentrations largely reflect the concentrations during high flow periods when the majority of the phosphorus enters the Lake. Although 29% of the TP load to Lake Erie enters from the connecting channels, the TP concentration at the mouth of the Detroit River is very low (13 µg/L). The large volume of water entering the St. Clair River from Lake Huron with very low TP concentrations simply dilutes both the point and nonpoint source inputs into the connecting channels. The highest concentrations for both TP and DRP occur in the Maumee and Sandusky rivers, while the lowest concentrations occur in the Grand River (Ohio). The Grand River watershed has similar land use to that of much of the United States drainage to the central and eastern basins of the Lake east of Cleveland. The concentrations of phosphorus entering the western basin from the Michigan tributaries (River Raisin) are also lower than those of the Maumee and Sandusky rivers.

The elevated sediment and nutrient concentrations of the Maumee and Sandusky rivers likely contribute to the sediment and algal plumes frequently observed from satellite images and aerial photography. These plumes often appear to be emanating from these rivers into the western basin and Sandusky Bay. Comparable algal and sediment plumes are not seen in the flows from the Detroit River. Since the Maumee and Sandusky have the highest DRP loads by far, this study will focus on those areas for further investigation and implementation of recommendations.

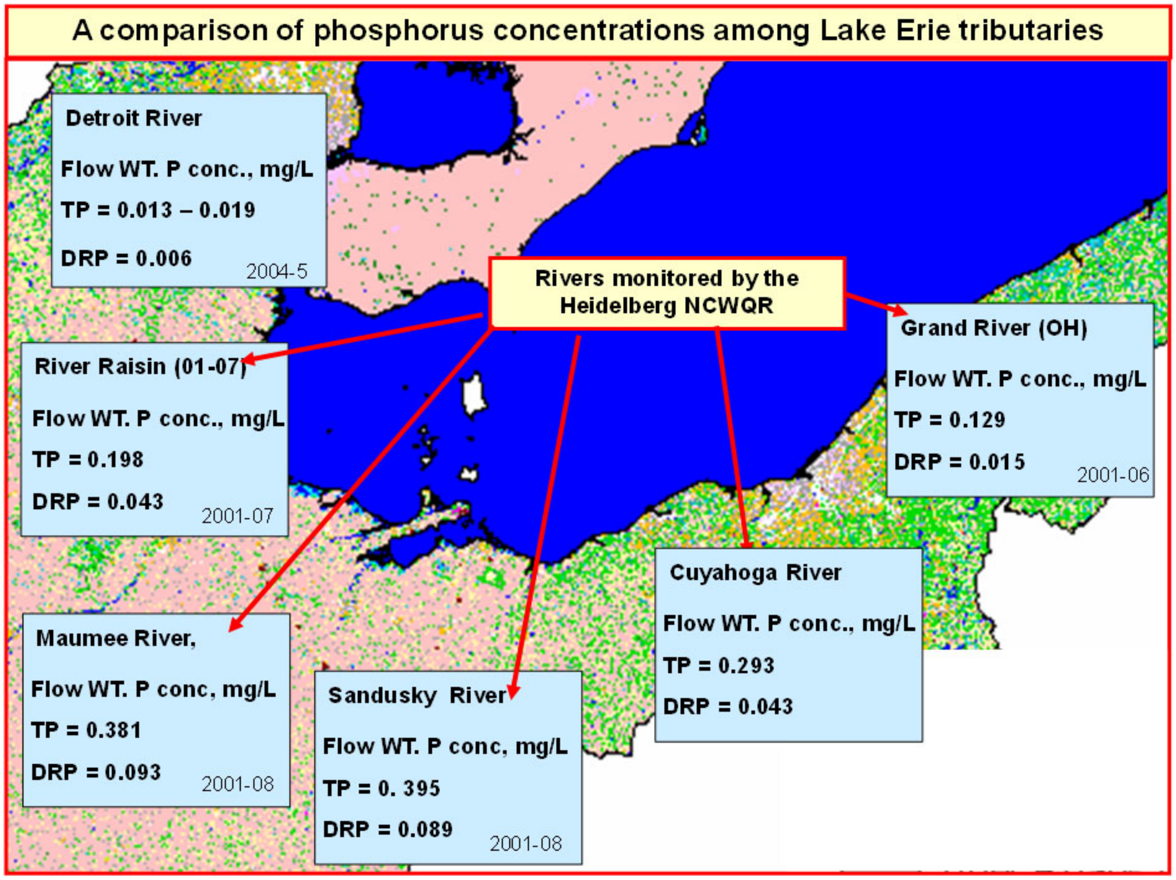
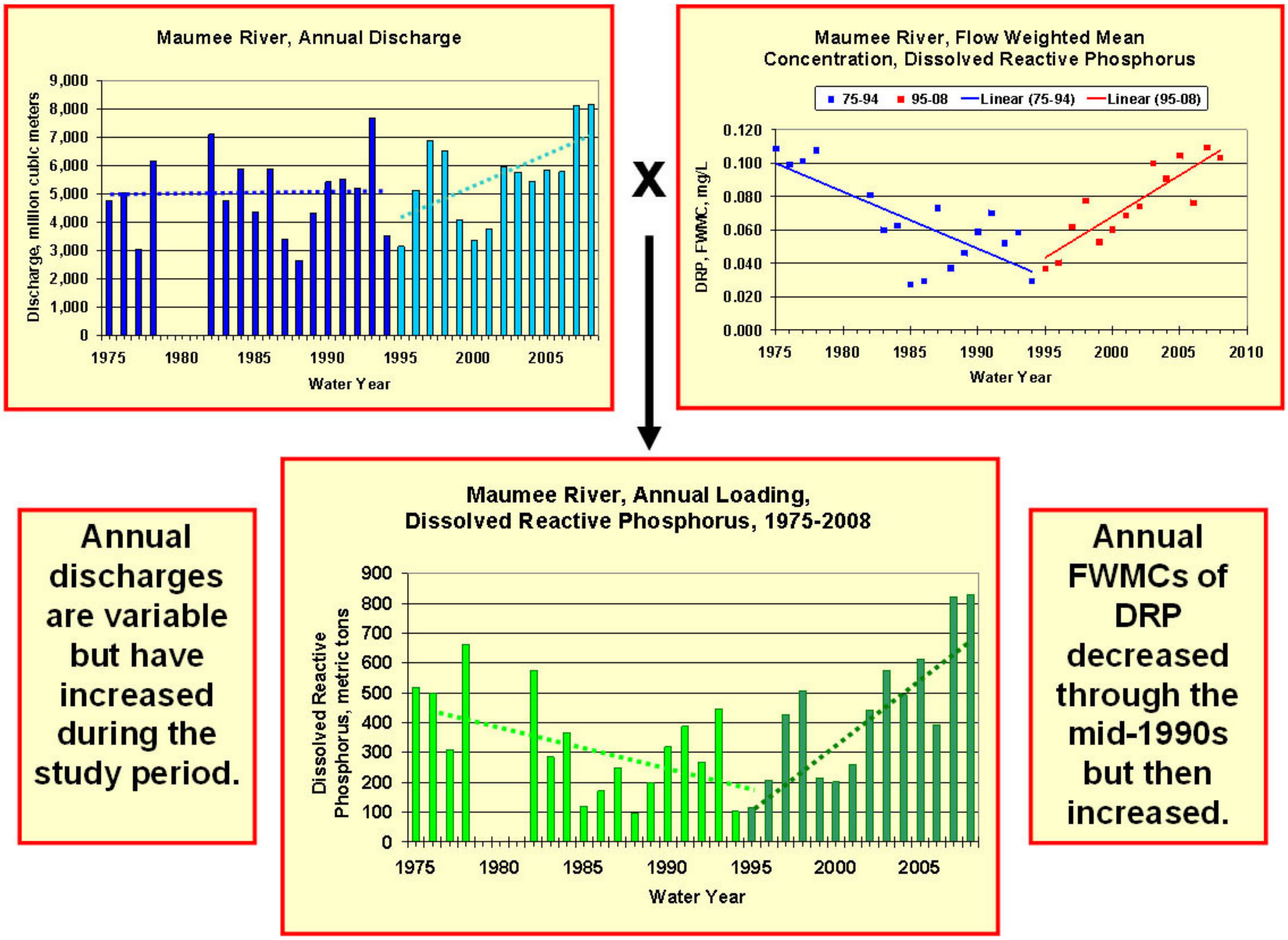


Figure 8 — Flow-weighted concentrations of TP and DRP in tributaries entering Lake Erie. (Based on data from the Heidelberg University Tributary Monitoring Program as supported by the Ohio Department of Natural Resources and the Michigan Department of Environmental Quality. Detroit River data is from Joe DePinto of LimnoTech and the Detroit River Interconnecting Channel Study. Data assembled and analyzed by David Baker, Heidelberg University)

2.3 — Trends in Bioavailable Phosphorus in Western Basin Tributaries

The target phosphorus load for Lake Erie set in the GLWQA was based on TP. The TP discharged from point sources was greater than 85% DRP and considered to be 100% bioavailable. When it became evident that agricultural land uses were a major source of TP entering the lake, and that most of that phosphorus was attached to suspended sediment particles, questions were raised regarding the bioavailability of that particulate phosphorus relative to the bioavailability of phosphorus derived from point sources. On average, DRP comprised 16% to 19% of the total phosphorus loads from the Maumee and Sandusky watersheds during the mid-1970s to mid-1980s. Studies of particulate phosphorus from northwestern Ohio rivers showed that about 30% of that phosphorus was readily bioavailable, as measured by NaOH extraction procedures (DePinto et al., 1981).

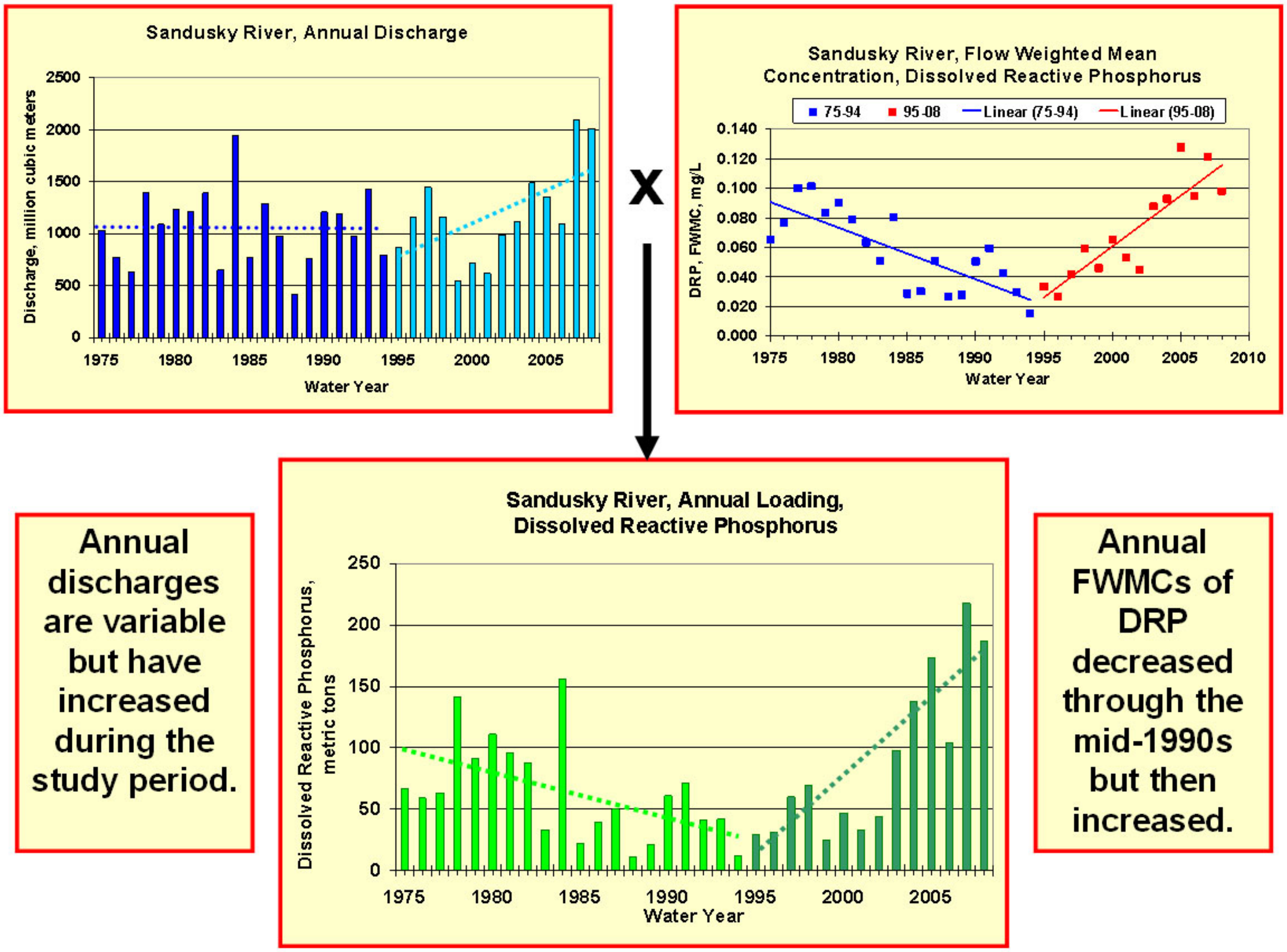
The records for the annual load of DRP from 1975 through the 2008 water year are shown in Figure 9 for the Maumee River and Figure 10 for the Sandusky River. These figures include the annual discharge, the annual flow-weighted mean concentration (FWMC) of DRP and the annual load. For both the Maumee and Sandusky rivers, the flow-weighted mean concentrations and loads decreased from the beginning of the sampling program through the mid-1990s. Since that time the flow-weighted concentrations have increased by large amounts. These increases coupled with increases in annual discharge, have led to very large increases in the loading of DRP.



Annual discharges are variable but have increased during the study period.

Annual FWMCs of DRP decreased through the mid-1990s but then increased.

Figure 9 — Annual discharges, flow-weighted mean concentrations and loads of DRP for the Maumee River at Waterville, 1975-2008. (Data from the Heidelberg University Ohio Tributary Loading Program as supported by the Ohio Department of Natural Resources. Graphs prepared by David Baker)



Annual discharges are variable but have increased during the study period.

Annual FWMCs of DRP decreased through the mid-1990s but then increased.

Figure 10 — Annual discharges and flow-weighted mean concentrations and loads of DRP for the Sandusky River near Fremont, 1975-2008. (Data from the Heidelberg University Ohio Tributary Loading Program as supported by the Ohio Department of Natural Resources. Graphs prepared by David Baker)

The annual mean phytoplankton biomass variation in the western and central basins (Figure 11) shows a similar pattern to the DRP values. The increase in cyanobacterial biomass (primarily *Microcystis*) in the western basin also suggests a connection to the increase in soluble P loads from the Maumee River (Figure 12).

Although there is not a direct correlation, it also appears that the increasing loads of DRP from the Maumee and Sandusky Rivers are affecting walleye fisheries in Lake Erie. When combined DRP loads from the Maumee and Sandusky Rivers have exceeded 400 metric tonnes during the years 1975 through 2008, the combined U.S. - Canada walleye catch averaged only 3.877 million fish (range: 0.098-6.800 million, SD: 2.088 million, N=16), as compared to 5.741 million fish (range: 2.645-10.026 million, SD: 2.160 million, N=15) during years when loads were less than 400 metric tonnes. Walleye catches vary directly with walleye abundance, in large part because the fishery is managed. Walleye abundance is driven by natural reproduction success. While a direct relationship between DRP loads from Ohio tributaries to walleye hatch strength is not discernable at present, periods of highly eutrophic conditions in the western basin have been historically detrimental to walleye (Knight, 1997; Ludsin et al., 2001). There has not been an above-average walleye hatch in Lake Erie since 2003 (Personal communication, Roger Knight, Division of Wildlife, ODNR 2010). Additional research is needed to understand the linkages among DRP, biological production of lower trophic level organisms (algae and zooplankton), and fish.

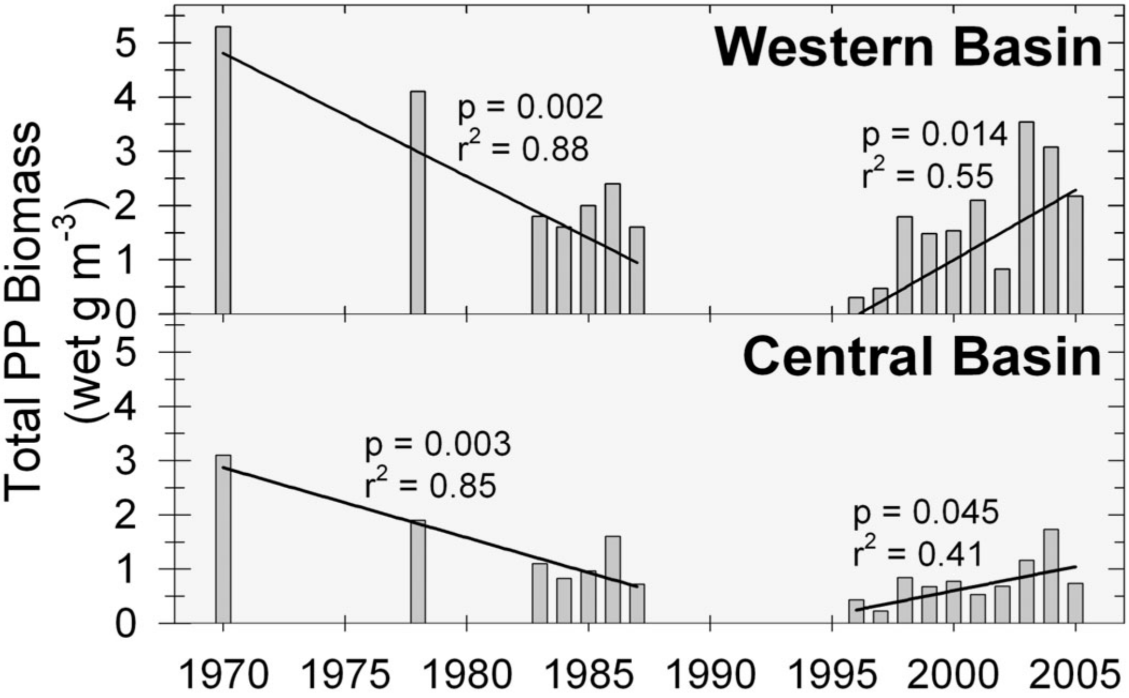


Figure 11 — Annual mean phytoplankton biomass in Lake Erie's western and central basins, 1970-2005. 1970-1986 bars are arithmetic means, whereas those from 1996-2005 are geometric means. Probability (p) and r^2 are for the regressions of biomass vs. time for the periods shown. (Analysis by Joe Conroy, The Ohio State University)

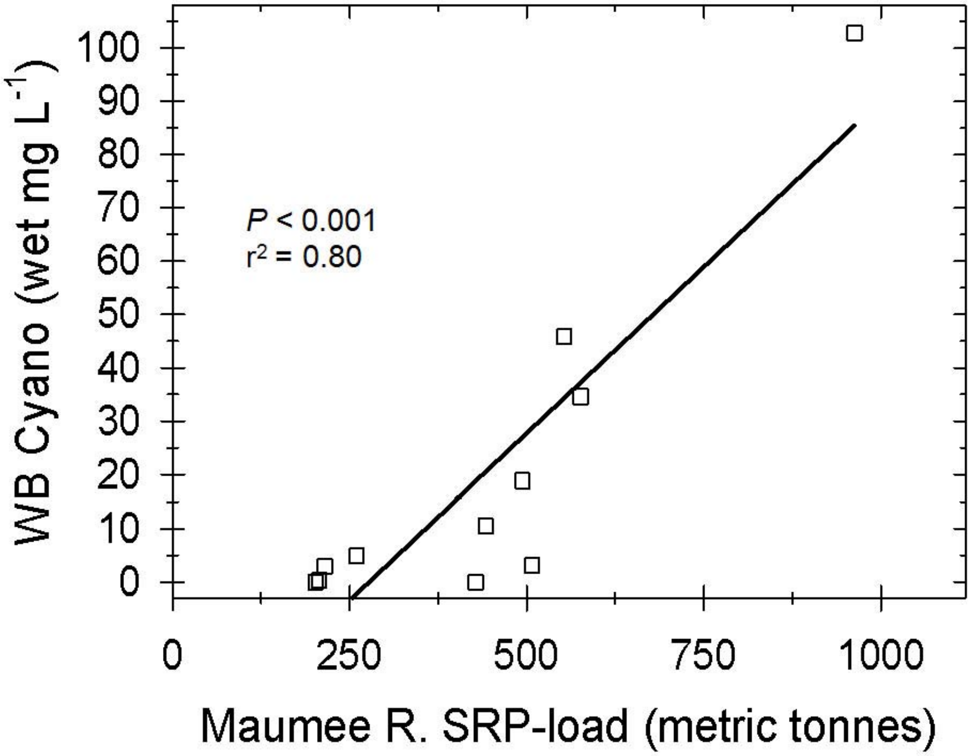


Figure 12 — Median cyanobacterial biomass in the Lake Erie western basin relative to SRP loading from the Maumee River, 1996-2007. Data are from ODNR's Lake Erie monitoring program. (Analysis by D. Kane, Defiance College)

The loading of both particulate P and DRP has changed during the long-term monitoring period. Particulate phosphorus has decreased in response to the various erosion control practices such as no-till and reduced tillage. After rapid decreases in DRP loading through the mid-1990s, DRP loading has rapidly increased. The net effects of these changes on total bioavailable phosphorus loading are shown for the Maumee River in Figure 13 and for the Sandusky River in Figure 14. For both rivers, the bioavailable phosphorus transport at the loading stations is now higher than at any other time during the 34-year monitoring period. These estimates assume that the proportion of particulate P that is bioavailable is still 30% (as measured in the 1980s) and that DRP still represents about 91% of the total dissolved bioavailable phosphorus (i.e., total dissolved bioavailable phosphorus equals 110% of the DRP). Research is now underway to determine if these proportions have remained unchanged since the 1980s.

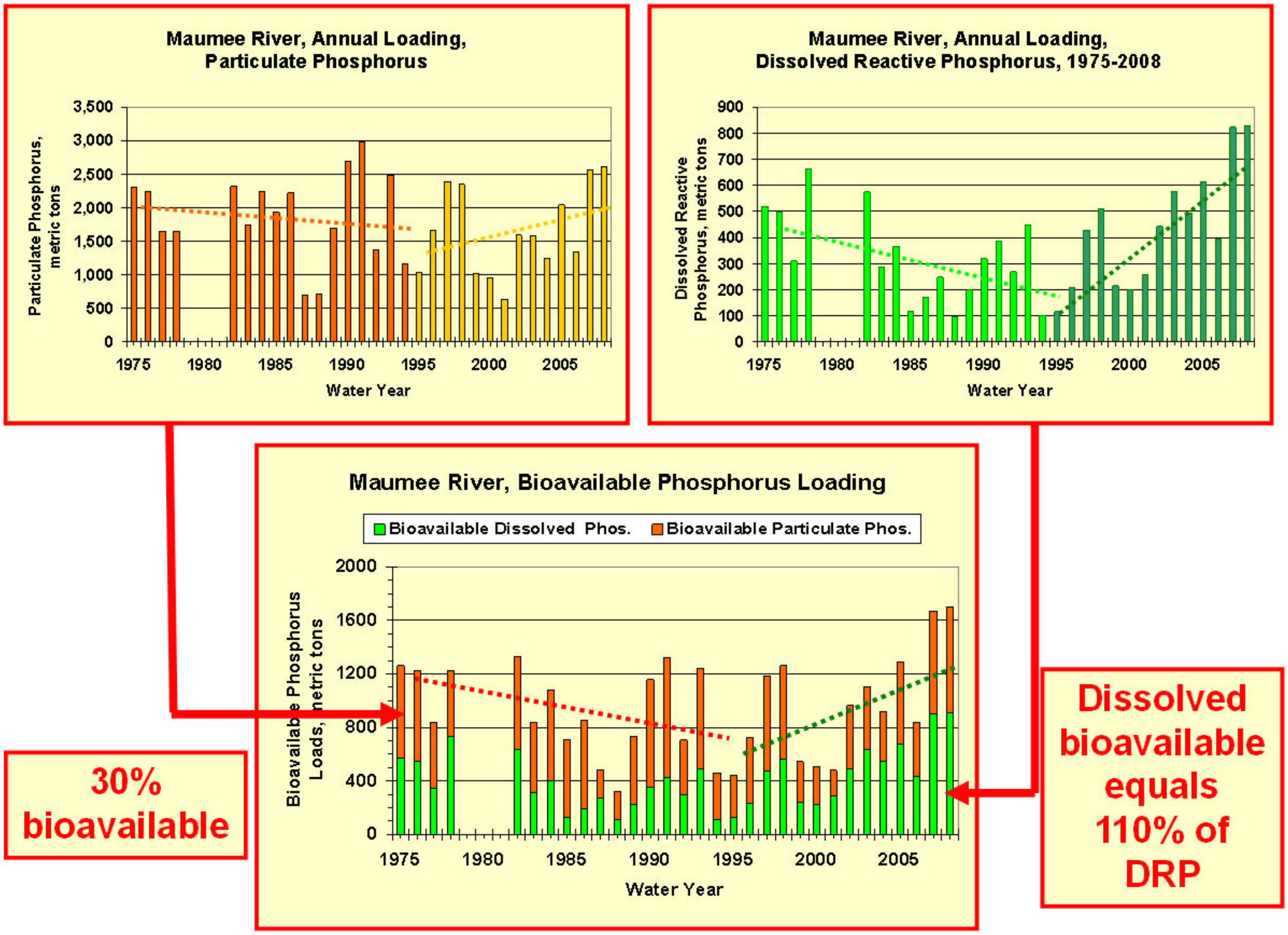


Figure 13 — Estimates of the export of bioavailable phosphorus from the Maumee River at Waterville, 1975-2008. Percentages of bioavailability based on unpublished research by the National Center for Water Quality Research at Heidelberg University (Graphs prepared by David Baker)

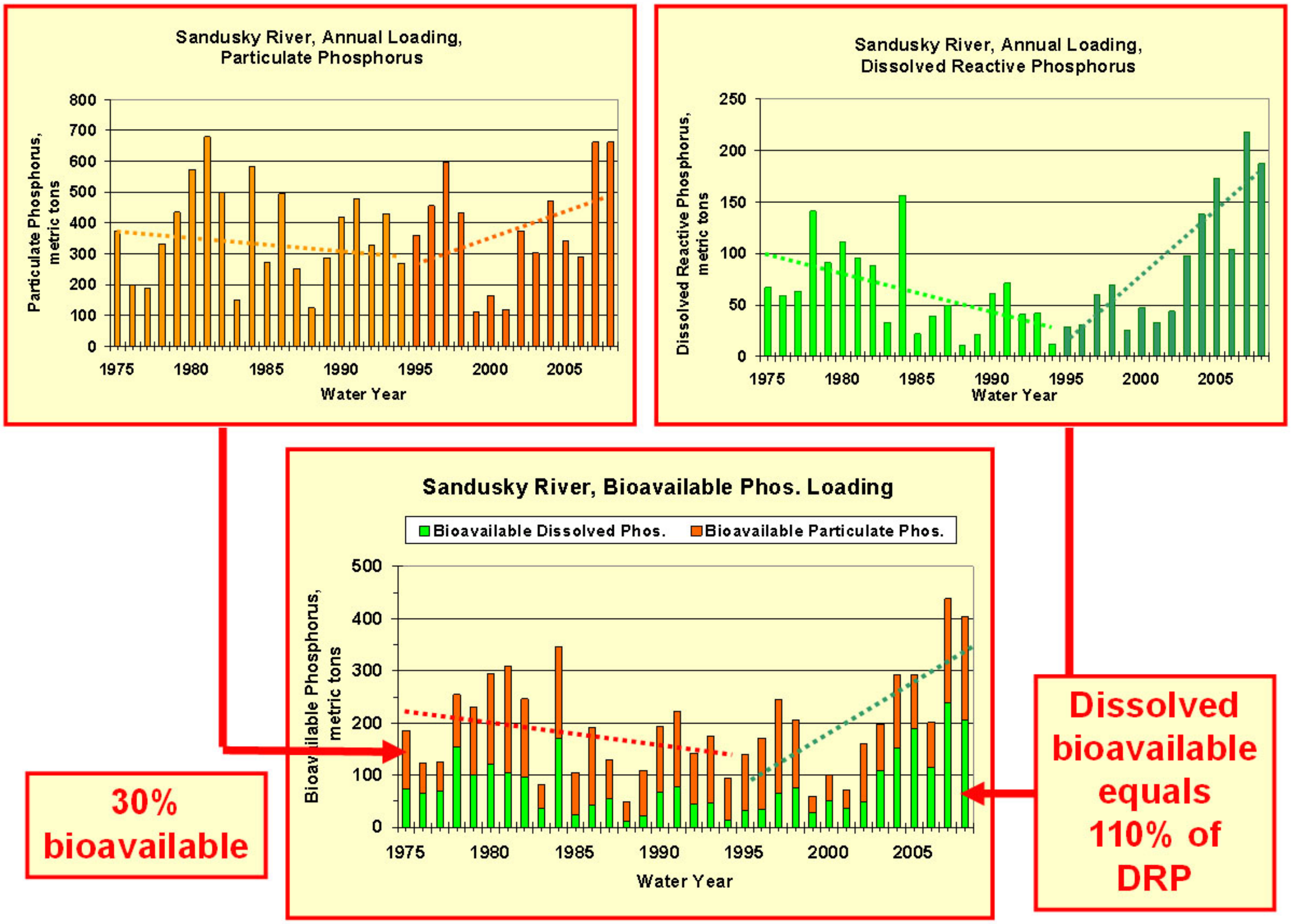


Figure 14 — Estimates of the export of bioavailable phosphorus from the Sandusky River at Fremont, 1975-2008. Percentages of bioavailability are based on unpublished research by the National Center for Water Quality Research at Heidelberg University. (Graphs prepared by David Baker)

2.4 — Land Use Influences on Nutrient Loads

Land cover and land use in the Lake Erie basin ultimately impact nutrient and DRP loads to the Lake. Humans are an integral part of the Lake Erie ecosystem and manage the use (agriculture, recreational lands, urban development, transportation, and utility right-of-ways) and the non-use (wetlands, forest, and shrub land) of the entire Lake Erie basin landscape. Nutrient loads to the Lake are the result of both natural and human-influenced runoff. There is an imbalance of nutrients delivered to the Lake due to the density of the human footprint in the urban setting, the widespread use of agricultural fertilizers, and the density of livestock operations.

Alexander and Smith (2006) looked at trends in nutrient enrichment in U.S. rivers in relation to changes in stream trophic conditions. Similar to the findings by Heidelberg University's Ohio tributary monitoring program, they observed declines in total phosphorus (TP) concentrations in approximately 40% of the monitored sites from the mid 1970s to the mid 1990s, even though 60% of the sites in predominantly urban and agriculture watersheds were still considered eutrophic. In agricultural areas, commercial nitrogen and phosphorus fertilizer use increased by orders of magnitude from the 1960s through the early 1980s, when its use peaked. Thereafter, nitrogen use varied, but overall showed a net average increase of 25% from 1973 through 1995. In contrast, commercial phosphorus fertilizer use showed a net average decline of a similar magnitude over this same period.

2.5 — Land Use and Land Cover: Ohio's Contribution to Lake Erie Tributaries

Land use and land cover in the Lake Erie basin is characterized by the 2001 National Land Cover Data (NLCD), released by the Multi Resolution Land-use Consortium (MRLC) in 2007. The data were collected and processed from 2001 satellite imagery data from the Landsat 7 multi-spectral scanner (MSS). Other efforts specific to Ohio have been done using Landsat 7 data as well, such as the 2001 land use data interpreted by ODNR and the 2004 land-use characterization effort by Ohio EPA. Neither of these data layers extended beyond the State boundaries, and therefore do not include those portions of the Maumee and Ottawa River watersheds that extend into Indiana and Michigan, nor do they include portions of the Conneaut River watershed that extend into Pennsylvania. Land use and land cover classifications provided by the 2001 NLCD range from the general classification (Level I - urban, agriculture, forest, grassland, to wetland) to the more specific (Level II - urban low density residential, row crops, pasture/rangeland, etc.). Table 2 shows the Level I and II land use classification types reported by the 2001 NLCD for all watersheds fully or partially within the Ohio Lake Erie watershed. Additionally, 2001 NLCD land use/land cover was calculated for each of the large scale (8-digit) hydrologic units that are fully within or partially contain portions of Ohio. Complete tables showing Level I classifications for each hydrologic unit fully within or draining portions of Ohio to Lake Erie can be found in the Appendix Table A-1.

Overall agricultural row crops accounted for 59% of land use in the Ohio watersheds draining to Lake Erie, followed by urban residential and commercial at 16%, forested lands and wetlands combined at 16%, and pasture at 5% (Figure 15). Ohio tributaries draining to the western basin of Lake Erie (Ottawa, Maumee, Toussaint, Portage, and Sandusky rivers) show a disproportionately high percentage of row-crop agriculture at 72% when compared to the tributaries draining to the central basin (Huron, Vermilion, Black, Rocky, Cuyahoga, Grand and Ashtabula rivers) of Lake Erie, at 26%. Tributaries draining to the central basin show an integrated mix of land use from row-crop agriculture (26%), to urban residential and commercial (27%) and forest cover (30%) (Figure 15).

In Northwest Ohio agriculture is the dominant land use in watersheds such as the Auglaize, Blanchard, Sandusky, Tiffin, and Upper Maumee, where agricultural row crops account for 52-82% of the land use; pasture accounts for 1-17% of the land use; urban land accounts for 8-14%, and forest and wetland land cover accounts for 5-13%. Alternatively, watersheds in Northeast Ohio, such as the Cuyahoga, Chagrin, Black, and Ashtabula are heavily influenced by commercial, residential and transportation land uses, although natural land cover and agriculture land use are also prevalent. Urban land in these watersheds ranges from 21-56%, forest and wetland cover ranges from 31-46%, and agriculture ranges from 28-36%.

Figure 16 shows several representative watersheds within the Lake Erie Basin and their relative land-use percentages. Bean Creek and the Tiffin, St. Joseph and Auglaize rivers are all sub-watersheds of the Maumee River basin, whereas the Vermilion, Black, Rocky and Cuyahoga rivers each drain directly to the central basin of Lake Erie. Of the many Lake Erie riverine watersheds, the Auglaize River has the highest percentage of row-crop agriculture at 82%. The Tiffin River and Bean Creek, and the St. Joseph River have the highest percentage of pasture land draining to the western basin of Lake Erie at 10 and 17%, respectively. Moreover, despite the urban and forest dominated nature of the Northeast Ohio watersheds, pastures in the Vermilion, Black, Rocky and Cuyahoga river, still account for 12 to 8% of the land use.

Table 2 — Land Use / Land Cover Classifications for the 2001 National Land Cover Data (NLCD), and the relative percentages for Ohio tributaries draining to Lake Erie. Percentages are rounded to the nearest 0.1% so may not sum to 100%

Level I	Level II - 2001 NLCD Classes	Ohio tributaries to Lake Erie
1. Water	11. Open water	1.5%
2. Urban Land	21. Developed, Open Space	8.4%
	22. Developed, Low Intensity	5.6%
	23. Developed, Medium Intensity	1.7%
	24. Developed, High Intensity	0.7%
3. Barren Land	31. Barren Land	0.1%
4. Forest land	41 Deciduous forest land	13.1%
	42 Evergreen forest land	0.2%
	43 Mixed forest land	0.0%
5. Shrub land	52. Scrub/Shrub	0.2%
7. Grass Land	71. Grassland/Herbaceous	1.4%
8. Agricultural Land	81. Pasture/Hay	5.4%
	82. Cultivated Crops	59.1%
9. Wetlands	90. Woody Wetlands	2.0%
	95. Emergent Herbaceous Wetlands	0.6%

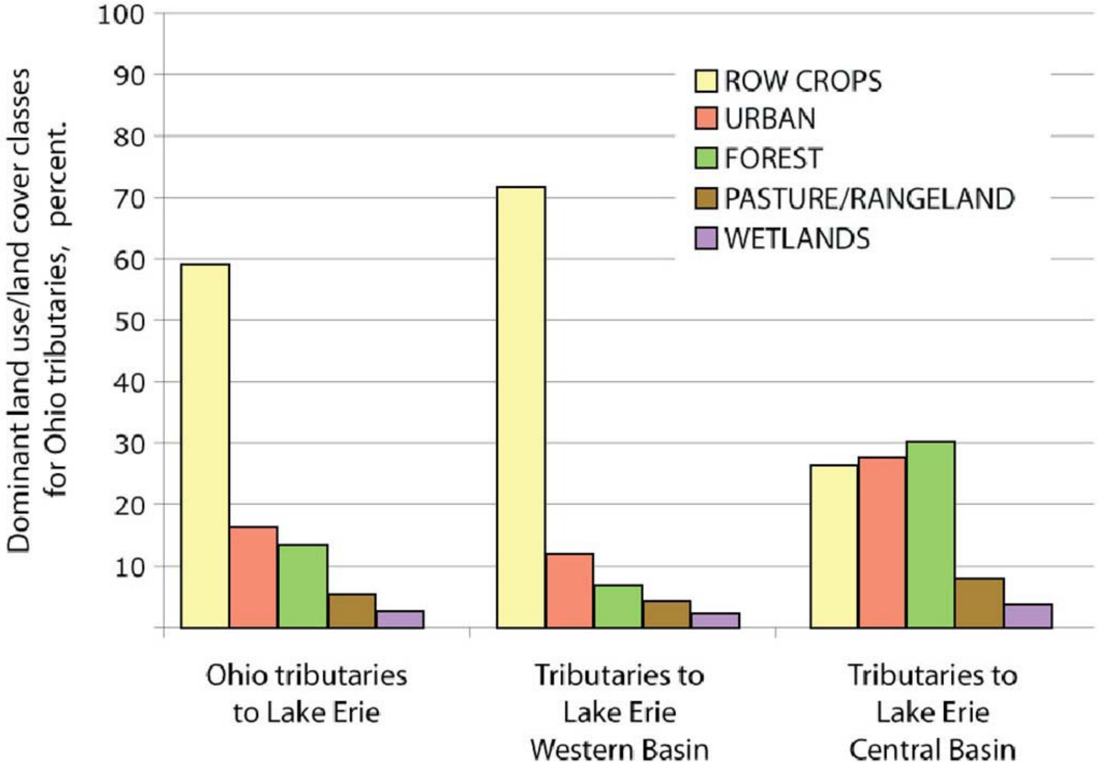


Figure 15 — Dominant land use/land cover classes for groups of tributaries in the Lake Erie basin. Row-crop agriculture is more prevalent in tributaries draining to the western basin, whereas mixed land use/land cover is found in the tributaries draining to the central basin. (Prepared by Dan Button, USGS for the Phosphorus Task Force)

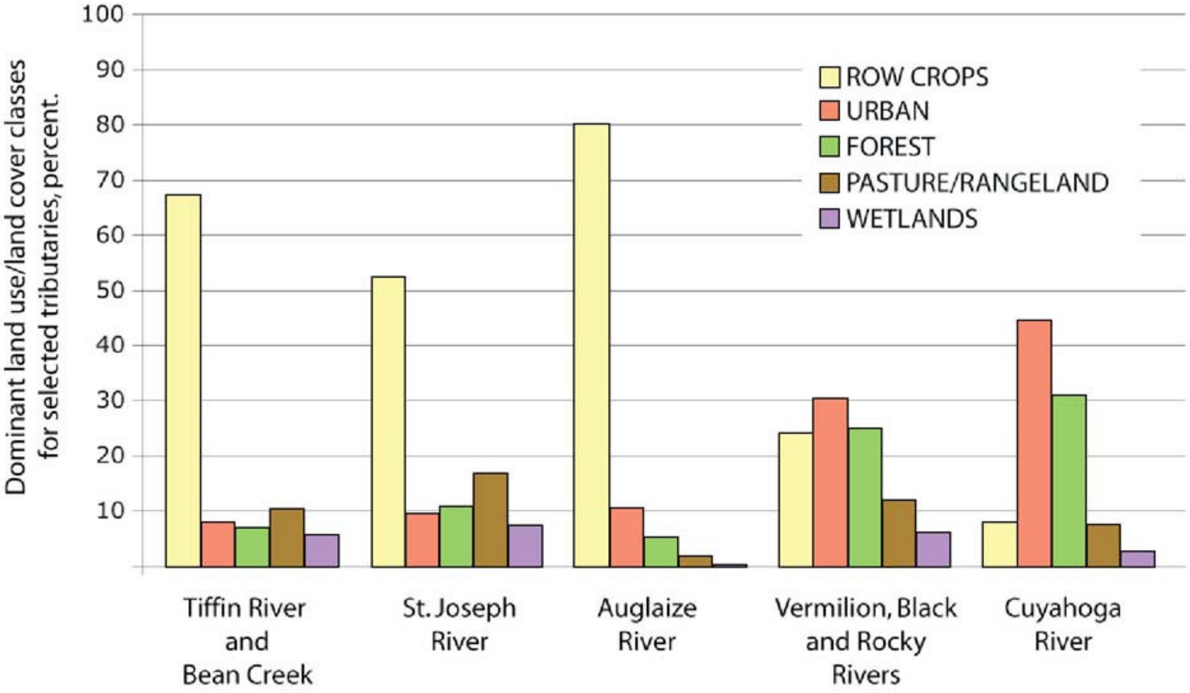


Figure 16 — Dominant land use/land cover classes for a select few watersheds in the Lake Erie basin. Row-crop agriculture is more prevalent in Northwest Ohio watersheds than in the urban and forest dominated watersheds in Central and Northeast Ohio

Section 3 — Types and Dynamics of Phosphorus in Water and Soils

3.1 — Phosphorus Dynamics in Water

Phosphorus is an essential nutrient for living organisms and is often the limiting nutrient for plant growth (Walker et al., 2007; Dodson, 2005). Phosphorus is found in many forms in the aquatic ecosystem. Total phosphorus (TP) measures all of the phosphorus present in the water, and it is frequently used to measure a lake's nutrient status. Most lakes have TP concentrations between 10µg/L and 80µg/L, but very clear ultra-oligotrophic lakes may have only 1µg/L of TP while hyper-eutrophic lakes may have 200µg/L of TP (Dodson, 2005). Flowing streams can have even higher concentrations, particularly after storm events or if they are the recipients of highly concentrated discharges. Dissolved reactive phosphorus (DRP) consists of both inorganic and organic forms that are dissolved in water. DRP is largely bio-available phosphorus that is available to phytoplankton, macro-algae, and macrophytes. Orthophosphate is an inorganic form of DRP which has an electrostatic attraction to polar chemicals including ferric hydroxide colloids.

Additional forms of phosphorus include particulate organic phosphorus and particulate inorganic phosphorus. Particulate organic phosphorus is incorporated into living organisms and released through feces or when the organism dies (i.e. dead leaves). Particulate inorganic phosphorus is typically orthophosphate attached to particles, and this form is insoluble in water. Particulate phosphorus ends up sinking to the bottom of lakes or streams, where it either becomes trapped within the sediments or is taken up by aquatic plants. Once the phosphorus is taken up by aquatic plants the phosphorus does not return to the aquatic ecosystem until the plant dies and begins to decay. Streambed or lakebed phosphorus can also be recirculated by strong storms or heavy flows.

These types of phosphorus enter the aquatic ecosystem through many avenues. Natural pathways for phosphorus are usually from waste products of organisms, decaying organisms, rocks and dissolved minerals containing phosphorus, atmospheric deposition and tributary inputs. Human activities can add significant amounts of phosphorus to aquatic ecosystems through industrial and municipal effluents, detergents, fertilizer runoff, agricultural activities, and increased soil erosion (Walker et al., 2007).

Typically Lake Erie's central and eastern basins undergo thermal stratification into three main layers during the summer months: the epilimnion (warmer upper layer); the metalimnion (the transition layer between warm upper and cool bottom waters); and the hypolimnion (cool bottom layer). During thermal stratification the three layers do not mix and oxygen can become depleted in the hypolimnion. In Lake Erie, oxygen typically becomes depleted (hypoxia/anoxia) only in the central basin because its morphology supports the development of a relatively thin hypolimnion. Oxygen becomes depleted because it is consumed by bacteria and fungi engaged in the decay of algae and other organic matter. Oxygen in the hypolimnion does not get replenished until the lake mixes in the fall after stratification ends. Additional phosphorus continues to be transported from the epilimnion to the hypolimnion as algae die off and fall to the bottom to decompose.

Phosphorus regeneration back into the water column happens aerobically during decomposition. Another process happens in summer during periods of stagnation in the western basin and when the central basin hypolimnion becomes anoxic. Under anaerobic conditions this regeneration releases DRP that was weakly bound to clays and ferric hydroxide. The sediment-to-phosphorus bond is sensitive to redox potential which responds to low oxygen concentrations and anoxia, as ferric iron is reduced to the more soluble ferrous form. This explains how this phosphorus stays in the sediment through most of the year. Sediment regeneration phenomena are incorporated into observations of ambient phosphorus in lakes and do not represent a new load or a new source of phosphorus. Sediment phosphorus re-cycling can delay the recovery of lakes but even when the re-cycling occurs, the phosphorus inexorably moves towards permanent storage or to the outflow so the net effect in the long term is to clean the lake (Hiriart-Baer et al., 2008).

The fall weather cools the epilimnion and causes thermal stratification to end. The lake circulates freely from top to bottom and the oxygenated surface water mixes with the phosphorus-rich bottom water. This causes the entire water column to become phosphorus enriched. Much of this phosphorus is left within the water column until spring since the phytoplankton growth has slowed due to the cooler temperatures and shorter day length.

Many types of compounds in particulate and soluble forms with different abilities to grow algae (bioavailability) may be components of total phosphorus (TP). Apatite mineral phosphorus (calcium hydroxyl phosphate) from shore erosion, for example, is a particulate form that is largely unavailable to algae. Dissolved reactive phosphorus (DRP) is a soluble form found in sewage and fertilizers that is highly bioavailable. Algal cells (particulate) contain organic phosphorus which will be released upon decomposition. Where there are high loads and concentrations of TP there is usually a significant component of bioavailable P such as DRP. This is why TP load has become a sort of shorthand criterion for communicating the nutrient status of water with regard to potential algal problems. Operationally, TP is easier to measure chemically than its component fractions, and this is another reason for its general usage.

Recent open water spring TP concentrations have not consistently been below target levels (eastern and central basins: 10 µg/L; western basin: 15 µg/L). For example, in 2007 average spring TP concentrations were: 29±12 µg/L, 12±3 µg/L and 17±7 µg/L, for the western, central and eastern basin, respectively. Western basin concentrations tend to be much higher than the other basins. Spring TP concentrations had been decreasing in all three basins over the last three decades.

Summer TP concentrations decline in all three basins, and in 2006 average summer epilimnetic TP concentrations were: 24±18 µg/L; 10±5 µg/L; and 6±2 µg/L, for the western, central and eastern basins, respectively. A phosphorus gradient from the west to the east is apparent. In the summer, both the east and central basins are at or below their water quality target of 10 µg/L, and have been for the past decade with few exceptions. Summer TP concentrations in the western basin, however, are often above the water quality target of 15 µg/L, and seem to exhibit a higher variability than either the central or eastern basins.

The relationship between phosphorus and algae as indicated by chlorophyll remains strong in offshore waters. Nearshore, there is a serious problem with attached filamentous algae in the eastern basin and parts of the western basin. Algal problems are usually associated with sources of elevated nutrient supplies. The presence of dreissenid mussels has been found to support increased *Cladophora* growth in the eastern basin. The filter feeding by the mussels increases water clarity to provide more light and also recycles phosphorus in the benthic area for use in *Cladophora* growth (Higgins et al., 2005). A correlation has not been established between dreissenids and *Lyngbya*.

The nearshore forms a small part of the lake area but it is the most visible and most heavily used by humans, therefore, phosphorus-algae relationships here are particularly important to the public's perception of Lake Erie's health. However, any scientific definition of "nearshore" remains controversial. For some, the surf and swash zone at the shoreline means nearshore while to others the water between 0 and 20 meters deep may constitute the nearshore. Generally, given the open boundaries of the nearshore, it must be characterized operationally since there is no consistent, defensible, and unique definition from an ecological perspective. Due to its shallow depth, most of the western basin is nearshore along with Maumee Bay, Sandusky Bay, the river mouth outflow areas and the shore of the central basin out to the 15 meter depth contour. In general, the ranges of total phosphorus and chlorophyll-a concentrations in the nearshore and offshore areas overlap. However, both the variability and the average concentrations are generally higher nearshore (Kelly, 2008).

3.2 — Glacial Geology, Physiographic Regions and Soils of Northwest Ohio

This section provides a brief background on the formation of the soils in this region because they have a significant impact on how the area is drained and how nutrients are cycled. Soil as discussed in this document refers to mineral-based soils, but not the organic soils formed in glacial-aged peat deposits (See *www.dnr.state.oh.us/Portals/10/pdf/glacial.pdf* for the locations of significant peat deposits). Organic soils containing high amounts of organic materials behave differently than the "typical" mineral soils that are discussed in this document. Furthermore, organic soils need to remain saturated to survive. Since most of these soils are tile drained and, therefore, unsaturated for at least some portions of the year, they are oxidizing and slowly disappearing from the landscape.

The formation of the clay-rich soils in northwest and north central Ohio is a two part process including the deposition of the parent materials during glacial ice melting and the subsequent process of soil formation. The first important consideration is the grain-size (texture) of the "parent material" on which the soils are formed. The Lake Erie watershed glacial deposits post-date the Erie-Interstadial meltback event of glacial ice during the Late-Wisconsinan ice age. Large lakes formed in front of the retreating ice, filled with fine-grained water-lain layered deposits. Some of these deposits remain today and can be seen as lake deposits and wave-planed ground moraine as far south as Mercer, Logan, and Marion counties. When the Late Wisconsinan ice re-advanced, it ground up and reworked the previous lake beds, creating a much finer glacial drift than that found further south and east in Ohio. The southern boundary is generally considered the Broadway-Powell End Moraine which is the dark green band that touches the Franklin-Delaware County line. This area is referred to as the Central Ohio Clayey Till Plain physiographic region of Ohio and can be seen on the map at: *www.dnr.state.oh.us/Portals/10/pdf/physio.pdf* .

Approximately 14,000 years ago, the Late-Wisconsinan-aged ice melted back out of Ohio and a series of larger and older Lake Eries were formed. The oldest and highest lake was Lake Maumee and its shoreline can be seen on *www.dnr.state.oh.us/Portals/10/pdf/glacial.pdf* , the southern shore found in Van Wert, Allen, and Hancock counties and represented on this figure as the large wave-planed ground moraine and lake deposits in northwestern and north central Ohio. This area is also identified on *www.dnr.state.oh.us/Portals/10/pdf/physio.pdf* as the (7) Maumee Lake Plains. It is not uncommon for these materials to be made up of 40 to 50% (or even more) clay-sized textural materials.

Over time, the amount of clay-sized (colloidal) textural materials within these deposits increased as part of the ensuing weathering and soil forming processes. Also, clay-sized materials moved out of the upper or "A" horizon and were deposited into the "B" horizon, further enriching the amount of clay-sized materials that are found near the surface in agricultural settings where the upper or "A" horizon has been eroded away. Some of these "B" horizon soils now contain 70% or more clay-sized materials in their textural classifications. These soils are easily recognized on *www.dnr.state.oh.us/Portals/12/soils/pdf/SoilRegions.pdf* as the Region 1 Hoytville-Nappanee-Paulding-Toledo Association in the Maumee Lake Plains region of the physiographic map (*www.dnr.state.oh.us/Portals/10/pdf/physio.pdf*).

It is not, however, solely the amount of clay-sized materials that affects the transport of phosphorus from the uplands to the lake. It is also the types and relative abundance of specific clay minerals that are contained within the clay-sized portion of the soils. For the most part, clay minerals in northwest and north central Ohio are Illite, Kaolinite and Chlorite. There are very limited amounts of high shrink-swell Smectite clay minerals in Ohio, especially this portion of Ohio. The clay minerals have negative charges on them and have the ability to bind with particulate phosphorus, allowing that portion of the total phosphorus load to be transported into western Lake Erie with the sediment load. Since clay-sized materials take so long to settle out in quiet water and can be so easily re-suspended, these colloidal clay minerals can be actively re-suspended in the water column and/or can flocculate and fall to the bottom where some portion of the particulate PO^4 can be dissolved and returned to the lake as a flux of dissolved PO^4 (See Figure 34).

For more information on these topics, see Brockman and Szabo (2000), Tornes et al. (2000), Szabo (2006), Weatherington-Rice et al. (2006) and Kim (2007).

3.3 — Phosphorus Dynamics in Soil

Compared to the concentrations of P in lake water and lake sediments, the P content of soil is enormous, ranging from 200 to 5,000 mg/kg with a mean of 600 mg/kg (Lindsay, 1979). However, the soil solution concentration is rarely greater than 1% of the total P content (Brady and Weil, 2002). Soil P naturally fluctuates between dissolved forms, in soil solution (pore water) or runoff/leachate, and solid forms, such as a component of a large variety of P minerals, but it is the dissolved P that feeds plants and algae. Nevertheless, in soil systems, the equilibrium between DRP and solid mineral forms of P is regulated primarily by the solubility of the P-minerals present in the soil or added as P fertilizer, manure/biosolids, and to a lesser extent by the decomposition of organic matter.

A fundamental concept of equilibrium is the understanding that few chemical reactions proceed only in one direction, but are reversible, at least to some extent. This is certainly true for reactions that involve soil phosphorus (P) in natural soil systems. Neither dissolved nor mineral forms of P remain as discrete entities, but rather, are always moving toward equilibrium with each other. Henry Louis Le Chatelier, a French chemist, stated that when an equilibrium system undergoes a perturbation the system will adjust to offset the perturbation and re-establish equilibrium (Chang, 1991). There are a large variety of soil P minerals with a wide range in mineral solubilities. Additions of highly soluble P minerals, such as P fertilizer and manure/biosolids, perturb the equilibrium system triggering a multitude of reactions to re-establish equilibrium. Similarly, depletion of soil solution P by plant and micro-organism P uptake, as well as removal in runoff water or leachate perturb the equilibrium triggering reactions to re-establish equilibrium.

Soil P minerals impose limits on the concentration of P (and other elements) in the soil solution. If the soil solution becomes too concentrated (supersaturated), with respect to any soil P mineral, then that mineral will begin to precipitate removing dissolved P from solution. For example, when completely soluble P fertilizer is added to the soil, it does not remain completely soluble for long. In fact, in most cases, the dissolved P concentration declines quickly as dissolved ions establish lower free-energy states by precipitating into more stable P minerals. Alternatively if the soil solution becomes too dilute (under-saturated) with respect to the P-minerals present, they will begin to dissolve. Both the precipitation of DRP and dissolution of mineral P are natural processes that tend to maintain soil solution P equilibrium. Both precipitation and dissolution can be operating at the same time. When the two processes are equivalent and there are no observable changes in soil solution P, the system is said to be at steady state or dynamic equilibrium (Lindsay, 1979; Chang, 1991).

Under natural soil conditions, temperature, pH and dissolved chemicals will also play a role in phosphorus solubility. Soil pH can have a tremendous effect on soil mineral solubility, as can be seen by comparing the equilibrium solution P concentrations for some common soil P minerals at soil pH 5 with those at pH 7 (Table 3). Note that the iron (Fe) and aluminum (Al) minerals are less soluble (more stable) at low pH and the calcium (Ca) minerals are less soluble (more stable) at high pH.

Table 3 — Phosphorus (P) solution concentration at pH 5 and 7 for typical soil P minerals (Lindsay, 1979)

P-Mineral		pH 5	pH 7
		------ mg P/L ------	
Variscite	$AlPO_4 \cdot H_2O$	1.24	98.1
K-taranakite	$H_6K_3Al_5(PO_4)_8 \cdot 18H_2O$	24.6	490
Strengite	$FePO_4 \cdot 2H_2O$	0.049	31.0
Brushite	$CaHPO_4 \cdot H_2O$	310	4.92
Hydroxapatite	$Ca_5(PO_4)_3OH$	196	$1.96x10^{-3}$
Fluorapatite	$Ca_5(PO_4)F$	0.317	$6.0x10^{-5}$

Another solid-phase stable binding mechanism for P is the adsorption, or surface binding, of P onto metal oxide clay minerals, primarily of iron (Fe) or aluminum (Al). These surface reactions are referred to as specific adsorption or ligand exchange, where phosphate is the ligand. Other chemicals such as sulfate and some organic acids can compete with phosphate for these binding sites. Although specific adsorption is a solid-phase form of P unlike other mineral forms, binding to oxide surfaces is not concentration dependent, so even at low solution P concentrations, P can bind to oxide surfaces. Removal of soil solution P by plants or microorganisms, P leaching into the soil profile, and loss of dissolved P in runoff water can all remove P from the soil solution. As the soil solution P becomes depleted, mineral species begin to dissolve to re-establish the soil solution P at the equilibrium concentration (Figure 17).

Alternatively, large inputs of highly soluble P as fertilizer or in manure or biosolids and, to a lesser extent, the decomposition of plant or other soil biota residue will increase the precipitation of soil P minerals and adsorption onto oxide surfaces, thereby sequestering the P in less soluble forms (Figure 17).

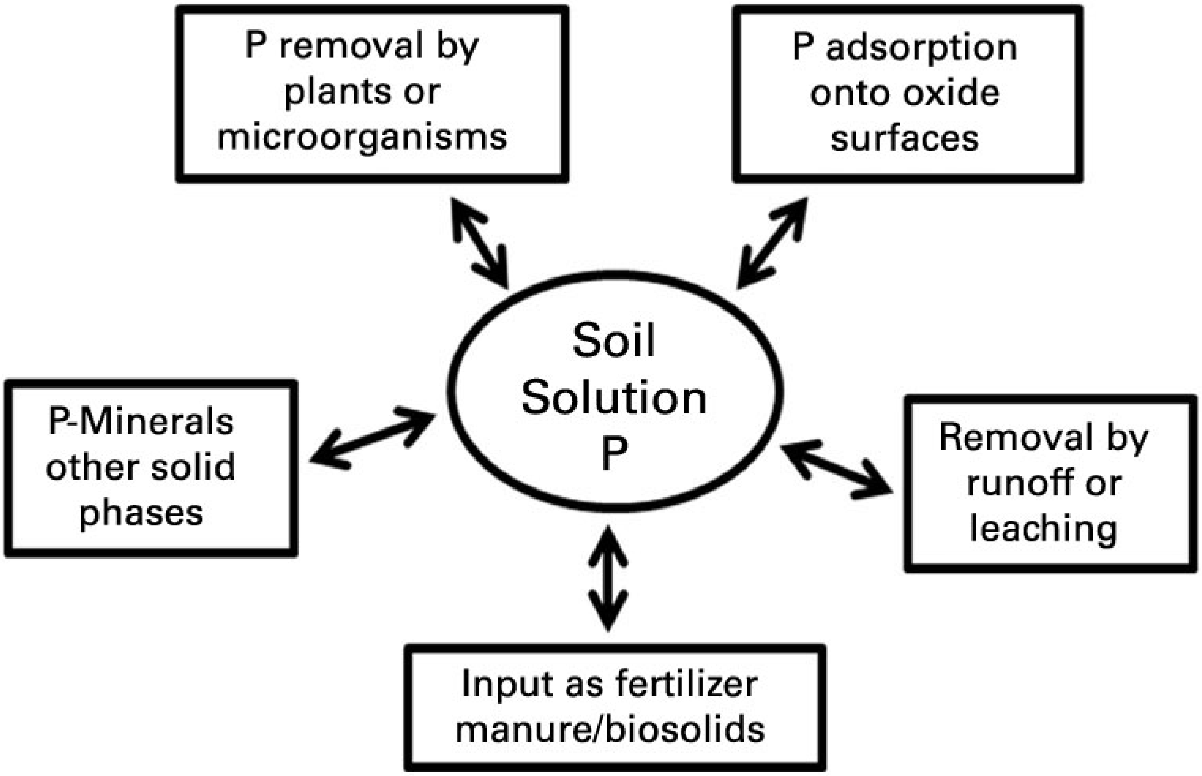


Figure 17 — Factors affecting soil solution phosphorus concentration (Lindsay, 1979)

3.3.1 — Intensity and Capacity Factors

In addition to soil solution P, two important parameters influencing P availability to a growing crop are the soil's intensity and capacity factors. The intensity factor is the measured P concentration in the soil solution. The capacity factor is the ability of the soil to replenish the soil solution P concentration as it becomes depleted due to plant uptake or P transport through runoff/leaching. Differing mineral P solubilities will determine both the intensity and capacity factors.

Given the large number of P minerals exerting control on soil solution P equilibriums, both the intensity and capacity factors are subject to change depending on soil mineralogy. For example, Figure 18 illustrates the relationship between intensity and quantity factors for 3 minerals A, B & C. The solubility of mineral A is the highest, so as long as it is present the equilibrium solution concentration will be maintained at the high A level. This means that the solution will be supersaturated with respect to minerals B and C so they will be precipitating, removing P from solution and contributing to continued dissolution of mineral A. Once all of mineral A has dissolved, the new equilibrium soil solution concentration will be set at level B. Solution P at level B is still supersaturated with respect to mineral C. As long as mineral B remains, mineral C will continue to precipitate contributing to the continued dissolution of mineral B. Ultimately, in this example, mineral C will control the solution P concentration at level C. As the intensity diminishes, the capacity is increasing as less stable more soluble P minerals transform into more stable less soluble P minerals over time. However, the solution P concentration (Intensity) at level C may not be sufficient for crop nutrition. In addition, as mentioned earlier, other factors contribute to soil solution P, such as degradation of organic P, equilibrium between the soil solution and oxide bound P. As these contributions enter the solution, they too are subject to the P solubility of the controlling minerals. The transformation of more soluble less stable to less soluble more stable P minerals explains why additions of highly soluble P fertilizer do not remain highly soluble for long. Alternatively, Figure 18 shows that even at low total and low soil test P levels the equilibrium soil solution P concentration will be set by the most soluble controlling P mineral present (Lindsay, 1979). Phosphorus soil chemistry is thus as complex as it is interesting. There are many "players" (i.e., minerals, oxide surfaces, organic matter, fertilizer) all competing to control soil solution P concentrations.

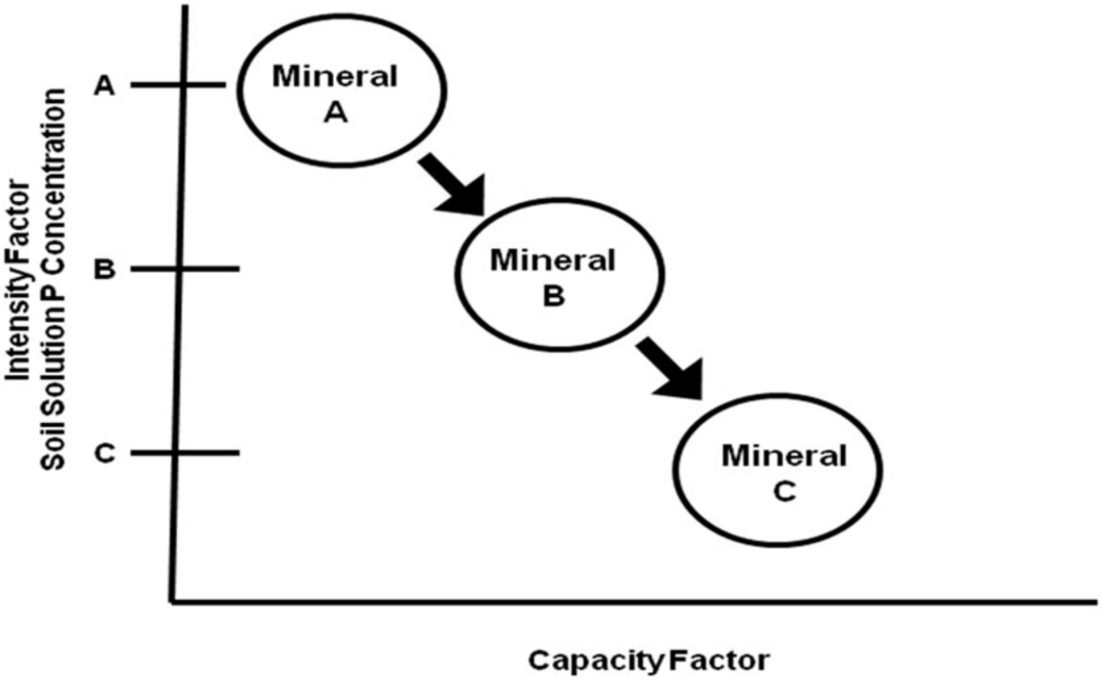


Figure 18 — Relationship between intensity and capacity factors as less stable P minerals transform into more stable P minerals over time (Lindsay, 1979)

Section 4 — Sources of Phosphorus Delivered to Surface Waters

4.1 — Point Sources

4.1.1 — Wastewater Treatment Plants

Point sources are very consistent from day to day and year to year. As described previously, aggressive action related to controlling the discharge of TP from point sources, largely wastewater treatment plants (WWTPs), led to rapid and significant decreases in TP loads to the lake by the early 1980s. Between 1972 and 1985 approximately $8.8 billion was spent by the U.S. and Canada in upgrades to WWTPs. Phosphorus released from point sources is generally considered to be nearly all bioavailable (Black, 1980; Sonzogni et al., 1982) so concentrating on reducing these sources first had the most immediate impact on the lake.

Dave Dolan (currently with the University of Wisconsin – Green Bay) has calculated TP loads to Lake Erie for a number of years. This was first done for the International Joint Commission to determine whether the loading targets set in the Great Lakes Water Quality Agreement were being met. More recently, the U.S. EPA has funded this work to follow changes in both point and nonpoint sources of TP relative to biological changes observed in the lake. Dolan follows the approach described earlier in the background section (c.f., Section 2.1) as developed under LEWMS and PLUARG (c.f., Dolan and McGunagle, 2005). Point source calculations are based on data in U.S. EPA's Permit Compliance System (PCS) database. The direct point sources are those discharging directly to the lake or downstream of the USGS gauging/monitoring station. The indirect point sources are those discharging above the gauging station and are included as part of the overall tributary load. A comparison of Dolan's data since 1985 shows the annual loads from both direct and indirect point sources to be fairly consistent (Figure 4).

There are 703 Ohio National Pollutant Discharge Elimination System (NPDES) permitted WWTPs discharging to the Ohio Lake Erie watershed. They account for a total discharge volume of approximately 1,076 million gallons per day (MGD). About 464 (66%) of these permits are issued to small package plants discharging less than 50,000 gallons per day. However, the majority of the flow comes from the 12 (1.7%) major WWTPs with a discharge greater than 15 MGD. These are also the plants that contribute the majority of the phosphorus load. Based on U.S. EPA PCS data, Dolan estimates an average load of 585 metric tonnes per annum (MTA) of total phosphorus from Ohio WWTPs.

4.1.2 — Bypasses and Combined Sewer Overflows (CSOs)

The WWTP estimates do not include bypasses that occur when wet weather flows exceed the capacity of the WWTP. Under these high-flow conditions, influent to the plant receives only partial treatment before being discharged to the receiving water. Although the phosphorus concentration in these bypasses may be higher than what is found in the treated effluent, the TP load is only a small percentage of the total yearly load discharged by the WWTP. Not enough information is available on the concentrations in bypasses or the volume of the discharge to estimate a load.

Combined sewer overflows (CSOs) may discharge sewage directly into the Lake and its tributaries when storm water overloads the capacity of storm drains designed to discharge through WWTPs. Unfortunately, there are few direct measurements of TP or DRP contributions from CSOs. For the purposes of this exercise, therefore, using TP measurements from some of the Northeast Ohio Regional Sewer District (NEORSD) CSOs and an estimated total CSO annual flow of 10.9 billion gallons as presented in a 2007 report on sewage overflows to Lake Erie (Environment Ohio, 2007), the Task Force estimates an annual CSO TP load to Lake Erie of 90.4 MTA.

4.1.3 — Industrial Point Sources

As compared to WWTPs, there are few industrial sources of TP in the Ohio Lake Erie watershed. There are 84 dischargers with NPDES permits that include phosphorus monitoring or loading conditions. Of these, it is the few dischargers with a high effluent volume that contribute the majority of the load. Most of those discharges are associated with food processing. Dolan calculated an average load of 32.5 MTA from industrial sources.

4.1.4 — Home Sewage Treatment Systems

The Ohio Department of Health examined the potential contribution of phosphorus from home sewage treatment systems (HSTS) (ODH, 2008). They estimated a total of 25 MGD of effluent was generated from the approximately 148,000 homes with discharging home sewage treatment systems in the Lake Erie watershed. Assuming an average TP concentration of 10 mg/L, the average annual TP load was estimated to be 352 MTA. However, trying to determine how much of this TP load actually reaches the local waterway is difficult. For the purposes of this exercise the Phosphorus Task Force chose to estimate that about 25% of the 352 MTA TP discharge eventually reaches a waterway, for a total load of 88 MTA. Data also collected by ODH indicate that 23% of the HSTS installed are failing, with an additional 13% projected to fail within the next 5 years. Soil limitations, substandard or poor design, space limitations, system age, shallow seasonal water tables and poor operation and maintenance were reported as reasons for system failures. These issues could increase TP loads from HSTS in the future and increases the potential for localized water quality impacts.

4.1.5 — Summary and Recommendations for Point Sources

Combining Dolan's average estimates for WWTP loads (585 MTA), Dolan's average industrial loads (32.5 MTA), and the HSTS load estimate (88 MTA) with the CSO load estimate (90.4 MTA), generates an average annual total point source TP load to Lake Erie from Ohio of 795.9 MTA. Considering the fact that most of the phosphorus in the point source load is bioavailable, this is a significant source of phosphorus to Lake Erie. However, this load has remained fairly consistent since 1981 and is not considered to be a significant contributor to the increases in DRP loads being measured in Ohio's Lake Erie tributaries.

Recommendations for future actions relative to phosphorus point source loads include: 1) maintain an effective permit compliance and enforcement program for NPDES-permitted facilities of all types; 2) maintain timely issuance of discharge permits; 3) continue to enforce implementation of Long Term Control Plans for CSOs, sanitary sewer overflows and bypasses; and 4) evaluate the need to further reduce phosphorus concentrations in effluents based on the findings of TMDL studies, watershed plans, and the Lake Erie Lakewide Management Plan (LaMP).

Specific recommendations with respect to HSTS include: 1) Establish statewide rules for HSTS management to provide program continuity across the state; 2) design systems for proper treatment (not off-site disposal) of household sewage; 3) ensure proper design and siting of systems based on soil and site characteristics combined with an inspection and maintenance program; 4) minimize the use of off-lot discharge; and 5) develop training and continuing education programs for system designers, installers, inspectors, regulators, and operators.

4.2 — Nonpoint Sources

Nonpoint sources of phosphorus have typically been associated with sediment load and considered to be of low bioavailability. In comparison to point source loads, nonpoint source loads are difficult to quantify. However, now that the majority of annual phosphorus loading to Lake Erie has been documented to be from the storm-pulsed runoff from the landscape into the tributaries that drain to Lake Erie, a focus on better management of nonpoint sources will be needed. The connection to weather events makes these loads highly variable from week to week and year to year. Accordingly, the control of nonpoint source runoff must be addressed through the implementation of a variety of best management practices (BMPs) in the drainage basin. This section addresses nonpoint sources of phosphorus from agriculture, urban storm water runoff, turf grass management, and the use of orthophosphate in public water supplies.

4.2.1 — Agriculture

4.2.1.1 — Overview of Historical Trends

Across the United States, agriculture has been in a constant state of change. Market forces, consumer demands, economic and environmental considerations all place ongoing challenges to the sustainability of today's farmers. As one farmer put it "change is occurring faster than most farms can plan and adapt to it." From 210,000 farms a century ago, Ohio has decreased to 89,000 farms statewide in 1978 and to 75,000 farms in 2007. Because of specialization, the remaining 75,000 farms do not grow nearly the diverse varieties of crops and livestock of 30 years ago.

As shown in Table 4 below, Ohio livestock production has undergone the following changes from 1978 to 2007.

Table 4 — Change in number of farms raising livestock

	1978	2007
Number of farms with cattle	43,000	26,000
Number of farms with hogs	17,000	3,700
Number of farms with dairy cattle	12,698	3,650

While the numbers of farms and total animals raised have decreased, the number of animals per farm has increased.

Row crop agriculture including corn, soybeans, wheat, and other forages is still the predominant land use in Ohio and in the Lake Erie watershed. Based on 2001 National Land Cover Data, 59% of the Ohio Lake Erie watershed is in row crop agriculture. This ranges from highs of 78% and 76% in the Maumee and the Sandusky drainages, respectively, to a low of 16% in the Cuyahoga and 6% in the Chagrin. Areas and percentages for the major tributaries can be found in Appendix Figure A-1 and Table A-1.

Corn, soybeans, wheat and hay crop acreage information for Ohio collected from the USDA National Agricultural Statistics Service indicates that in the Lake Erie basin, corn acreage has not changed appreciably since the late 1970s while soybean acreage has increased. Wheat acreage has remained constant, but hay acreage has decreased. However, advances in agricultural technologies have resulted in increased yields for corn and soybeans on relatively the same numbers of acres.

The adoption of conservation practices (such as no-till and reduced tillage) over the last 30 years significantly reduced soil erosion rates and the associated phosphorus loads. As discussed previously, focusing on soil conservation methods was the recommended approach to reducing nonpoint phosphorus loads because a large portion of the agricultural nonpoint source phosphorus load was attributed to particulate phosphorus attached to sediment particles. However, since tributary watershed loads of DRP have been increasing since the early 1990s, phosphorus loading from nonpoint sources may no longer be primarily related to sediment load.

4.2.1.2 — Fertilizer Management in Row Crop Agriculture

The Task Force considered the multiple variables related to fertilizer management in row crop agriculture. Since the majority of current phosphorus loading to Lake Erie has been documented to be related to storm-pulsed runoff from the landscape, the methods, amount, form, placement and timing of phosphorus applied to the agricultural landscape are key management considerations. Figure 19 provides an estimate of the total annual elemental phosphorus (in metric tonnes) that is used in the Lake Erie watershed by way of commercial fertilizer application, manure production, and biosolids from WWTPs intended for agronomic application in the watershed.

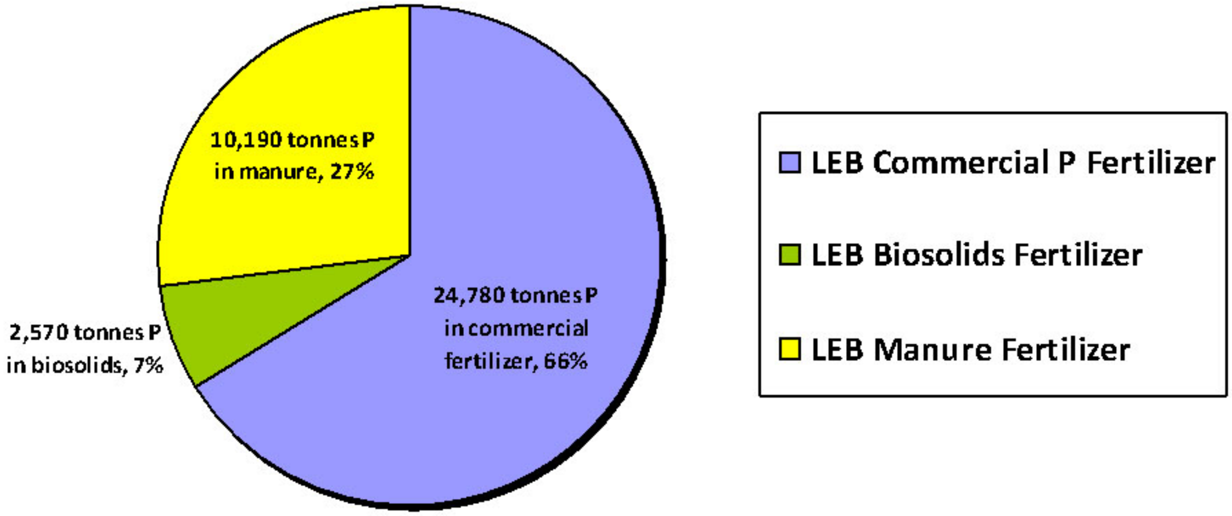


Figure 19 — Ohio EPA comparison of estimated elemental P handled annually (in metric tonnes) for commercial fertilizer, manure and biosolids on the agricultural landscape in the Ohio Lake Erie basin (LEB). (Estimates are based on available data from 2006, 2007 and 2008)

The Task Force analyzed each of these three inputs of phosphorus into the Lake Erie basin to understand changes in fertilizer and landscape management since the mid 1990s when the algal blooms began to re-appear.

4.2.1.3 — Commercial Inorganic Phosphorus Fertilizer

Analysis of statewide Ohio phosphorus fertilizer sales from 1955 through 2006 reveals that fertilizer sales have decreased dramatically from the late 1970s and early 1980s when they were at their peak (Figure 20), with some stabilization beginning in about 1991. Sales trends in the Ohio Lake Erie watershed were estimated by developing a ratio based upon Lake Erie watershed agricultural land area in production versus total Ohio agricultural land area in production and multiplying by the tonnage of P fertilizer sold in Ohio, producing an estimate of 62,600 tons (56,789 MT) of phosphate (P_2O_5) or 27,320 tons (24,784 MT) of elemental phosphorus land applied in the Lake Erie watershed for agronomic use in 2006.

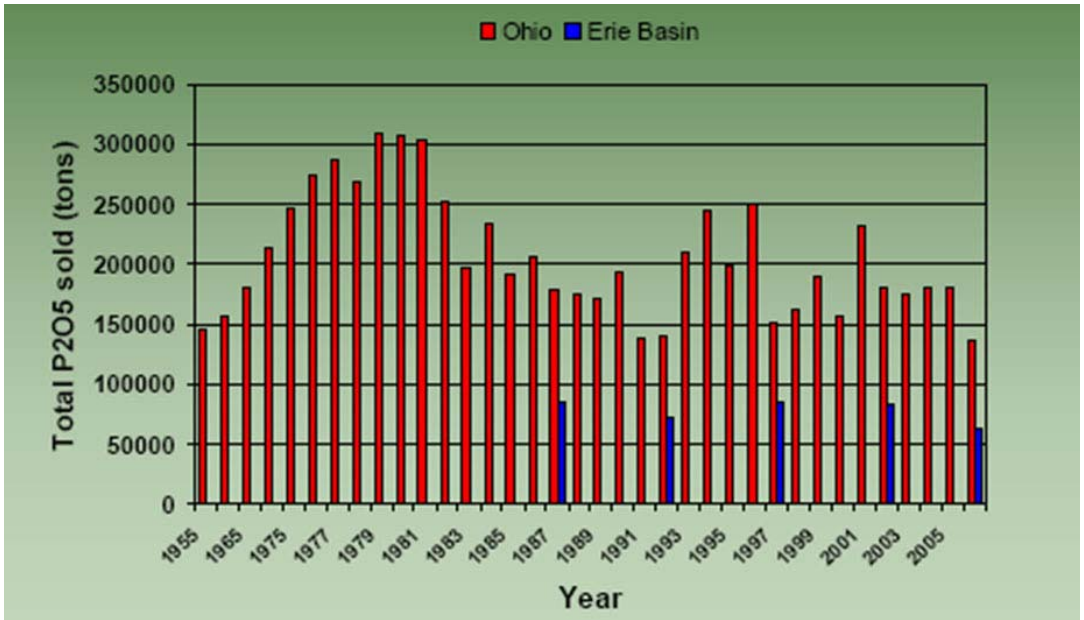


Figure 20 — Analysis of Ohio commercial phosphorus fertilizer sales from 1955-2006.
Source: Commercial Fertilizer Report, published by the Association of American Plant Control Officials

There is neither an exact means to track fertilizer usage by watershed nor a way to estimate how much of the phosphorus-containing commercial fertilizer that was sold in Ohio was land applied in the Lake Erie watershed. While this approach affects the accuracy of the estimates, the Task Force compared these estimates with those for other inputs of P to the Lake. Additional knowledge gaps include an understanding of the portion or percentage by fertilizer type sold and land applied from year to year in the Lake Erie drainage area. Other unknowns include the relative seasonal timing of the commercial P fertilizer applications across the basin.

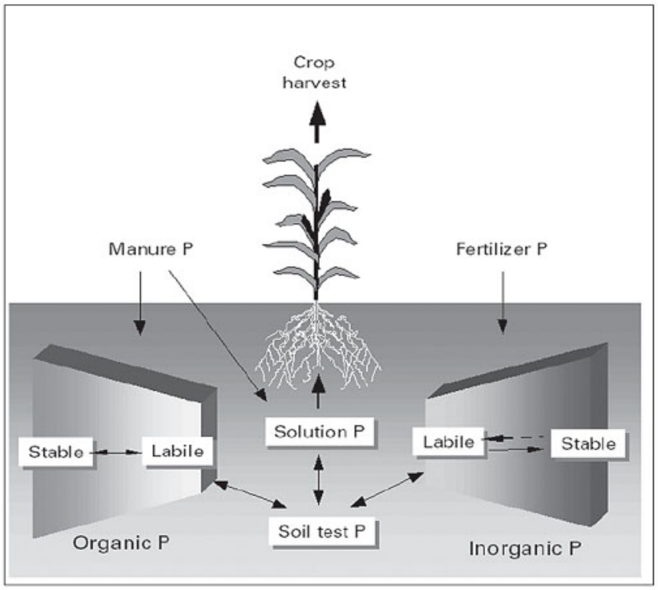


Figure 21 — The main phosphorus pools in soil. (Sharpley 2006)

Commercial fertilizer containing phosphorus is manufactured by converting rock phosphate [$Ca_3(PO_4)_2$] into a product that is much more water soluble. Wet or dry treatment processes are used to produce phosphoric acid. The forms of P in the acid are orthophosphate or polyphosphate that converts to orthophosphate upon contact with soil. Either these fertilizers or manures provide the principal P inputs for crops in interaction with the P pools found in the soil (Figure 21).

According to Wortman et al. (2005), "Soluble Soil P is typically less than 1% of total soil P and is readily available to plants. Labile Soil P is typically less than 5% of soil P and is less tightly bonded than stable P. Stable P is more than 95% of the total soil P. It includes tightly bonded P in secondary and primary minerals and in organic forms." Orthophosphate is readily used by plants and it is the form of interest relative to the increasing DRP load to Lake Erie. It is a key nutrient in the development of harmful algal blooms (HABs). Application of fertilizer to soils causes an initial increase in soluble P at the point of contact, but chemical equilibrium is rapidly re-established as much of the P enters the labile pool (Wortman et al., 2005).

All of the forms of commercial phosphorus fertilizers in use today (Superphosphate [$Ca(H_2PO_4)_2$ + $CaSO_4$, 7.5-9% P], Concentrated Super Phosphate [also $Ca(H_2PO_4)_2$, but without $CaSO_4$, 17-23% P], Monoammonium Phosphate [MAP], Diammonium Phosphate [DAP] and Ammonium Polyphosphate [APP]) exhibit relatively high water solubility (>80%) compared to the insolubility of the rock phosphate [$Ca_3(PO_4)_2$] used as the starting P material in making superphosphate and concentrated super phosphate fertilizers. The more soluble commercial fertilizer forms have been in use since the 1940s, therefore the increased solubility of fertilizers is not considered to be a recent change that is contributing to the increasing DRP loads and the recurrence of the algal blooms in Lake Erie.

4.2.1.4 — Manure Phosphorus Fertilizer

Manure is another source of fertilizer utilized on the agricultural landscape and includes both organic and inorganic phosphorus compounds. Land application of manure is estimated to contribute approximately 27% of the annual fertilizer input in the Lake Erie basin (Figure 19).

Manure has been used for many centuries as an important source of fertilizer. Sources include animal manure, various types of compost, and biosolids. In manure, 45-70% of the P is inorganic, and the rest is organic. While dependent on soil temperature, soil pH and soil moisture, organic P decomposes and mineralizes somewhat readily, with the final decomposition product being orthophosphate (DRP) (Rehm et al., 2002).

Kleinman et.al (2002) compared the relative solubility between different types of manure P and diammonium phosphate (DAP) fertilizer, a commonly used commercial fertilizer. They compared dissolved P in runoff from plots applied with swine, dairy, and poultry manures with runoff from a plot fertilized with DAP. Each manure type released soluble nutrients in runoff in concentrations less than, but at least half of the value of concentration of soluble nutrients released by DAP. Similarly, Mallarino and Haq (2009) found DAP contributed much higher concentrations in runoff generated from fields treated with equal amounts of DAP, swine, poultry, or beef manure (100 lb P_2O_5/acre) applied without incorporation into the soil (Figure 22).

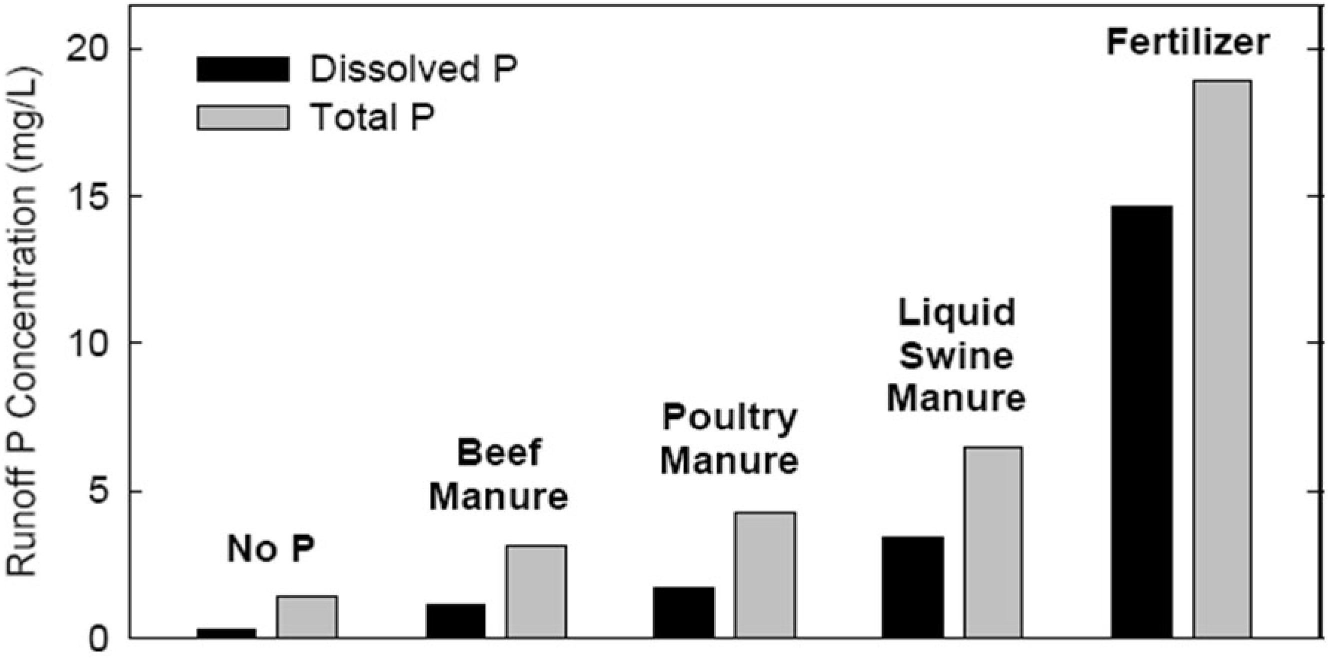


Figure 22 — Runoff P concentration within 24 hours of applying 100 lb P2O5/acre using fertilizer (DAP), beef, poultry, or swine manure without incorporation into the soil (averages across 21 Iowa fields). (Source: Mallarino and Haq, 2009)

The amount of P applied to the Lake Erie drainage basin as manure is related to the number of animals present and the relative P content and excretion rate of their respective manures. Accordingly, the Task Force quantified the livestock and poultry population in the Lake Erie basin using available data from the National Agriculture Statistics Service, Ohio Department of Agriculture-Livestock Environmental Permitting Program, Indiana Department of Environmental Management (IDEM), and interviews with Ohio livestock industry representatives. Using the estimated livestock and poultry inventory numbers, a calculation was made based on manure-P production estimates by species to estimate the current amount of manure-generated phosphorus land-applied in the Lake Erie basin. The total estimate of elemental manure P generated (and assumed to be land-applied) in the Lake Erie basin in 2007 is approximately 11,235 tons (10,192 MT) of manure-derived elemental P (Figure 19).

Swine

Swine inventory numbers reached a low point in 1993 (~611,400), down almost 30% from a 1984 inventory. However, swine numbers have since rebounded to a near historic high level (~860,000 in 2006). The Ohio EPA analyzed the swine population inventory in facilities in the Lake Erie basin, including those in Indiana and Michigan, and estimated ~950,000 swine were located in the basin in 2007. The mid-1990s marked a shift in swine housing towards larger and more concentrated swine facilities (960-1000 head per/barn, up to 2000 per barn). Today, almost all swine manure systems are liquid systems. In total, swine-generated elemental P was estimated to be 3800 tons (3447 MT) P in 2007 which is approximately 34% of all Lake Erie basin manure production.

Cattle (Dairy and Non-Dairy)

The reported inventories for cattle in the Ohio Lake Erie basin were highest in 1975 when numbers exceeded 603,000 head. By 1997 the cattle inventory in the Ohio Lake Erie basin had decreased to 339,000, a drop of almost 44%. For the past 10 years, however, cattle inventories in the Ohio Lake Erie basin have remained relatively constant at around 338,000 head.

Cattle herds can be on pasture, in complete confinement, on open-feedlots, or a combination of these systems. Manure management in open confinement areas is crucial to efficient agronomic use of manure nutrients due to the exposure to precipitation. In a confinement system, manure may be managed as a solid pen-pack material, or as is the case in larger cattle confinement facilities in Ohio, liquid manure storage and management systems are primarily used.

While overall cattle numbers are down, dairy cattle inventories in the Ohio Lake Erie basin show an increase of 39% since 2002. Beginning in the late 1990s, a trend toward construction of large, confined dairy facilities with herds from 650 to 3000 head began to occur. Many new dairies are located in the Lake Erie basin, especially the upper Maumee watershed in Michigan, Indiana, and Ohio. The largest dairy operations, i.e., those with greater than 500 head, handle the bulk of their manure as a liquid. Dairies with more than 700 head are also required (under Concentrated Animal Feeding Operation Rules) to contain and manage storm water runoff from the production area.

In total, cattle-generated elemental P was estimated to be 5670 tons (5144 MT) P in 2007, which is 50% of the total Lake Erie basin manure production. Approximately 36.5% of all cattle manure generated in the Lake Erie basin (from OH, IN, and MI) is generated by producing dairy cows.

Poultry-Egg Laying and Turkey Operations and Poultry Manure Brokering

Ohio EPA analyzed the poultry layer population and grower turkey inventory to include Ohio, Indiana and Michigan facilities in the Lake Erie basin and provided an estimate of 7.72 million hens and pullets (baby hens) and 266,000 grower turkeys located in the basin in 2007. NASS data are vague with respect to poultry operations. The Ohio Department of Agriculture, Livestock Permitting Program provided inspection data for Ohio where approximately 87% of the Lake Erie basin egg-laying hens and pullets are located. These data were considered to be an accurate source for inventory and manure generation calculations. Almost all of the Lake Erie basin turkey population is located in Ohio.

A large portion of the Lake Erie basin egg-layer inventory sits on or is very close to the Lake Erie/Ohio River watershed divide in Ohio. In those cases, a 50% adjustment was made to account for poultry manure anticipated to be land applied outside the Lake Erie watershed. In western Ohio, an estimate was needed to account for poultry manure generated outside the Lake Erie watershed (especially in Grand Lake St. Mary’s and Wabash River watersheds) and hauled north into the Lake Erie watershed.

For poultry-egg laying generated manure-P, approximately 870 tons (789 MT) of P (7.7 % of Lake Erie basin manure production total) was generated in 2007. For turkey generated manure-P, approximately 260 tons (236 MT) P (2.3 % of Lake Erie basin manure production total) was generated in 2007. Poultry manure brokered into the Lake Erie watershed was estimated to contain at least 640 tons (581 MT) of elemental P in 2008 or 5.7% of the annual total estimated manure-generated phosphorus in the Lake Erie basin.

4.2.1.5 — Biosolids in the Lake Erie Basin

Application of biosolids from wastewater treatment plants onto agricultural land may only be done according to Ohio EPA permit requirements. Estimates provided by Ohio EPA show that approximately 123,000 tons (111,503 MT) of biosolids were land applied in the Lake Erie watershed in 2007. Ohio EPA conducted a literature review and a cross verification of Ohio NPDES biosolids monitoring reports and found that phosphorus concentrations in biosolids are highly variable and are dependent upon the type of wastewater treatment plant and how the biosolids are processed. Typical concentrations of phosphorus in biosolids range from 10,000-36,000 mg/kg.

Using the tonnage described above, this calculates to a range of 1,230 tons (1116 MT) – 4,428 tons (4017 MT) (average = 2,829 tons/2566 MT) of total elemental P per year from land applied biosolids in Ohio. This estimate does not include biosolids generated and land applied from municipalities or industries in Lake Erie basin counties of Indiana and Michigan. As previously stated, land application of biosolids represent 6.8% of the total application of fertilizer.

4.2.1.6 — Glyphosate as a Source of Phosphorus

Another potential source of phosphorus is the application of glyphosate. Glyphosate is the main chemical in the commonly applied herbicide Roundup which is also used to pre-treat corn and soybean seeds prior to planting. The preliminary results of recent research by McKay and Bullerjahn of Bowling Green State University suggest that blue-green algae (cyanobacteria) can utilize the phosphonate portion of the glyphosate molecule. Phosphonate is traditionally viewed as a form of phosphorus that is not highly bioavailable. The researchers estimate that as much as 1,000 metric tonnes of Roundup is applied in the Lake Erie watershed per year, and it is being detected in adjacent waterways particularly in the spring. The next step in their research is to determine if the presence of glyphosate is increasing the amount of blue-green algae (Brannan 2009).

Mullen and Diedrick (2009) took a different look at glyphosate to determine if it could be a significant source of phosphorus loads. The 1,000 metric tonnes of glyphosate converts to about 2.2 million pounds. Assuming that the phosphonate content of glyphosate averages 15% (depending on the formulation) it works out to about 330,000 lbs. of phosphonate (approximately 150 metric tonnes of elemental P) applied. Spreading this over the approximately 3.7 million acres of corn and soybeans in the Lake Erie watershed that would likely receive glyphosate treatment, results in about 0.1 lbs per acre, most of which should be absorbed in the process of killing weeds. Although it does not appear to represent a significant threat to water quality, there may be a risk of transport if glyphosate is applied near surface waters or when conditions threaten a major storm water/sediment runoff event.

4.2.1.7 — Balance of Agricultural Phosphorus Inputs and Outputs

Based upon current estimates from NASS on crop acres and productivity in the state of Ohio, state-wide fertilizer sales trends, and manure generated from animal production, the state of Ohio has been approaching a phosphorus balance in the last decade (Figure 23). This “balance” has historically not existed. This balance between phosphorus inputs (fertilization of both commercial fertilizer and animal waste) and phosphorus crop removal is likely the result of several factors including: higher fertilizer prices; decreased animal numbers; improved crop productivity; newer crop varieties and hybrids; and increased awareness of nutrient management.

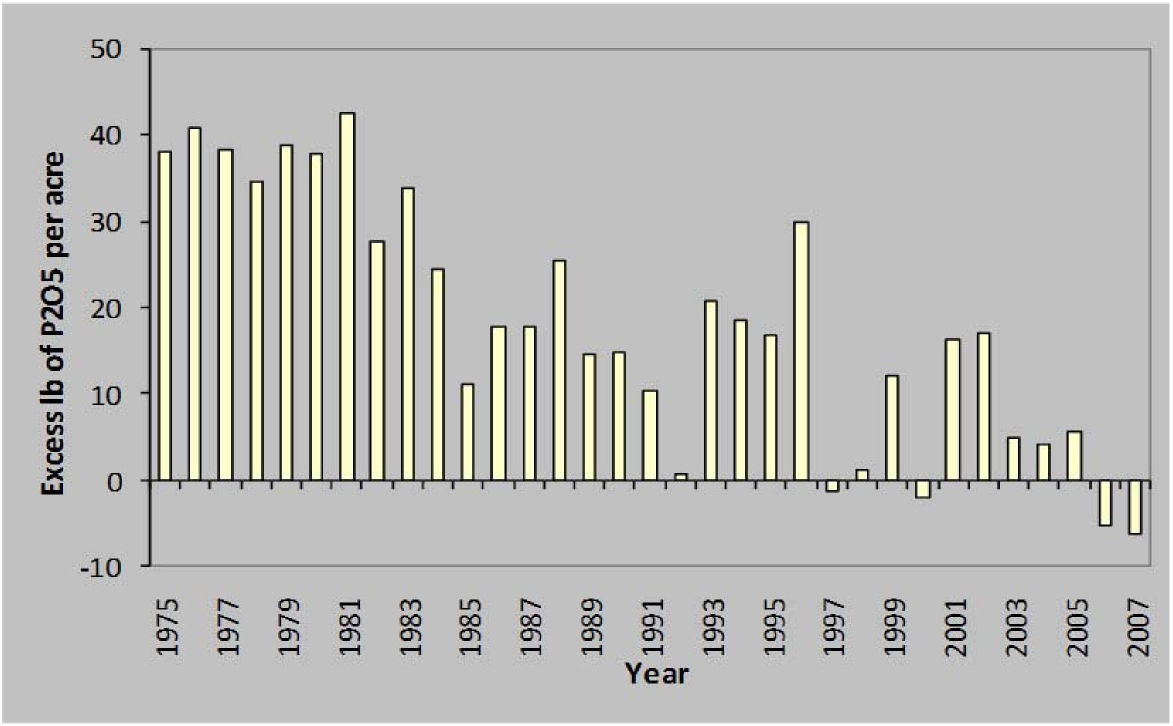


Figure 23 — Excess phosphate per acre based upon commercial fertilizer sales information in the state of Ohio, manure generated from animal operations and the resultant amount of phosphorus that theoretically will be land applied, and crop removal phosphorus estimates based upon USDA-NASS information. (USDA-NASS, 2007; Terry, 2006; OSU, 2006; Bast et al., 2009)

Despite this net balance, the DRP load to Lake Erie continues to increase. This suggests that there are changes in agriculture having an effect on the delivery of DRP to Lake Erie. Nutrient inputs to the Lake Erie watersheds need to be managed carefully for the timing of applications, the amount applied and the degree to which applications are incorporated into the soil profile.

Some of the aspects that may be influencing changes in nutrient movement include:

- Changes in tillage practices, such as increases in the use of minimum till and no-till. In addition, there is more fall preparation of seedbeds for spring planting (stale seedbeds).
- Changes in drainage and runoff related to installation of surface drainage systems; installation of additional subsurface drainage on closer spacing; enlarging fields and removing fencerows; and utilizing tillage practices that minimize surface roughness.
- Larger farms and larger fields have resulted in changes in the type and size of equipment used. Planters and tillage equipment range from 30 to 120 feet in width compared to those 12 to 24 feet in width used in the 1970s. Larger farms require spreading the work load over the year which increases the tendency of applying fertilizer after crop harvest.
- Changing methods, amount, form, timing and placement of nutrients, such as; more surface application of nutrients with less incorporation, instead of using row fertilizers.
- Unknown and uncertain use of soil testing to assess field nutrient levels prior to application and unknown and uncertain adherence with nutrient application recommendations.
- Changes in soil quality, such as: decreasing soil organic matter content, soil tilth and infiltration rates; and increasing compaction, soil densities and aggregation.

- Phosphorus build-up (stratification) in the upper two inches of the soil may result in increased DRP concentrations in runoff water. Stratification can result from surface application of fertilizers and manures and the phosphorus releases from the breakdown of crop residue in the soil surface. Further study is needed on the extent of stratification and its potential role in DRP in runoff.

Positive changes in nutrient management include utilizing precision farming and grid sampling which result in more detailed specificity in the application of fertilizers designed to meet agronomic needs. However, these practices have not been adopted at a scale sufficient to counteract excessive movement.

Task Force participants readily acknowledge that these trends are having significant impact in agricultural management. And based on what we know today, these trends are nearly impossible to quantify in terms of their contribution to nutrient movement from fields to the western basin of Lake Erie. The research recommendations discussed later in this report will yield many answers to the knowledge gaps we have. But the Task Force also acknowledges that much needs to be done to address nutrient management in the near term to address the issue of algal blooms.

The ability of soils to adsorb phosphorus and the soil nutrient interactions for many of the over 400 soil types in Ohio (especially the lakebed soils of the Lake Erie basin) are not well known and will require additional research. Current tools to assist agricultural managers with nutrient management include the use of soil tests and other indices. These tools provide managers with the data and assessment of field-based conditions to guide nutrient inputs to agricultural fields. While these tools have been in use for many years, their application needs to increase significantly to adapt nutrient management practices to highly variable and frequently changing conditions. The following section describes these tools and their current application in Ohio.

4.2.1.8 — Soil Tests and the Phosphorus Index

The Ohio State University is the primary source of agricultural nutrient recommendations in Ohio. Recommendations were developed for the Tri-State area of Ohio, Michigan and Indiana through collaboration with Ohio State University, Michigan State University and Purdue University. These recommendations are agronomic in nature and based upon soil test information. Current phosphorus recommendations were developed through years of field experimentation to identify a soil extractant that provides a good approximation of available phosphorus, and are now based upon Bray-Kurtz P1 extractable phosphorus. This is an acidic solution that causes aluminum and calcium-phosphate minerals to dissolve representing the soil's ability to re-supply solution phosphorus during a growing season as plants take up phosphorus from solution. Thus available P, expressed in a soil test report, is not a measure of solution P.

Critical levels and rate recommendations were then determined based upon correlations between crop yield and soil test level. Based upon several site years of information collected at the Western Research Station of the Ohio Agricultural Research and Development Center, the critical level for both corn and soybeans was identified at 15 ppm or 30 pounds per acre (Figures 24 and 25). These two figures illustrate that as soil test phosphorus approaches 15 ppm (30 pounds per acre) the probability of nutrient deficiency decreases as does the probability of crop response to additional phosphorus. Traditionally, critical levels are set when the percent of maximum yield surpasses 95% which is evident from both figures at or near 15 ppm/30 pounds per acre. Current Tri-State critical levels for soil test phosphorus are presented Table 5.

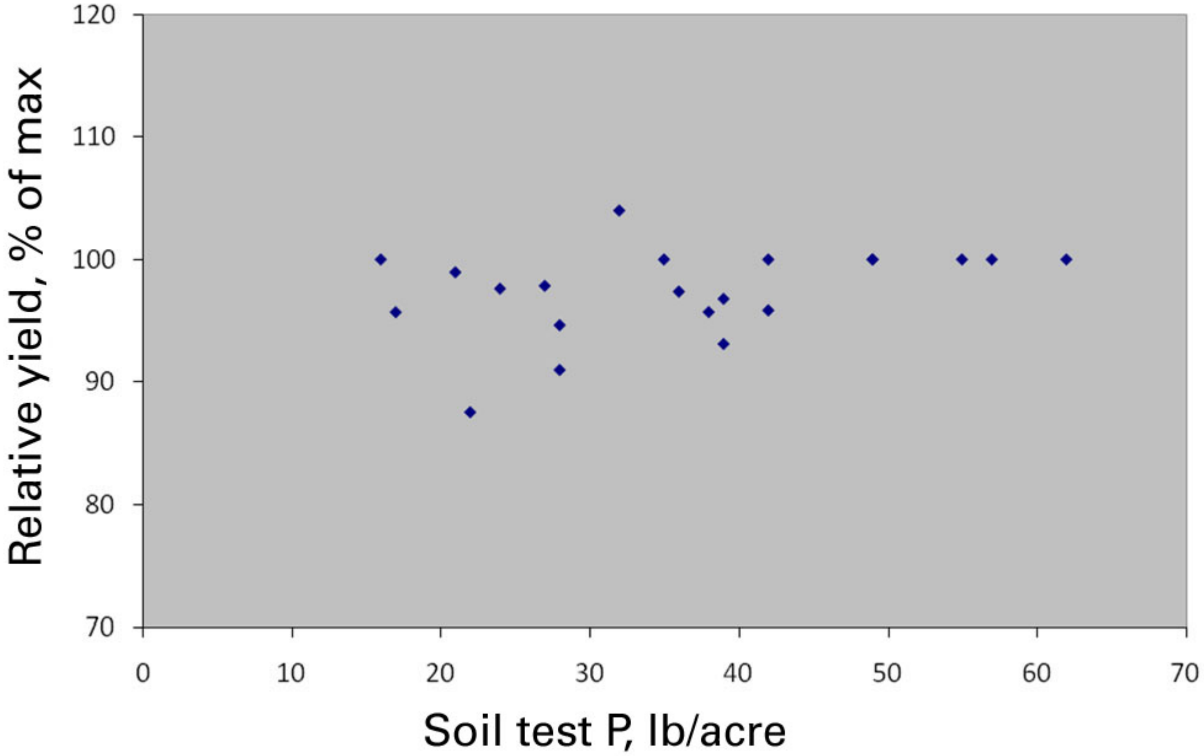


Figure 24 — Correlation between soil test P level and corn relative yield as the result of tests conducted at the Western Research Station of the Ohio Agricultural Research Development Center, 1993-1999

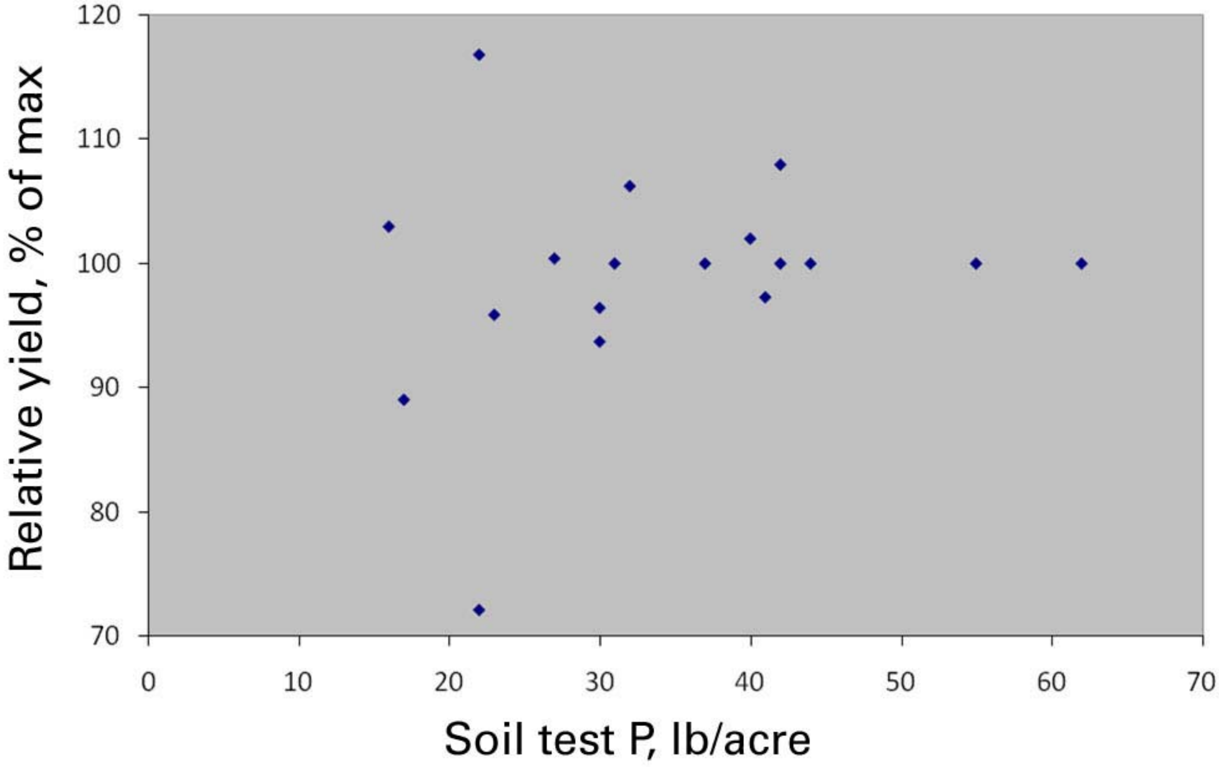


Figure 25 — Correlation between soil test P level and soybean relative yield level tests at the Western Research Station, 1994 – 1999

Table 5 — Current critical soil test phosphorus levels for corn, soybean, wheat and alfalfa. (OSU Extension Bulletin E-2567)

Crop	Critical level ppm (lb/acre)
Corn	15 (30)
Soybean	15 (30)
Wheat	25 (50)
Alfalfa	25 (50)

Ohio fertilizer recommendations are based upon a build-up, maintenance, drawdown concept. Soils with soil test phosphorus levels below the critical, receive recommendations designed to increase the soil test to the critical level within four years. Soils with soil test phosphorus levels at or slightly above (plus 15 ppm or 30 pounds per acre), receive a recommendation designed to replace crop removal so as to maintain current soil test levels. Soils with soil test phosphorus levels well above the critical (> 15 ppm or 30 pounds per acre), receive recommendations that decrease the recommended phosphorus rate to reduce soil test levels. Soil with soil test levels well above the critical (≥ 40 ppm or 80 pounds per acre for corn and soybeans), receive a phosphorus recommendation of zero.

Many land grant universities do not utilize the build-up, maintenance, and drawdown approach to phosphorus recommendations. However, due to spatial variability in soil test phosphorus, the Tri-State continues to endorse the build-up, maintenance, and drawdown approach. Fields that have soil test levels near or just slightly above the current critical level are likely to have areas of the field where soil test P is below the critical. In order to ensure that these areas are as productive as possible, the field still receives a phosphorus recommendation. Current Tri-State phosphorus recommendations for corn and soybeans are present in Tables 6 and 7.

Table 6 — Current Tri-State phosphorus recommendations for corn. (OSU Extension Bulletin E-2567)

	Yield potential (bu/acre)				
Soil test	100	120	140	160	180
ppm (lb/acre)	------------lb P_2O_5 per acre---------				
5 (10)	85	95	100	110	115
10 (20)	60	70	75	85	90
15-30 (30-60)	35	45	50	60	65
35 (70)	20	20	25	30	35
40 (80)	0	0	0	0	0

Table 7 — Current Tri-State phosphorus recommendations for soybeans. (OSU Extension Bulletin E-2567)

	Yield potential (bu/acre)				
Soil test	30	40	50	60	70
ppm (lb/acre)	------------lb P_2O_5 per acre---------				
5 (10)	75	80	90	100	105
10 (20)	50	55	65	75	80
15-30 (30-60)	25	30	40	50	55
35 (70)	10	15	25	25	30
40 (80)	0	0	0	0	0

In response to continued degradation of surface water, the USDA-NRCS in each state has been mandated to choose a P-based nutrient management strategy. One of these approaches has been establishing a P risk index system to evaluate the risk of P transport. Lemunyon and Gilbert (1993) first proposed the P risk index in order to identify agricultural fields vulnerable to P loss (transport). In a P Index, site characteristics contributing to P loss are considered, and weighting factors (modifiers) are often applied to account for differences in each characteristic's relative contribution to P loss (Dayton and Basta, 2005). In Ohio, the risk of agricultural P transport into surface water is assessed by either the USDA-NRCS-Ohio P Index Assessment Procedure or the Soil Test Risk Assessment Procedure (STRAP) within the Nitrogen and Phosphorus Risk Assessment Procedures (Ohio NRCS, 2001).

The Ohio P Index is a procedure that combines well established factors that influence the transport of P from agricultural fields to surface waters. Each factor is evaluated based on site specific data and weighted, or modified, according to its overall effect on P transport. Each of the site sub-values are added together to establish an overall site rating, or score, of Low, Moderate, High or Very High risk. The P Index is a tool used to evaluate the risk of agricultural P transport at the field scale. All P indices, including Ohio's, consider both P transport and source factors. Transport factors considered in the P Index include: soil erosion potential; field runoff class; and connectivity to water. Source factors considered in the P Index include: soil test P (STP); planned amount of P fertilizer (manure/biosolids or inorganic) applications; and method of P fertilizer application (management). In addition, the P Index score is reduced by 2 points if a designed filter strip (≥ 33 ft wide) is installed to intercept surface runoff.

Based on the risk assessment score, the appropriate land treatment and nutrient application treatments can be planned to minimize phosphorus transport from the site. Field characteristics relevant to both P transport and P source factors considered in the Ohio P Index are shown below.

P Index Score = Transport Factors + P Source Factors

Transport Factors	P Source Factors
Soil erosion potential	Soil test P
Connectivity to waterway	Planned P fertilizer applications
Runoff class (slope)	Method/timing of fertilizer application
Presence of filter strip	

Initially used to assess risk, the P index is nationally developing into a tool to evaluate alternative management practices for planning and regulation of P application (Benning and Wortman, 2005). In fact, currently the Ohio NRCS is reviewing the Ohio P Index with the intention of validating and, if necessary, revising the parameters presently used. A team of agency representatives, scientists and agriculture professionals has been assembled, as the Ohio P-Index Revision Team, to accomplish this effort. The existing Ohio P Index parameters are programmed into the Purdue Manure Management Planner (MMP). Ohio NRCS requires the use of the MMP software when developing a Comprehensive Nutrient Management Plan (CNMP). Therefore, whenever a CNMP is developed the P Index is being utilized to help prioritize fields for nutrient application. A P Index system is especially valuable for sites that may already have excessive STP, in that it considers a multitude of management practices which can be used to reduce the risk of P transport.

The Soil Test Risk Assessment Procedure (STRAP) is used to predict risk of P transport based on the Bray-P1 extractable STP level. As STP levels increase above150 mg/kg Bray-P1 it is presumed that there will be an increase in P transport and no additional phosphorus application is recommended. Once field STP levels exceed 150 mg/kg Bray-P, the P Index can be used to evaluate risk of P transport and it is possible that the use of the P Index may allow for additional P application. The benefit of a threshold P level is it is quicker and easier to explain to farmers, suppliers and nutrient applicators than the P Index. It is understood that the P soil test threshold number will be higher than agronomic P sufficiency for crop needs. However, considering the increase in DRP in Ohio streams, the current threshold value of 150 mg P/kg is being brought into question. Currently, 150 mg kg^{-1} Bray-P1 extractable P is considered the threshold STP level where risk of increased P transport is considered likely. Testing the validity of this claim and identifying a soil P test method, whether it continues to be Bray-P1 or another, that is strongly related to P runoff (transport), have been identified as top priorities of the Ohio NRCS sponsored, Ohio P-Index Revision Team. As illustrated in Figure 26, soil has an assimilative (binding) capacity for P. Phosphorus becomes more soluble and the risk of P transport increases as the soils assimilative capacity is exceeded.

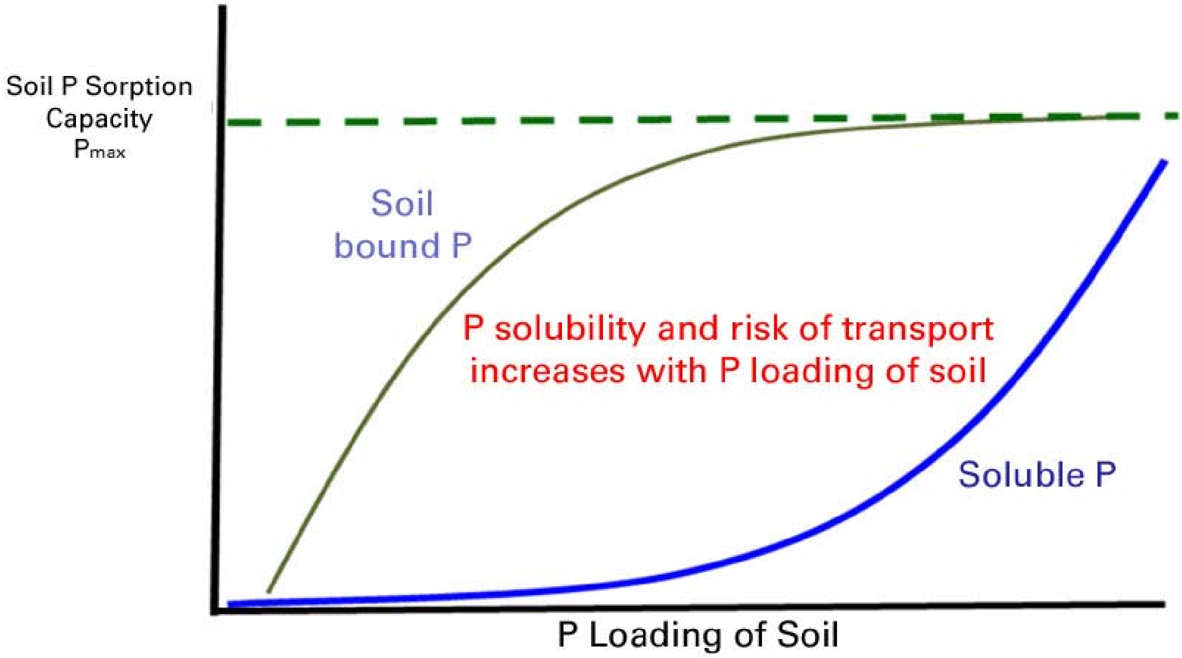


Figure 26 — Schematic presentation of the assimilative binding capacity of soil for phosphorus

Many factors influence whether P is bound to the soil or dissolved in the soil solution, as discussed in Section 3.3. An example of the complexity is illustrated by the data plotted in Figure 27. These data are from a long term small plot P runoff experiment being conducted at the Ohio State University, Waterman Research Farm. Relationships between STP and runoff dissolved P (RDP) under varying treatments are being evaluated using simulated rainfall. Thirty-two field plots (2x2m) were established and initial background surface STP (22 to 136 mg/kg Bray-P1) and RDP (0.12 to 1.4 mgP/L) were determined. Varying amounts of poultry litter were thoroughly tilled into the plots to provide a broad range of STP levels and the plots were allowed to age for 1 year. The plots were re-evaluated after one year and STP ranged from 30.5 to 753 mg/kg Bray-P1, and RDP ranged from 0.14 to 3.0 mgP/L. With all of the data plotted for the entire experiment with and without added manure, Figure 27A shows a strongly significant ($r^2 = 0.68$, $P<0.01$) relationship between RDP and Bray-P1. However, a closer examination suggests that this relationship may be misleading and not represent what is happening at low STP.

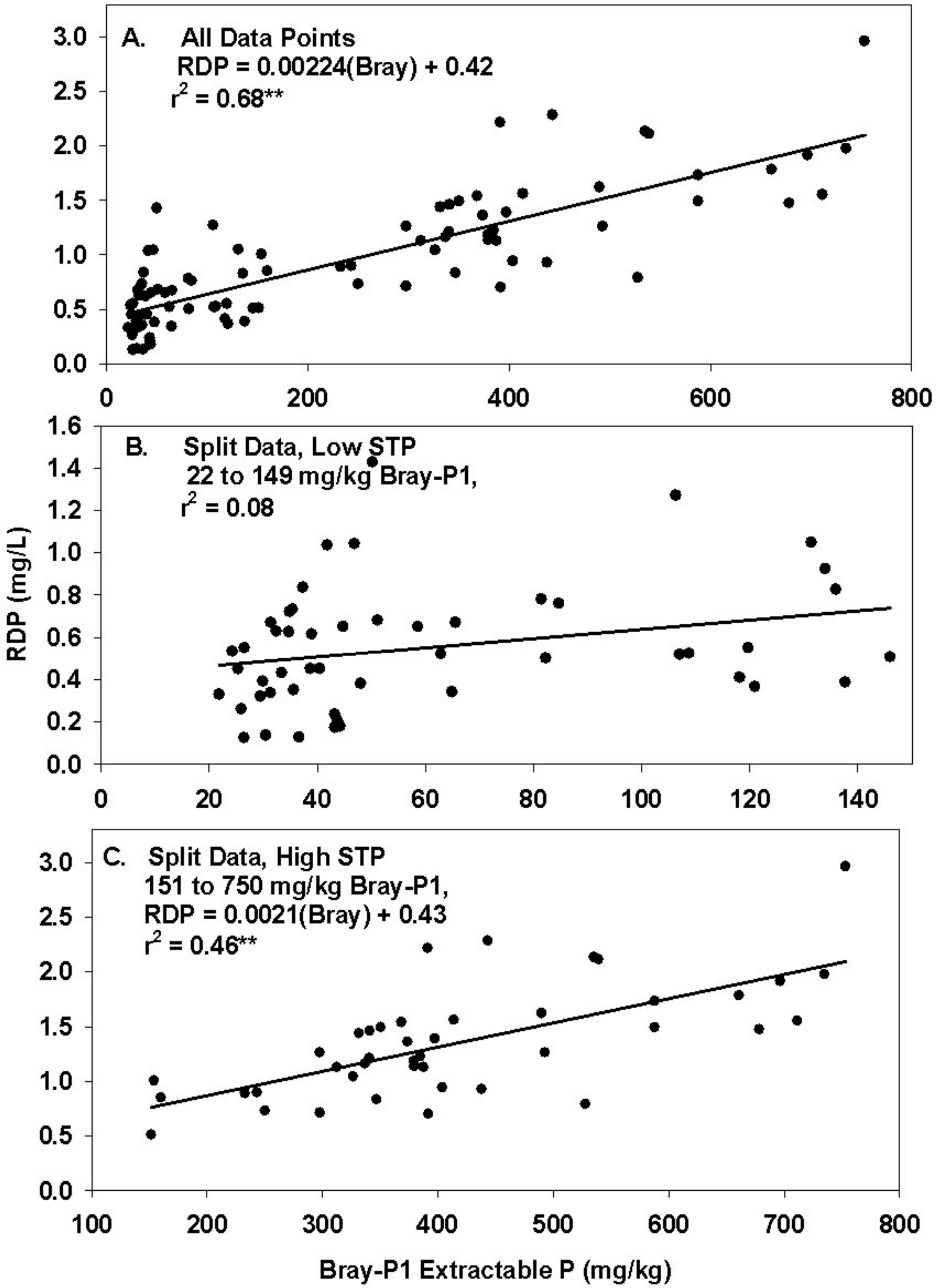


Figure 27 — The complexity of the relationship between soil test phosphorus (STP) and runoff dissolved phosphorus (RDP) under varying treatments using simulated rainfall. (Note: RDP is equivalent to DRP)

In Figure 27B, only lower STP (22 to 149mg/kg Bray-P1) samples are plotted. There is no relationship between RDP and STP, with RDP ranging from 0.12 to1.4 mgP/L. The variability in RDP at seemingly low STP levels is not surprising. Soil P solubility/runoff potential is controlled by a combination of P mineralogy (speciation) and soil properties as well as by the actual amount of soil P, as discussed in Section 3.3. This is especially apparent at low levels.

Figure 27C considers only the higher STP (149 to 753 mg/kg Bray-P1) and again there is a significant ($r^2 = 0.46$, $P<0.01$) relationship between RDP and STP. When soil P is excessive, soil properties relevant to P assimilation become saturated and P solubility/runoff P control is shifted toward the mineralogy (speciation) of the added P (fertilizer/manure). It is interesting that, while the addition of high levels of poultry litter resulted in an almost six-fold increase in STP, there was only an approximately two-fold increase in RDP, again, illustrating the soil's assimilative capacity to bind P.

Ideally, a soil test used to evaluate P transport risk should function across a range of soil types, STP levels, and management practices. Although STP is not the only site characteristic that contributes to P transport, identifying a STP level where P solubility begins to rise sharply is an important part of understanding the risk of P transport. Traditionally, phosphorus soil tests are designed to predict the amount of P available for crop nutrition and the probability of a crop response to P fertilizer across a growing season (Bray and Kurtz, 1945; Mehlich, 1984). Due to increasing concern about P transport and water quality issues, there has recently been an attempt to extrapolate STP data to predict risk of P transport (Dayton and Basta, 2005; Sims et al., 2000; Hooda et al., 2000; Pote et al., 1996; Sharpley et al., 1996; Sharpley, 1995). However, little comprehensive data across a range of STP under varying site conditions (tillage, soil type) is available to determine if this extrapolation is valid (Sims et al., 2000). Further, it is likely that other STP methods, not directly related to crop fertility, may do a better job at predicting risk of P transport.

Some small plot work has shown agronomic soil tests, such as Bray-P1 and Mehlich 3, correlate with DRP (Pote et. al., 1996; Sims et al., 2002; Andraski and Bundy, 2003). However, application of these models to soils with different P retention properties has not been successful (Schroeder et al., 2004), possibly because both Mehlich 3 and Bray-P1 are strong acid fluoride extractions. Some recent work has suggested that water or weak salt solution extractable P may mimic what happens in soil during rainfall and so better predict runoff P (Dayton and Basta, 2005; Hooda et al., 2000; Pote et al., 1996).

Another potential issue that may make extrapolation of soil fertility P testing inappropriate for evaluating environmental P transport risk is that when STP is used to evaluate fertility for crop nutrition the soil is sampled up to 8 inches deep, to represent P availability in the root zone. However, runoff P is a surface phenomenon and is strongly related to the upper couple of inches of soil (Sharpley and Halvorson, 1994). If the soil is well mixed and the STP is consistent throughout the soil test depth there is no problem. However, if soil P becomes stratified due to surface applications of P fertilizer that are not incorporated into the soil, a surface soil sample may be more representative of P transport risk than a soil sample used to evaluate crop nutrition. This may become increasingly important in no- or low-till situations.

Increased robustness of the relationship between STP and runoff P will make STP a powerful and inexpensive tool to make accurate estimates of the risk of P transport. However, in order to be robust, models must be developed across different soils and tillage/management practices, across different soil P levels and perhaps using surface soil samples, as these factors may alter P retention and release (Dayton and Basta, 2005; Sharpley, 1995; Sharpley et al., 1996; Pote et al., 1999). Nationally, as well as in Ohio, this has implications for previously set STP thresholds as well as the soil test methods used that are presumed to be protective of surface water quality.

4.2.1.9 — Fall and Winter Fertilizer Application

Fall and winter application of agriculture nutrient applications is often identified with increased potential for nutrient runoff. The runoff potential is a result of application on frozen or snow covered ground, when there is little to no opportunity for plant uptake or for the nutrients to incorporate into the soil leaving the nutrients susceptible to runoff. Recent trends in weather patterns in the Ohio region indicate higher intensity storms overall and less snowfall in winter. These trends parallel observed increases in winter runoff and associated increases in DRP.

Many factors influence nutrient applications in the fall and winter. Fertilizer dealers must turn over their inventory, particularly in the months between harvest and the end of planting. The quicker a dealer can turn their inventory, the more likely they can purchase new inventory at a lower price. Historically, fertilizer costs rise almost weekly over the winter as spring demand approaches. Most dealers need to turn their inventory 6-10 times during this period.

Farmers must also manage their inventories for space and cost considerations. Farmers may not be able to buy all of what they will need for a season due to inventory limitations. At the same time, farmers must be concerned about having the material on hand at the time they have available to apply.

Labor and equipment availability in the winter months are key considerations for both dealers and farmers. The more days a dealer can make the equipment available, the more opportunities it will be used by area farmers, adding more profit with existing assets. Likewise, farmers experience the same concern about optimizing availability of labor and equipment. Farmers also want to avoid soil compaction, a particular consideration with the tight clay soils of northwest Ohio, creating more incentive to utilize heavy equipment on frozen ground.

There are also many time sensitive tasks in the late winter, early spring timeframe that affect both dealers and farmers. These include:

- Seed and herbicide delivery and application
- Wheat nitrogen top dress, insecticide and fungicide
- Corn starter delivery
- Adapting to changes in plans (crops, labor and other business operations)
- Nitrogen delivery and application for corn
- Equipment upkeep

These activities occur during a critical time period in preparation for the upcoming crop year. If a delay to apply fertilizer goes on too long, a farmer may not apply for the crop year, creating missed opportunities for the dealer and farmer concern of lost yields. Some farmers will look to apply a double application the following year to make up for the missed application. There are also misperceptions that remain among some farmers about how long nutrients must be on the ground to break down and enter the “soil solution” to be available for the impending crops to take them up. All of these influences must be taken into account as we look to adapt past practices for agricultural production and reduction of nutrient runoff (Joe Nestor, Nestor Ag LLC, personal communication).

4.2.1.10 — Agricultural Summary and Recommendations

Agriculture is the largest land use in the Lake Erie watershed, especially in the western Lake Erie basin. While the DRP has been increasing, phosphorus application to cropland has decreased, crop production and yields have increased, soil erosion levels have decreased, and particulate phosphorus monitored in the streams has decreased. We do not have all the answers at this time as to what is causing the increasing DRP, but there are research projects underway and proposed that will provide the much needed information to direct future actions.

Given the changes and trends in agriculture previously discussed, we do know that agriculture needs to begin addressing movement of nutrients as best we know how right now. While there is a lack of evidence that differentiates the relative contribution of application of commercial fertilizers and land application of manure to P runoff, we do know that practices that address the methods, amount, form, placement, timing and incorporation will significantly benefit both sources of DRP. And, while there are many uncontrollable limitations and factors that enter into management of any landscape, including weather conditions which can change on a daily, weekly, monthly or annual basis, there are several Best Management Practices for nutrient management that need to be utilized. These practices have been documented to Avoid, Control and Trap (ACT) nutrients from getting into our streams and lakes. The list of recommended priority practices is presented in Appendix B. These practices address the timing, amount and incorporation considerations and apply to both the application of commercial fertilizers and land application of manure.

Some of these practices include:

- Soil testing according to University recommendations for frequency and sampling methodology;
- Follow Tri-State Fertility recommendations for application of additional nutrients to attain the planned for crops and yields;
- Applying nutrients to a growing crop or cover crop significantly increases the chance for nutrients to be taken up and temporarily stored in plant tissue. The growing crop also reduces soil erosion and increases water infiltration reducing both DRP and particulate P;
- Apply additional nutrients under conditions that will reduce chances of movement off site, avoiding frozen and snow covered ground application when possible and incorporating nutrients into soil where possible;
- Encourage and promote Recommended BMPs for nutrient management (Appendix B); and
- Utilize and install more effective hydraulic buffers (such as filter areas, wetlands, controlled drainage, cover crops and other practices in Appendix B) designed to reduce the rate and amount of water leaving the landscape and to filter and treat nutrients moving from the field to and through surface and subsurface drainage systems, waterways, streams and rivers.

Additional and more detailed actions can be found in the Recommendations Matrix.

4.2.2 — Urban/Residential Sources of Phosphorus

4.2.2.1 — Urban Storm Water Runoff

Storm water runoff from urban areas is another source of phosphorus loading and can be locally significant. Phosphorus in urban runoff is generated from multiple sources including sediments from erosion, fertilizers, detergents, leaves and other detritus, lubricants, animal waste (e.g., from Canada geese and pets) and organic and inorganic chemical decomposition (Carpenter et al., 1998; and Burton and Pitt, 2001). Data isolating urban phosphorus sources in Ohio are limited.

Information does exist regarding export coefficients associated with different land uses and representing loading rates that have been used by Ohio EPA to assess potential sources and to develop TMDL phosphorus targets (Ohio EPA, 2003).

One example that demonstrates localized significance of urban sources of phosphorus was shown by a study of nonpoint sources of phosphorus in Lake Champlain where 18% of the annual nonpoint source phosphorus load was attributed to urban lands although urban land use constituted only 3% of the area (Meals and Budd, 1998). Urban areas as well as agricultural croplands and livestock operations are a contributor of total phosphorus as shown by data from the Nationwide Urban Runoff Program (NURP) and other studies.

Just as the relative phosphorus concentration contributed from agricultural areas can be correlated with sediments associated with erosion from crop fields, an important portion of phosphorus contributed to urban or urbanizing streams is associated with construction site erosion and other significant erosion problems such as stream bank erosion. In one Wisconsin study, construction sites were associated with 28% of the phosphorus in streams. Land under construction has the greatest potential to generate phosphorus relative to other land uses, temporarily generating even greater loads per area than agricultural row crops (Burton and Pitt, 2001). As of March 10, 2003 Ohio EPA began implementation of Phase II storm water regulations which decreased the acreage-size for NPDES permit regulated constructions sites from 5.0 acres down to 1.0 acres. Some assumption of greater erosion and sediment control and lower phosphorus export might be made for these sites.

Phosphorus loads can also be generated from established impervious areas such as commercial, industrial, high density residential, freeways and parking areas (Burton and Pitt, 2001). Recently, the City of Columbus reported average event mean concentration (EMC) data for phosphorus and orthophosphate from a variety of catchments from four runoff events (one in each season). Although only one year of monitoring data was reported, Columbus found that the average EMCs for TP (0.19 mg/L) from three residential watersheds fell below the NURP book value of 0.47 mg/L. A commercial urban watershed and an industrial watershed were also monitored. The commercial watershed average EMC for total phosphorus (0.10 mg/L) fell below the NURP book value of 0.24 mg/L; but the industrial watershed average EMC for total phosphorus (0.41 mg/L) was higher than the NURP book value of 0.24 mg/L. There are no comparable data for Ohio cities in the Lake Erie basin.

As discussed in Section 2.5, urban land accounts for a small percentage of land area in northwest Ohio (8 to 14 percent). The Task Force concludes that any phosphorus contribution from urban runoff may have localized impacts, but is likely not a significant contributor to the algal blooms in the western basin. Targeting strategies to address local impacts will best be realized with existing permitting programs supported by more comprehensive monitoring on the use of storm water BMPs. Ohio EPA has issued two watershed specific storm water permits for the Big Darby and portions of the Olentangy River watershed for construction activities. These permits have additional requirements that differ from other construction activity permits to address the unique conditions in these watersheds. While these watersheds are outside the Ohio Lake Erie basin, the Task Force supports the use of this permitting tool in watersheds experiencing land use change that may be impacting water quality.

U.S. EPA has recently announced plans to strengthen the storm water program with a proposed rulemaking. The purpose of the rulemaking is to:

- Redefine the area subject to federal storm water regulations;
- Establish specific requirements to control storm water discharges from new development and redevelopment;
- Develop a single set of consistent storm water requirements for all municipal separate storm sewer systems (MS4s);
- Require MS4s to address storm water discharges in areas of existing development; through retrofitting the sewer system or drainage area with improved storm water control measures; and
- Explore specific storm water provisions to protect sensitive areas.

At the time of publication of this Task Force report, the comment period on the proposed rules was still open.

4.2.2.2 — Turf Grass Management

Research data and estimates presented by The Scotts Miracle-Grow Company (Scotts) and the USDA-Agricultural Research Service described the common elements of fertilizer management on turf grass, including the expanse of turf in the U.S., and how nutrients are managed on turf. These presentations and a review of several referenced research citations allowed for beneficial deliberation on turf and its relative contribution to DRP loading in Lake Erie.

Turf or sod, for the purpose of this report, is defined as the managed surface layer of soil, grass and the matted roots of the plants. Turf is located all around us, especially within the urban landscape where it includes home lawns, roadsides, park areas, golf courses, schools, sports fields, sod farms, airports, cemeteries, churches, commercial properties and other general areas. There are 40 to 50 million acres of turf in the United States (Milesi et al., 2005; Morris, 2003). Based on a review of various statewide surveys nationwide and other references, home lawns account for approximately 40 to 60% of the area of all turf location-types. This accounts for between 80 and 90 million home lawns nationally (data provided in ARS and Scotts' presentations). More specific to Ohio, the Ohio Turf Grass Association noted there were 4 million acres of managed turf in Ohio, statewide. Data for the number of acres of turf grass in the Lake Erie basin are not available.

It is also estimated that 56% of all home lawn areas receive some degree of fertilization. Nationally, Scotts estimates that 2% of all total fertilizer use falls into the home use segment (i.e., the do-it-yourself or garden care) of the fertilizer industry. Scotts provided data accumulated from Wisconsin and Michigan in 2006 that showed homeowner use of fertilizer was approximately 2% in Wisconsin and 3% in Michigan of the statewide annual use of fertilizer.

As with other land-use types, there are many factors that influence the concentration of phosphorus and runoff volume from turf. These factors include but are not limited to fertilizer type, method of fertilizer application, rainfall amount and intensity, climate, type and health of vegetation, depth of turf, and slope. Key human variables that influence concentration of turf runoff water include fertilizer selection (type) and the method, timing and amount of fertilizer application.

Timing of turf fertilization before runoff producing rainfall greatly increases the risk for phosphorus loss from turf, whereas, “watering in” the fertilizer (i.e., applying a light amount of water without causing runoff) greatly decreases phosphorus losses from turf by up to an order of magnitude (Soldat and Petrovic, 2008). Phosphorus runoff losses from turf have been found to vary directly with application rate (e.g., lbs. of product/1000 ft^2) (Shuman, 2001; 2003). Typical commercial fertilizer for lawns contains low concentrations of inorganic phosphorus, which is highly soluble. Slow-release fertilizers exist to reduce large losses caused by runoff during intense rainfall.

Due to high nitrogen requirements for turf, fertilizer selection should focus upon those with a high N:P ratio. For example, fertilizer designed for lawn use has a high N:P ratio versus products available for garden and landscaping that have much lower N:P ratio (i.e., higher P concentration). Consumer education and the separation of products on display (lawn from garden) have been implemented to reduce confusion for the customer when selecting a product. A method for recycling nutrients back into a turf system and minimizing the need for additional phosphorus fertilization is to leave mown clippings to decompose back into the soil. This practice eventually causes re-release of available phosphorus to the growing turf, one of several best management practices (BMPs) for turf fertilizer management that contribute to better water quality (Table 8).

Table 8 — Recommended Lawn-Care BMPs for Water Quality Protection

1) **Choose a low or no P fertilizer.**
   Apply a product with an N-P-K formulation of 26-0-3.
2) **Choose fertilizer designed for lawns.**
   The word “lawn or turf” should be on the label. “All purpose” formulations should be avoided for lawn use.
3) **Read and follow label directions.**
   Apply at the spreader setting recommended on product label. Do not apply if heavy rainfall is expected.
4) **Use a drop or rotary spreader with deflector shield to keep fertilizer on lawn.**
   Keep fertilizer, leaves and other organic matter off of walks and driveways to reduce loss to storm sewers and streams.
5) **Mow lawn at the highest setting and leave the grass clippings on the lawn.**
   Mowing high allows the grass to develop a deep root system that retains and uses water more efficiently. Returning clippings recycles nutrients.
6) **Fertilize in spring after first cutting and once again in the fall between Labor Day and Halloween.**
   Only apply fertilizer when grass is growing enough to be mowed.
7) **Soil tests can help identify if other nutrients are needed.**
   Contact your County Extension.

Reference: *www.cleanwaternj.org*

Healthier turf grass systems also have better water retention. The more water that stays in the soil, the less volume there is to carry soluble phosphorus away. In general, turf systems, unlike most row crop land use, are permanent, and have much lower runoff coefficients. That is, with all other variables equal, less volume of water runs off from lawns and turf systems annually than from agricultural land-use where fields are left bare or with limited residue. This ideal is an example of why there has been so much recent focus on promoting the use of cover crops (for water sequestration and nutrient uptake) between commodity crop plantings on the agricultural landscape.

Given the low ratio of turf land area to row-crop agriculture land area in the Ohio Lake Erie basin, the relative contribution of DRP load to Lake Erie from turf is likely to be low. The Task Force recognized the importance of BMP education for citizenry in urban settings, and also recognized recent efforts between the home and garden fertilizer industry and various states (e.g., Florida and Minnesota) to lower or eliminate phosphorus from home lawn products. Scotts intends to remove all phosphorus from lawn maintenance products by 2012 (personal communication, Chris Wible, The Scotts Miracle-Gro Company, April 2010). Phosphorus will remain in products designed for lawn installation and lawn repairs. Lawns or other turf systems located close to surface waters or Lake Erie could be the cause of localized impairment and algal blooms and should be the primary focus of outreach to citizenry. This may also be more of an issue in urban areas. There are several communities around the Great Lakes that have adopted ordinances to ban the use of lawn fertilizers containing phosphorus. Results have indicated a measurable decrease in phosphorus in the local watershed.

4.2.2.3 — Orthophosphate Use in Public Water Systems

In 1993, the Ohio Environmental Protection Agency adopted rules (OAC 3745-81, Rules 80-90) regarding the control of lead and copper in public water system (PWS) distribution systems. In order to prevent lead and copper from leaching out of the pipes at levels potentially harming those individuals who are exposed to the contaminated water, anti-corrosive agents are required to be added to the water at the treatment plant. These agents work by forming a protective coating on the pipes. Most PWS began adding phosphate-based inhibitors (phosphate, orthophosphate, polyphosphates, and zinc orthophosphate) to accomplish this starting in the mid-1990s.

The typical target range for total phosphate concentrations in finished drinking water is 1.0-3.0 mg/L initially, followed by a 0.5-1.0 mg/L maintenance level thereafter. About 5% of PWS in the Ohio Lake Erie basin, which serve approximately 50% of the population on public water, add some form of phosphorus. The total phosphorus load from those PWS is 410.7 metric tonnes/year. According to industry estimates, approximately 15% of finished water is lost in the distribution system. Using this value, the total phosphorus load directly entering the environment from leaks in the distribution system is approximately 62 metric tonnes per year. This is about 2% of the total phosphorus load to Lake Erie from Ohio nonpoint and point sources (2004 water year) and less than 1% of the load from all sources. This estimate does not account for any losses before the treated water enters Lake Erie and, consequently, the actual load may be significantly lower.

Some of the remaining treated water is used for residential lawn sprinkling and could be an additional load to the lake. The amount of water used for this is considered to be relatively insignificant, though, compared to what reaches wastewater treatment plants (WWTPs). For the quantity entering WWTPs, if it is assumed that all of the phosphorus passes through the plant, then phosphorus addition to drinking water would account for approximately 59% of the 590 metric tonnes/year phosphorus load from Ohio point sources (2001-2005 average). This is most likely an overestimation, because some of the phosphorus is removed through treatment processes. An assessment of total phosphorus effluent concentrations at WWTPs across the basin indicates that there has been no significant increase in the overall loading from these plants in the time period following the addition of phosphates to drinking water. It is possible that the percentage that is dissolved reactive phosphorus in the effluent from WWTPs has increased since that time, but this parameter is not often monitored.

Based on the estimates for WWTP effluent loads and the direct contribution to Lake Erie from losses in the distribution system, the addition of orthophosphate to drinking water is considered to be a low-magnitude source.

4.2.2.4 — Toledo Harbor Dredging and Open Lake Disposal

Another potential source of phosphorus to Lake Erie is the open lake disposal of Toledo Harbor navigation channel maintenance dredged material. Due to the shallowness of the western basin and the huge sediment load from the Maumee River, approximately one million cubic yards of sediment should be dredged annually to maintain Toledo Harbor and the lake approach channel. Prior to 1987, most of this material was placed in a confined disposal facility. Over the years, the concentrations of some metals and other contaminants have been decreasing in the sediments. The Corps of Engineers now considers most of the sediment to be clean enough for open lake disposal. The Ohio EPA remains concerned about the total loading of phosphorus and other contaminants in the sediments as well as the sediment itself being a pollutant.

Could the open lake disposal of sediment be considered a contributor to the phosphorus concentrations in the lake? Studies have shown that the majority of the material removed from the channel does come down from the river watershed rather than being washed in from the lake bed (Bedford et. al., 1999). Dredging removes a large quantity of sediment (similar to the total annual sediment load of the Maumee River) from relative storage in the shipping channel to an open lake dumping ground where it is spread throughout Lake Erie, according to Dr. Bedford's work. What is not known, however, is the amount of phosphorus in this load that is bioavailable and if it is affecting the incidence of algal blooms. Recent calculations done by the Corps of Engineers, based on an average TP concentration of 584 mg/kg, indicate that open lake disposal of 1.25 million cubic yards of sediment would account for a TP load of approximately 1096 metric tonnes. Actual dredging has been on the order of 635,000 cubic yards/year and a backlog of sediment buildup in the channel is now estimated to be 4.4 million cubic yards. The 2010 dredging request was for up to 2 million cubic yards per year with 1.9 cubic yards proposed for open lake dumping. This would be approximately 1669 metric tonnes of TP per year.

The observations of the P Task Force were that the phosphorus concentrations in the sediment are similar to concentrations in agricultural soils. Aluminum concentrations in the sediment may be high enough to effectively tie up most of the phosphorus, keeping its bioavailability low. However, the constant mixing of the extremely fine clay sediment particles by wind and waves in the shallow western basin may increase the opportunity for phosphorus to dissolve in the water column. These sediments also have a fairly high iron concentration. As discussed in Section 6, much of the phosphorus on the surface sediments is bound with ferric iron. When the bottom water oxygen concentration drops below 2 ppm, iron reduction occurs and phosphorus is released into the water column. The western basin is known to stratify, if only ephemerally, but it can be enough to create anoxic conditions (Bartish, 1984).

Due to the lack of data related specifically to DRP and because the Task Force was focused primarily on assessing the sources/causes of increasing DRP in the rivers, they opted not to make any recommendations in regard to open lake disposal. However, considering the amount of sediment associated phosphorus that has been loaded into the lake for so many years, there could be an improvement to net phosphorus removal from the system if open lake disposal was discontinued.

Section 5 — Transport Mechanisms of Phosphorus to Lake Erie

In addition to identifying and monitoring sources of phosphorus to the aquatic system, it is important to understand how phosphorus moves through soils and into streams, and also how it is used or transformed in the stream before it reaches Lake Erie.

5.1 — Stream Assimilation

A healthy stream is able to process a certain amount of overland runoff without becoming degraded. Assimilative processes include the physical, chemical and biological components within a riparian corridor. Without the proper mix, a stream will degrade and likely affect the areas downstream, including Lake Erie. In addition to controlling the substances going into a stream, the natural physical features of the streamscape such as riparian zones, floodplains, channel morphology and habitat diversity must be preserved or the ability of the stream to assimilate nutrients or other pollutants may be compromised.

Riparian vegetation traps terrestrial sediment and the associated particulate phosphorus in surface runoff. The roots of both terrestrial and in-stream vegetation can also take up DRP in a stream habitat. Vegetated buffers, whether forested or grassed, can filter nutrients, provide habitat, provide shade to filter out light and control water temperature, stabilize stream banks and control erosion.

Floodplains provide similar services as riparian buffers. They also slow storm water runoff, reduce energy that would otherwise erode banks, provide storage of flood waters so nutrients can be released slowly as water levels recede, and help stabilize the stream morphology. The assimilative capacity of streams is greatest when there are natural stream features such as narrow low flow channels, accessible floodplains and forested riparian zones. Cumulatively, such a system results in a longer more natural nutrient spiral, buffered flows, stable geomorphology and reduced export of phosphorus downstream.

5.2 — Subsurface Drainage (Tile Drainage)

Subsurface drainage is an important production practice in the Lake Erie basin. It is widely adopted due to the soil and climatic conditions prevalent within this region and the need to support timely field operations for row crop grain production. Systematic subsurface drainage (i.e. the installation of 4-inch diameter drainage laterals at regular spacing in fields) expanded rapidly during the 1950s and 1960s, and continues to be a focus of growers. The successful transition to reduced and no-till farming is highly dependent upon good water management within the soil profile by using subsurface drainage. Properly designed and installed subsurface drainage enables earlier soil warming and deeper crop root penetration. Over time, subsurface drainage promotes the development of stable macropores that enhance infiltration and movement of water to the tile system.

Subsurface drainage promotes infiltration of a greater amount of precipitation, but it also promotes quicker delivery of infiltrated water to streams. As the infiltrated water moves through the upper portion of the profile and enters subsurface drainage tiles, it dissolves nutrients from the soil and quickly carries those nutrients to the streams with the drainage water. Consideration of the soil P levels at the surface (0.1-4 cm), termed the effective depth of interaction (Sharpley, 1985), likewise becomes an important factor for soil P release to leachate because topsoil generally serves as the primary source of leachate P that has moved by preferential flow along macropores (Addiscott and Thomas, 2000).

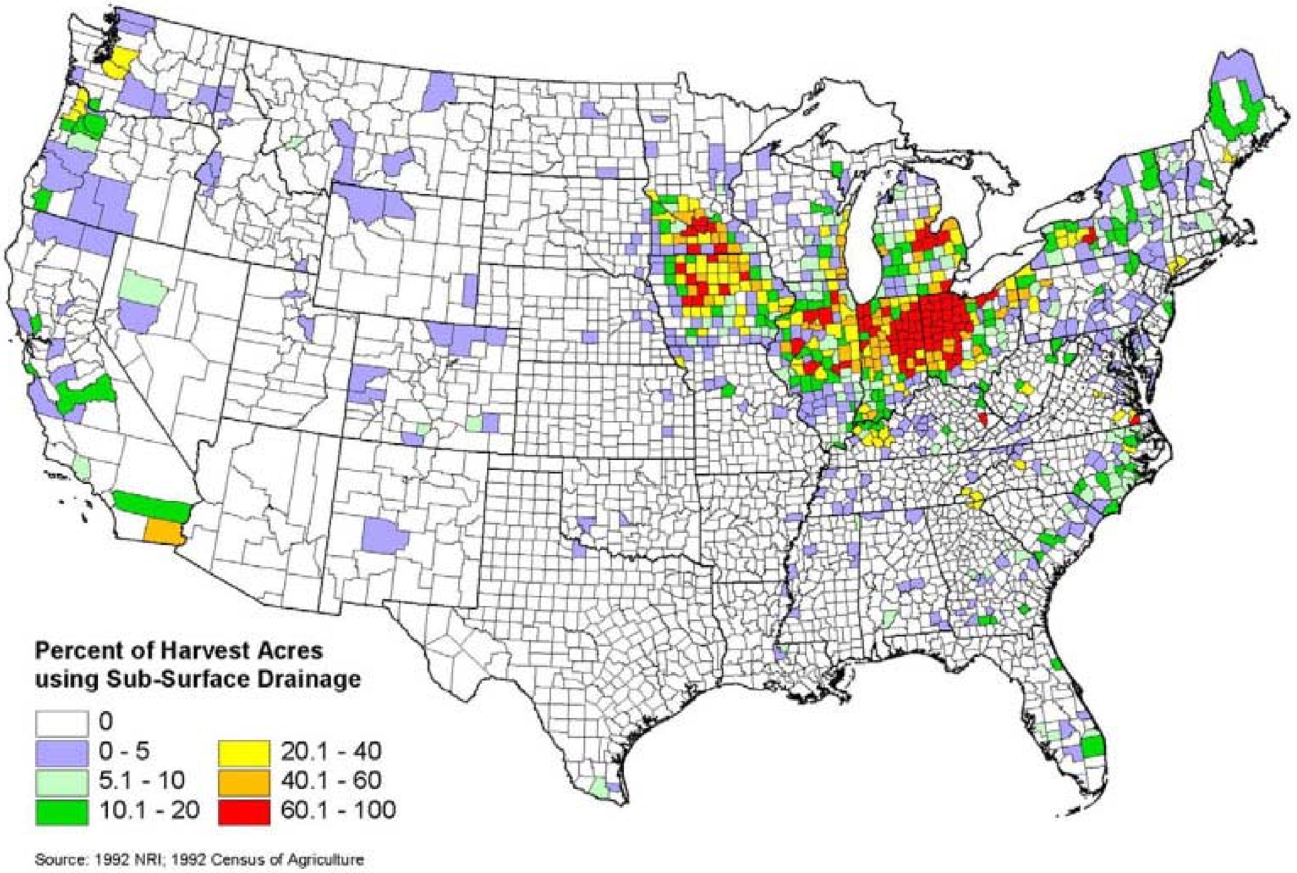
Subsurface drainage also promotes a well-aerated/oxidizing root zone within the soil. Soluble forms of phosphorus are more prevalent in poorly drained/reducing conditions in the root zone, so improving the subsurface drainage does not result in a direct increase in DRP. However, with subsurface drainage more of the incident precipitation moves into and through the soil profile and out through the drainage system, potentially exporting DRP encountered along this pathway.

According to unpublished data collected by the USDA-ARS Soil Drainage Research Unit, DRP is a normal constituent of tile drainage water from agricultural fields (personal communication, Norman Fausey, USDA-ARS, 2010). These data are part of on-going ARS research on drainage water quality and represent 1,364 tile discharge samples collected from one drainage tile outlet in Fulton County (Swan Creek Watershed) over the past 10 years. Approximately 40 acres drain to this outlet, and an automated sampler at the outlet collected samples at regular intervals during tile discharge events. The land was managed in a corn-soybean rotation with fertility inputs based on soil test recommendation. There were no surface inlets into the subsurface drainage system, and no manure was applied. The samples were analyzed for both total phosphorus and orthophosphate (i.e., dissolved form). Over the ten-year period, the average orthophosphate concentration was 0.10 mg/L and the average total phosphorus concentration was 0.19 mg/L. Similarly, the median orthophosphate and total phosphorus concentrations were 0.05 mg/L and 0.07 mg/L, respectively. The maximum concentrations observed during the 2005 to 2009 portion of the sampling period were 1.25 mg/L for DRP and 1.85 mg/L for TP.

This issue could be better mitigated by improved management of the drainage system through installation of drainage control structures or other hydraulic buffers, and by restricting pathways of preferential flow prior to or during nutrient application. Restricting leachate transport pathways points to other forms of modified tillage to prevent P losses from reduced tillage systems that preserve, even promote, preferential flow formation (Shipitalo et al., 2000).

Once the subsurface drainage infrastructure is in place, it is often utilized to provide an outlet for surface water in shallow depressions in crop fields and highway ditches. There is also considerable evidence of home sewage waste disposal via septic tanks with leach field systems being tied into subsurface drainage to provide an outlet. These sources of water contribute soluble and sediment bound phosphorus which can enrich the phosphorus content of the subsurface drainage waters not arising from the soil profile.

There are several BMPs (e.g., drainage control structures, cover crops, wetlands, etc.) available to reduce phosphorus loading to streams from tile drainage systems. These are described in Appendix B. Additionally, there have been recent projects in the Midwest where bio-reactors have been installed at tile drain outlets to reduce nutrient concentrations in the discharge. Bio-reactors for this discussion are best described as excavated trenches filled with wood chips. While there is limited information with respect to long-term effectiveness of bio-reactors on tile line outlets, results so far have been promising with respect to nitrogen removal in tile discharge. Additional research is on-going with respect to phosphorus in tile drainage water. In fact, the Ohio NRCS has agreed to fund tile drain bio-reactor projects in Ohio using EQIP funding.



Source: 1992 NRI; 1992 Census of Agriculture

Figure 28 — Percent of harvest acres in the United States using subsurface drainage in 1992. (NRI Census of Agriculture, 1992)

The 1992 census of agriculture showed that northwest Ohio has the highest percentage of harvested land with subsurface drainage in the Midwest (Figure 28). All northwest Ohio counties, as well as those Indiana counties in the Lake Erie watershed, had between 60.1 and 100% of harvested land drained by subsurface tile. There continues to be a significant amount of additional tile installed throughout the region at closer spacing in fields that are already tiled. This practice, known as lateral splitting, can in effect double the drainage tile density on fields already historically drained. For instance, a typical sub-surface drainage project on a row crop field with initial lateral spacing of 50 feet would have another set of laterals installed to make the spacing 25 feet. Spacing of laterals can be anywhere from 25 to 40 feet after a lateral splitting projects and as low as 15 to 20 feet on some fields (personal communication: Albert Maag, Putnam SWCD; Bill Beckman, Paulding SWCD; Jeff Ankney, Defiance SWCD; Ken Kottenbrock, Van Wert SWCD; Ron Cornwell, OLICA; and Joe Nester, Nester Ag LLC, February 15 and 16, 2010). The most poorly drained clayey soils, like the Lacustrine clays discussed in Section 5.3, generally have the closest lateral spacing and the shallowest tile depths. These land areas in northwest Ohio appear in light and medium blue on the glacial map of Ohio at *www.dnr.state.oh.us/Portals/10/pdf/glacial.pdf*.

Generally, decisions to install more subsurface tile in tight northwest Ohio clay soils have been made easier with the advent of yield monitors that have proven the economic benefit of increased crop yields in fields with closer lateral drain tile spacing. There have not been any updates to the 1992 subsurface drainage census, so there is no data on the current density of subsurface drainage.

The environmental ramifications of increased subsurface drainage density are not well understood. Closer spacing of drains does increase the volume of water removed by the subsurface drainage, although we do not know by how much. The closer lateral drainage spacing shortens the path length in the soil through which water travels to the subsurface tile. In addition, the frequency of macropores intersecting the drains is greater where drainage laterals are closer. With this in mind, the mains will run at full capacity for a longer period of time if the size of the main is not also increased when the laterals are split. This means more opportunity for transport of soluble nutrients as well as surface particles (soil and manure sediments) into the subsurface drainage systems and ultimately to surface water tributaries.

5.3 — Surface Drainage

Early surface drain projects in the western Lake Erie watershed were installed along old fence lines and connected to roadside ditches. The purpose of this practice was to facilitate surface drainage on low to zero-slope agricultural land to improve productivity and reduce incidence of plant disease. Lacustrine clay soils (including Latty, Paulding, Nappanee, Defiance, and to some degree Hoytville) are typical of the soils that are surface drained. These soils are predominantly located in Putnam, Defiance, Paulding, southern Henry and western Wood counties in Ohio (*www.dnr.state.oh.us/Portals/12/soils/pdf/SoilRegions.pdf*).

Coincident with technology improvements (e.g., rotary wheel surface drain implement), a trend began in the late 1980s to install surface drains in fields at regular intervals (e.g., at 500 to 600 foot spacing) to facilitate drainage and improve crop productivity. In general, in-field surface drains are installed so that farm implements can pass over and through surface drains during the normal course of farming operations with no setbacks. Fields where surface drains are installed are often drained with subsurface drainage tile as well.

There are no data on the extent of acreage drained by surface drains in the western Lake Erie basin. Observations by area soil and water professionals estimate current in-field surface drainage installations exist in 60 to 70-plus % of agricultural fields with the soil types described above. (personal communication: Albert Maag, Putnam SWCD; Bill Beckman, Paulding SWCD; Jeff Ankney, Defiance SWCD; Ken Kottenbrock, Van Wert SWCD; Ron Cornwell, OLICA; and Joe Nester, Nester Ag LLC, February 15 and 16, 2010).

The Ohio NRCS provides a set of practice standards to address 79 resource concerns related to farming (NRCS 2001). In 2007, the Ohio NRCS program evaluated these standards by ranking each practice standard against each resource concern. Using this ranking, Ohio EPA identified 27 resource concerns related to water quality and linked them to five leading causes of water quality impairment, including nutrient impairment. Ohio EPA then analyzed each of the practice standards for its relative benefit to address a particular cause of water quality impairment (*www.epa.ohio.gov/portals/35/lakeerie/ptaskforce/BMP_Effectiveness_Final030110.pdf*).

This initial analysis reveals that subsurface drainage and surface drainage are among the least effective practices for protecting water quality and may have the potential to worsen water quality. Alternatively, those NRCS BMPs that most effectively reduce the rate and amount of runoff from land to surface waters rank among the best practices for protecting water quality. While surface and subsurface drainage practices are not designed nor promoted for water quality, this analysis highlights the importance of balancing the selection of practices to best ameliorate potential water quality issues while meeting drainage needs for crop production. This analysis is a first step in development of a BMP decision tool that can point conservation planners toward the most effective practice or practices to address specifically identified resource concerns, including nutrients (N, P and DRP).

5.4 — Channelized Streams and Ditches

The practices of channelizing streams and maintaining ditches go hand in hand with installation of subsurface drainage. Channelized streams are constructed to increase capacity and flow rate for storm water runoff, as well as to increase the efficiency of the subsurface drainage tiles. A survey conducted by ODNR in 2006 indicated the extent of county-maintained projects includes approximately 121 miles of grassed waterways, 5,070 miles of subsurface mains, and 5,473 miles of open ditches statewide (Figure 29). Although unable to be quantified, the number of privately constructed and maintained ditch projects statewide is estimated to be in the thousands.

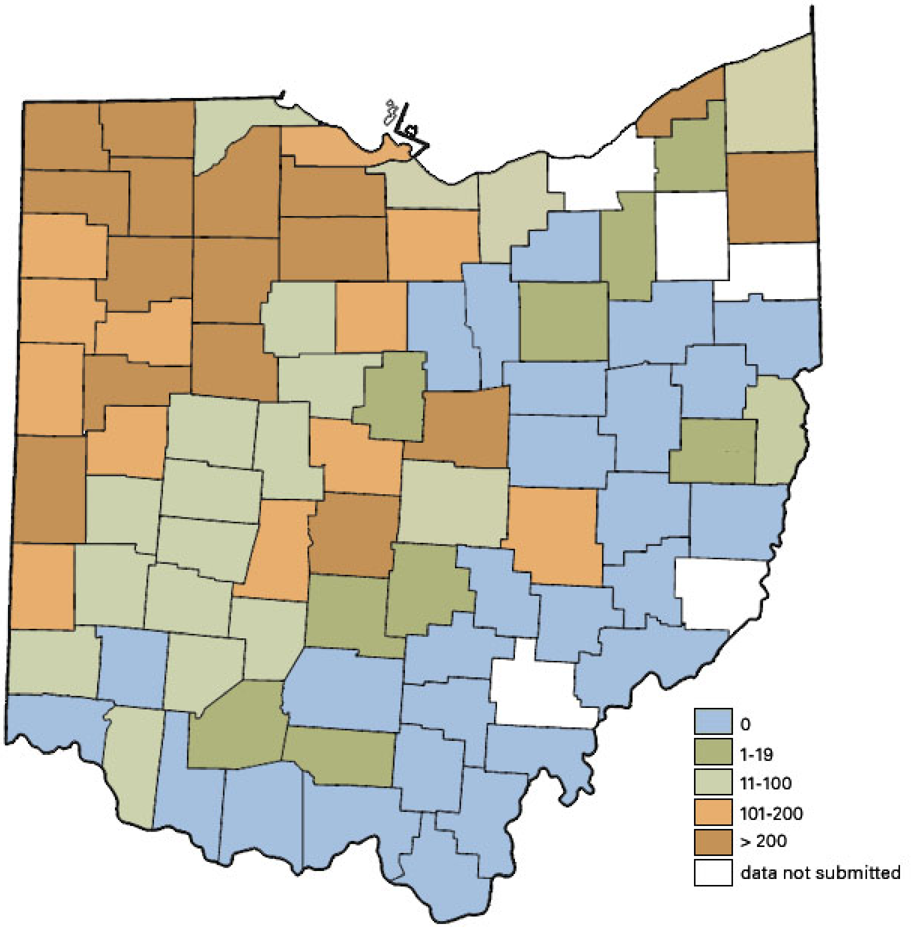

Total miles under maintenance
(open ditches, subsurface mains, and grassed waterways)

Chart developed from 2006 ODNR-DSWC
survey of county drainage programs

Figure 29 — Miles of maintained ditches, grassed waterways and subsurface mains in Ohio (ODNR, 2008)

Stream channelization and ditch projects constructed without best management practices often cause environmental impacts. Ohio EPA identifies disruption to the natural hydrology of a stream system (hydromodification) as one of the top five causes of aquatic life use impairment. In the Lake Erie basin, 87% of the area with recent assessment data is impaired due to hydromodification and/or habitat alteration (Ohio EPA, 2008).

Poor quality habitat with reduced or debilitated riparian zones (either no riparian zone is present or runoff bypasses the zone via field tiles) and simplified channel morphology generally exacerbate the deleterious effects of nutrients. Several factors that influence the severity of the nutrient impacts from channelized streams and ditches include:

- Reduction of the riparian uptake and conversion of nutrients;
- Decreased retention time for nutrients due to loss of sinuosity, increased gradient, increased flow velocity and lack of contact with a floodplain;
- Decreased retention of nutrients within the channel due to diminished filtering time during overland flow events; and
- Lack of riparian corridor leading to unblocked sunlight and stimulation of nuisance algal growth.

The Ohio Rural Drainage Advisory Committee was formed in 2006 to create a balance between drainage needs and environmental protection. The Committee has made recommendations for outreach and education, infrastructure, funding and incentives. The Ohio Drainage Manual has been updated as part of this effort. These actions, along with changes in Ohio's water quality standards regulations to include new use designations for primary headwater habitats, should lead to both improved tributary nutrient processing and wildlife biodiversity while improving management of storm water runoff.

5.5 — Summary and Recommendations

The Task Force concluded that diminished stream assimilative capacity and current drainage practices in northwest Ohio are contributing factors to the transport of DRP load to the western Lake Erie basin. The lack of available data, however, prevents a more thorough analysis of the scale of this contribution to the increases in tributary DRP loading.

Task Forces members support the work of the Ohio Rural Drainage Advisory Committee. These recommendations can provide both localized and downstream benefits and encourage more and larger stream restoration projects.

The P Task Force recommends that complementary practices (such as tile drainage control structures and management and other hydraulic/treatment buffers) be promoted to facilitate more widespread adoption of the BMPs designed to ameliorate water quality impairments attributable to subsurface drainage. Surface drainage systems should be evaluated to determine which complementary BMPs can best address water quality problems caused by pollutants carried by surface drainage systems.

Data on the extent of subsurface drainage is dated (1992) and lacks information on drainage intensity (e.g., lineal feet of tile/acre). The P Task Force recommends that the National Agricultural Statistics Service (NASS) be encouraged to include questions in the next Agricultural Census that can provide better information on subsurface drainage intensity. Alternatively, the P-Task Force recommends county level surveys be conducted to obtain information on subsurface drainage intensity.

The P Task Force recommends that more extensive research be conducted on sampling discharges from tile drain systems incorporating data on the land management variables that contribute to the quality of tile drain discharges.

The Task Force recommendations establishing a multi-stakeholder workgroup to build upon the initial Ohio EPA BMP effectiveness analysis by developing a robust BMP decision tool through consensus.

Section 6 — Internal Loading and Recycling Processes

6.1 — Background

Once phosphorus is delivered to the Lake it is subject to a complex series of in-lake processes including physical transport, biological uptake, and chemical transformations and reactions before deposition onto the sediment. In addition, much of the phosphorus that is deposited on the bottom is regenerated by microbial degradation of organic matter and by mineral and redox reactions and is recycled from the sediment back into the overlying water. As a result of this internal cycling of phosphorus, many lakes exhibit a slow response to reduced external phosphorus loading (Sondergaard et al., 2003). So although internal phosphorus loading is not “new” phosphorus to the lake system, understanding and quantifying these recycling processes are critical to addressing the larger management issues of establishing phosphorus loading targets and system response times.

There are three types of internal phosphorus cycling in Lake Erie. First, much of the phosphorus that is loaded to the Lake is delivered to the western basin. A portion is cycled in the western basin and the rest is transported to the east as loading to the central and eastern basins.

Second, there are various biological transformations and food chain transfers of phosphorus that recycle the highly bioavailable DRP to organic phosphorus in various trophic levels and the water column and to organic phosphorus in the sediment. Early modeling efforts used to establish target nutrient load levels were either empirical (Vollenweider, 1971) or assumed the lake behaves like a well mixed batch reactor (USACE, 1975; Chapra, 1977; DiToro and Connolly, 1980). These models developed into complex ecosystem models that used external nutrient loads and weather conditions as input and described the various biotic and abiotic pools of nutrients and trophic transfer as output. They were used to establish phosphorus loading rates to the lake based on minimizing the areal extent of the anoxic area in the central basin and maximizing the mean hypolimnetic dissolved oxygen concentration (Figure 30).

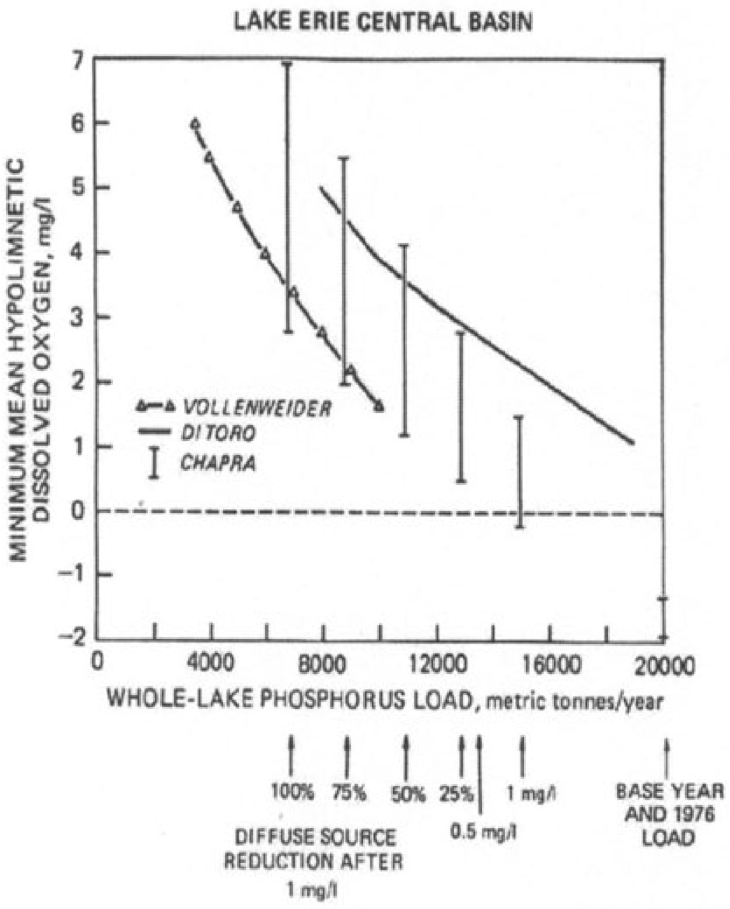


Figure 30 — Relationship between mean minimum hypolimnetic dissolved oxygen concentration and whole lake phosphorus load in the central basin of Lake Erie for the Vollenweider, Chapra and DiToro models (Figure provided by Joe DePinto, LimnoTech)

One major difference between early model representations of lake behavior and current conditions has been the invasion of dreissenids (zebra and quagga mussels). The arrival and establishment of dreissenids has led to huge alterations in the pathways of phosphorus transfer and in the ecology of Lake Erie (Figure 31). It has been proposed that the success of dreissenids in the nearshore environment has resulted in a cascade of effects which potentially make the nearshore zone overly significant in controlling whole lake dynamics (i.e., the nearshore shunt; Hecky et al., 2004). If true, then early models used to establish lakewide nutrient targets are invalid.

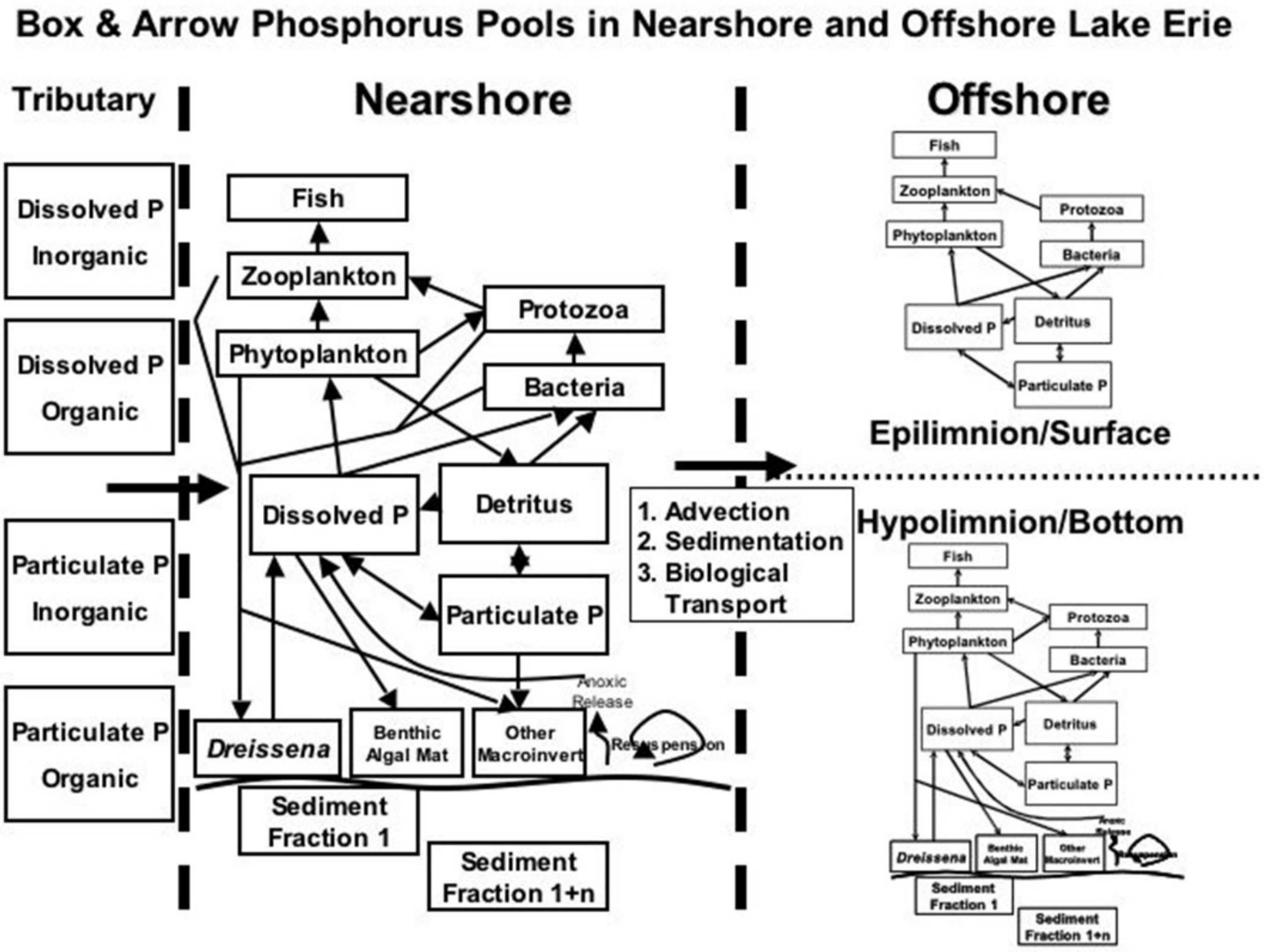


Figure 31 — Conceptual diagram of major nearshore and offshore nutrient pools and interactions following the establishment of dreissenid mussels in both the nearshore and hypolimnion benthos. (Graphic provided by Joe DePinto, LimnoTech)

The third type of internal lake phosphorus cycling is regeneration of sediment phosphorus and its transport back into the water column. Benthic phosphorus release from sediments subject to bottom water anoxia is well known (Mortimer, 1941). Benthic release of phosphorus may also occur under oxic bottom water conditions driven by organic matter degradation and biologically enhanced transport of dissolved or adsorbed phosphate from greater sediment depths (Meile and Van Cappellen, 2003; Slomp et al., 1998). In this case, the benthic release of phosphorus is controlled by the retention of phosphorus in the underlying anoxic sediment (Gächter and Müller, 2003; Moosmann et al., 2006).

The major forms of phosphorus in anoxic freshwater sediments are organic-P, phosphorus associated with Fe(III) oxyhydroxides, Fe(II) phosphate minerals (e.g., vivianite, $Fe_3(PO_4)_2 \cdot 8H_2O$) and calcium phosphates (House, 2003). Dissimilatory Fe(III) reduction by sulfides is typically limited in freshwater environments, where sulfate concentrations and sulfate reduction rates are low (Canavan et al., 2006; Wersin et al., 1991). Thus, in freshwater sediments, Fe(III)-oxyhydroxides may be an important sink for P. This has been observed in the freshwater part of the Scheldt estuary where Fe(III)-bound P accounts for up to 70% of total P burial (Hyacinthe and Van Cappellen, 2004). Ferrous phosphate minerals such as vivianite are also important as a sink for P when rates of sulfate reduction are low because the Fe^{2+} required for their formation is otherwise sequestered in the formation of FeS and FeS_2 (Gächter and Müller, 2003).

Recently there has been an attempt to account for benthic phosphorus release and phosphorus - iron mineral phases (DiToro, 2001; Canavan, 2006; personal communication Joe DePinto, LimnoTech, 2009). DiToro (2001) developed a model for phosphorus flux from a 2-layer sediment column in which the phosphorus in the sediment is subject to regeneration from organic matter, diffusion, burial and partitioning between the pore fluid and an iron oxyhydroxide solid phase (Figure 32).

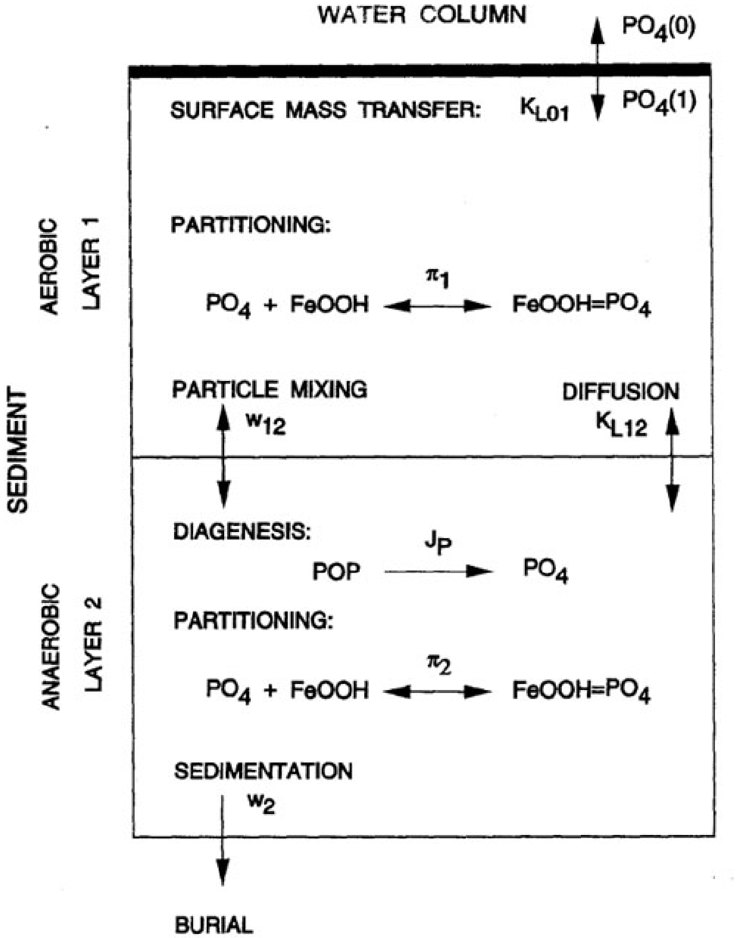


Figure 32 — DiToro's (2001) model for the internal loading of phosphorus from sediments

DiToro (2001) showed that although there is little relation between the depositional flux of phosphorus and the benthic release of phosphate from the sediments there is a significant increase in the phosphate flux when the bottom water oxygen concentration is less than about 2 mg/L (Figure 33). This increased flux at low oxygen concentration can be attributed to the reduction and dissolution of iron (III) oxyhydroxides and the concomitant release of sorbed phosphate.

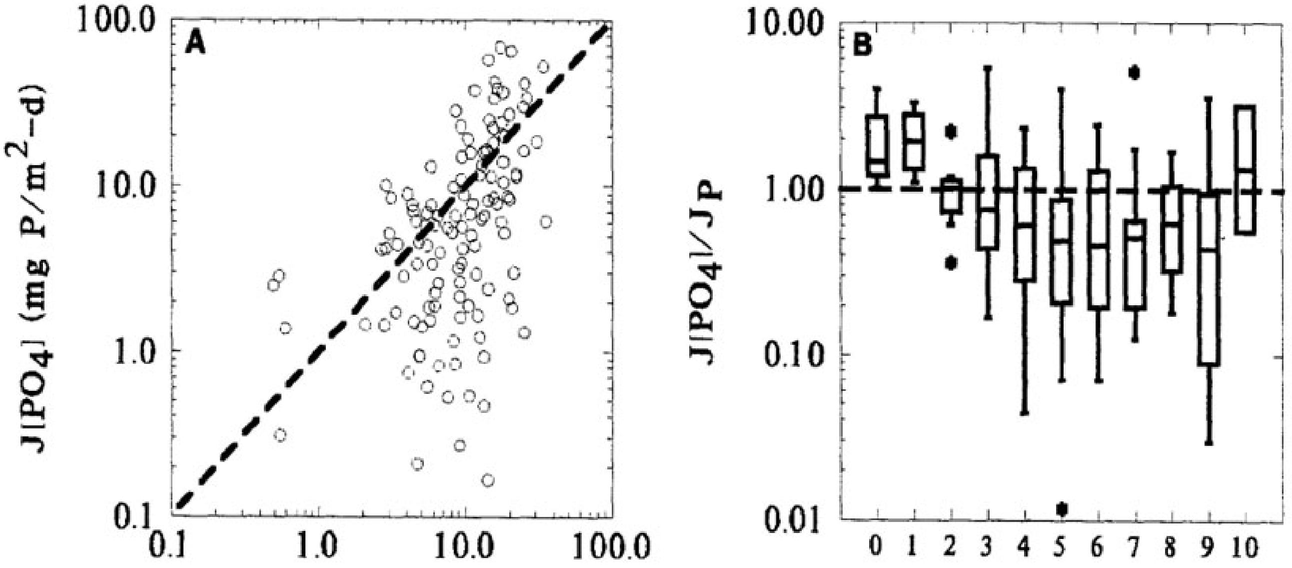


Fig. 6.6 (A) Phosphate flux $J[\mathrm{PO}_4]$ versus phosphorus diagenesis J_P. (B) Ratio of phosphate flux to phosphorus diagenesis $J[\mathrm{PO}_4]/J_\mathrm{P}$ versus overlying water dissolved oxygen concentration $[\mathrm{O}_2(0)]$.

Figure 33 — Relationship between the depositional flux of phosphorus (J_p) and the flux of phosphate ($J[PO_4]$) from sediments (left) and the flux of phosphate from sediment at different bottom water dissolved oxygen concentrations (right) (DiToro, 2001)

Canavan (2006) has conducted perhaps the most comprehensive study and modeling of phosphorus diagenesis and sediment flux. He collected pore water and solid phase data for sediments from Haringvliet Lake (The Netherlands) to investigate the coupling between the sedimentary cycles of iron, sulfur and phosphorus. He then modified the Van Cappellen and Wang (1996) multi-component reaction transport model to include phosphorus diagenesis. The extraction data indicate the presence of a reducible iron-phosphorus mineral (P-Fe (III)) in the surface sediment with an average molar Fe:P ratio of 2.6. Model results indicate that release of phosphate from this phase through reductive dissolution dominates the input of phosphate to the pore water in the upper 20 cm of the sediment. This is in agreement with DiToro's simpler model, although DiToro does not provide an Fe:P ratio for the mineral phase. Furthermore, Canavan finds that ~56% of the total P deposited on the sediment is returned to the overlying water through diffusion and bio-irrigation (the pumping of pore water by benthic macroinvertebrates through their burrows). The remaining phosphorus is buried in the form of organic phosphorus (P-org), P-Fe (III) and another inorganic P mineral phase (P-min). P-min accounts for 50% of total P burial and may be actively forming in the sediment.

Using the model, Canavan (2006) developed a sedimentary phosphorus cycle (Figure 34). His results show that release from P-Fe (III) is the dominant source of dissolved phosphorus in the sediment accounting for 75% of the total phosphate released within the upper 20 cm of the sediment. His model calculates that 58% of the Fe-oxide reduction is coupled to organic matter mineralization, with the remaining being accounted for by reaction with sulfide. The relatively low (~2.6) and constant molar Fe:P ratio with depth and nearly-identical dissolution kinetics of phosphorus and iron in ascorbate solution suggests the presence of a relatively stable iron (III) phosphate mineral as previously reported for sediments in the Scheldt estuary (Hyacinthe and Van Cappellen, 2004).

The P-Fe(III) phase is responsible for 17% of the total phosphorus burial below 20 cm depth. P-org is the other major source of pore water PO_4 and accounts for 33% of the total burial at 20 cm (Figure 34). Approximately 64% of the P-org and P-Fe(III) deposited on the sediment is released to the overlying water through bio-irrigation (47%) and diffusion (53%). Reversible sorption in combination with bio-turbation enhances the upward diffusive flux of dissolved phosphate (Slomp et al., 1998) and accounts for 25% of the total diffusive release at the sediment-water interface.

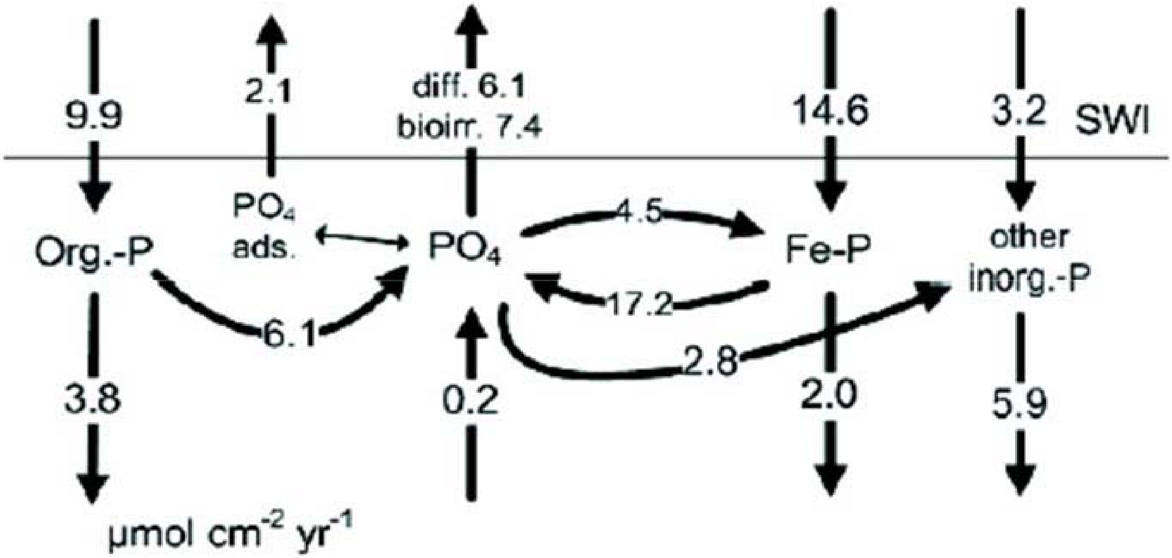


Figure 34 — Schematic representation of the modeled sediment P cycle. All rates and fluxes are presented in units of μmol $cm^{-2}y^{-1}$. The upper boundary of the calculation is the sediment water interface (SWI) and the lower boundary is 20 cm depth (Canavan, 2006)

Recent work in the Great Lakes on phosphate release from sediments has been conducted by Joe DePinto as part of the ECOFORE project. In the initial stages of the project DePinto and Fitzpatrick have developed a 1-D model in which the sediment is coupled to the overlying water. Phosphorus cycling in the sediment is based on the DiToro model (Figure 35). Phosphate release from the sediment is coupled to dissolved oxygen in the water column (Figure 36). In the model the central basin hydrodynamic model is physically driven by air temperature, wind speed, and solar radiation. It has a static surface level, 48 vertical layers of 0.5 m thickness and a varying thermocline depth. The simple DO model is linked to the hydrodynamic model based on a water column oxygen demand that is the aggregate of production and consumption processes. The sediment oxygen demand occurs in the bottom layer.

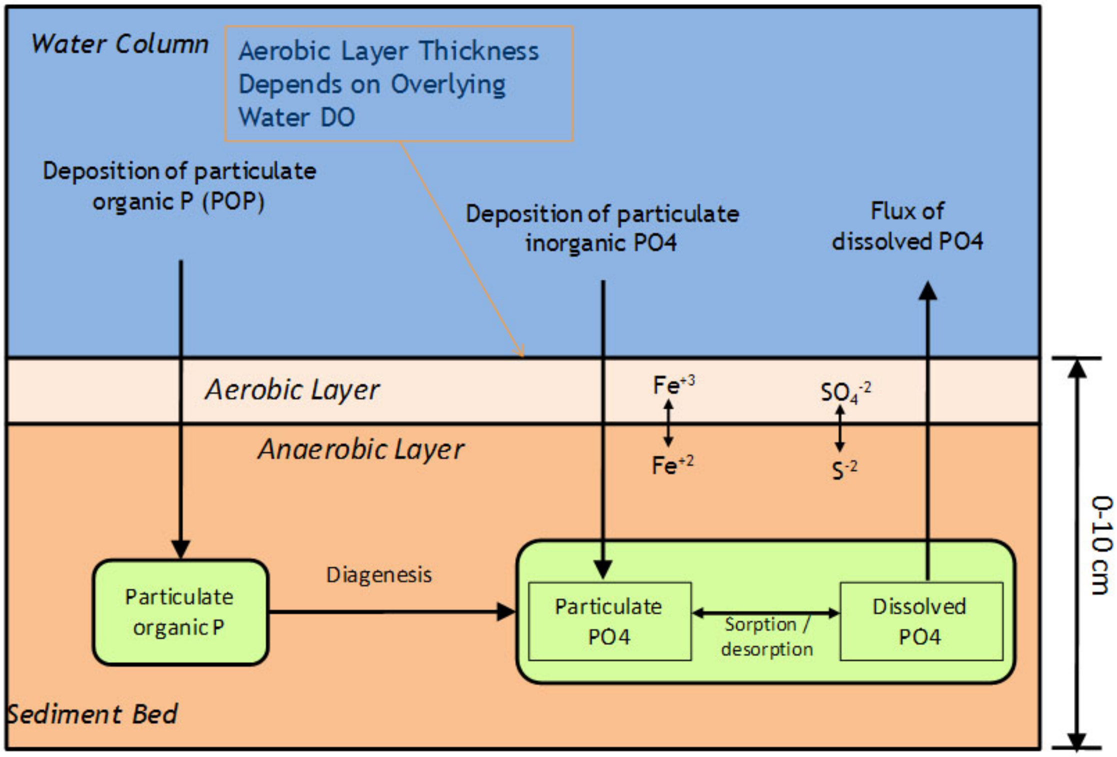
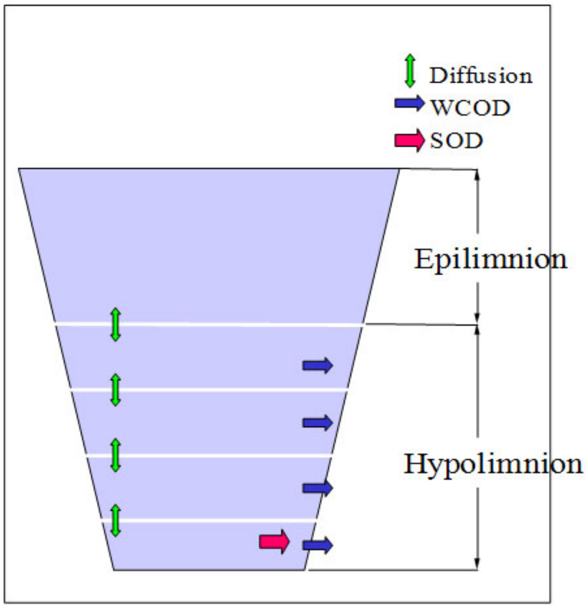


Figure 35 — Conceptual diagram of primary processes that affect sediment-water phosphorus exchange. (Sediment phosphorus model used in the ECOFORE project was provided by Joe DePinto, LimnoTech)



Model Description:

- 1D Vertical Dynamic Model for Central Basin
- Hydrodynamic model is physically driven
  - Air temp, wind speed, solar radiation
- Static Surface Level, varying thermocline depth
- 48 Vertical Layers of 0.5m thickness
- Simple Dissolved Oxygen Model linked to Hydrodynamic Model
  - DO rate term (WCOD) is aggregate of production and consumption processes in the water column
  - SOD in bottom layer

Figure 36 — ECOFORE one-dimensional linked hydrodynamic, dissolved oxygen and phosphorus model. (Graphic provided by Joe DePinto, LimnoTech)

The model results show a decrease in phosphate flux from 1985 to about 1995, and an increase in the Lake Erie phosphate release from the sediments since 1995 (Figure 37).

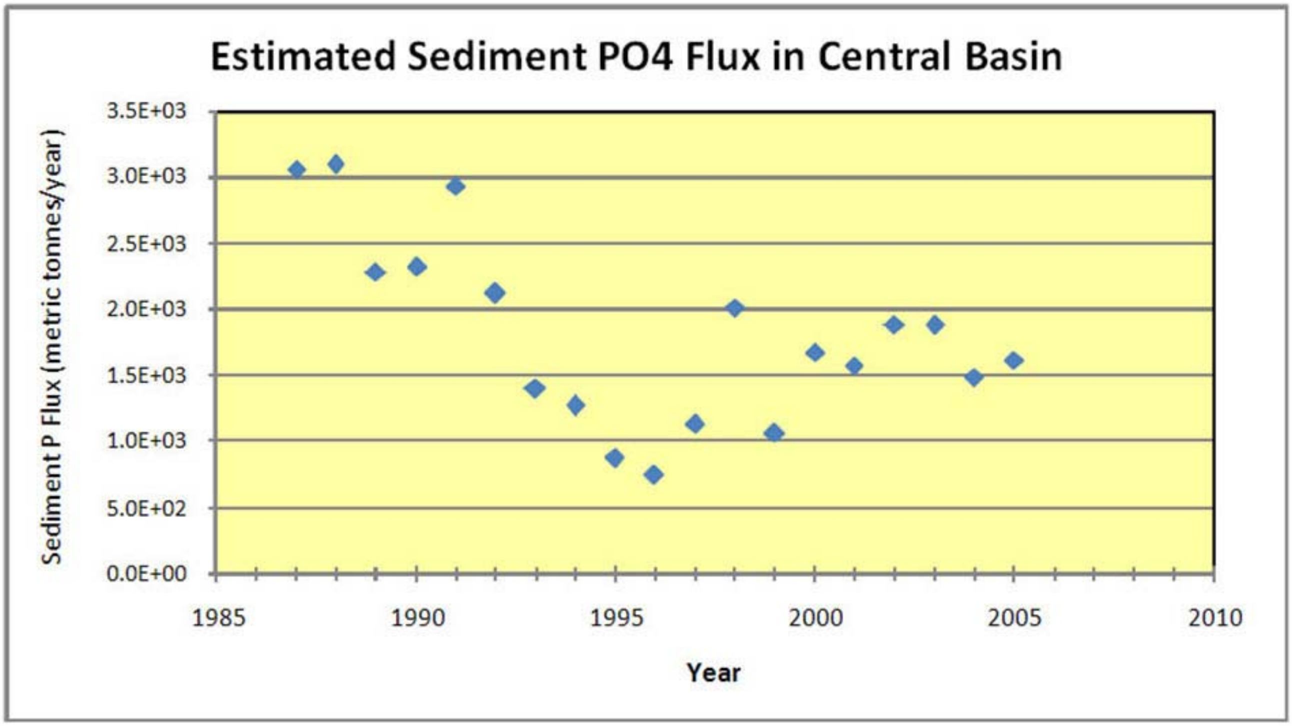


Figure 37 — Estimated annual phosphate fluxes from the sediments in the Lake Erie central basin since 1985. (Computed from area with overlying water dissolved oxygen < 2 mg/L * number of days with dissolved oxygen < 2 mg/L * 5 mg P/m^2/d) (Graphic by Joe DePinto, LimnoTech)

6.2 — Summary and Recommendations

This overview of prior work and current state of the knowledge about phosphorus behavior in sediment tells us the following about internal sources of phosphorus:

- About half of the phosphorus that is deposited as particulate organic phosphorus on the sediment surface is regenerated and returned to the water column as phosphate (inorganic phosphorus). This is a significant amount of phosphorus and is quantitatively important in the overall phosphorus budget of Lake Erie.
- Much of the phosphorus that is in the surface sediments is bound with ferric iron. When the bottom water oxygen concentration drops below about 2 ppm, iron reduction occurs and much of the adsorbed phosphorus is released to the water column.
- Biogeochemical models are needed to quantify the flux of phosphorus from the sediments to the overlying water. Current models for Great Lakes sediments are an improvement over older ecosystem models by including an iron (III) phosphate phase. However, these current models are still too simple, because other work has shown that phosphorus in sediments is also bound as organic phosphorus and as another mineral phase and that these forms of phosphorus are depth-dependent in the sediment.
- While it is important to acknowledge and understand the internal phosphorus cycle in the lake and the factors that influence release and use of phosphorus in the lake system, it is highly important to remember that once the phosphorus is in the lake there is nothing we can do. The focus of any phosphorus management work needs to be on the land to reduce phosphorus sources and loads. It may ultimately be necessary to adjust the existing loading targets to account for the impact of the changing internal load.

- In light of the substantial changes that are occurring in the lake, it is important to also consider the other components of the lake system that may be limiting factors in supporting algal populations. Other nutrients, such as nitrogen, have been steadily increasing over the years.
- Areas where additional research is needed to better understand internal phosphorus cycling are listed in the research agenda presented in Section 9.

Section 7 — Relevant Ongoing Actions

Since 2007, Ohio EPA, Division of Surface Water has significantly increased efforts to obtain DRP data in Ohio rivers. In 2007, 331 water samples were collected specifically for DRP analysis, while 806 samples were collected in 2008, an increase of 144%. Historically, considerable field staff time and effort went into collecting a discrete, field-filtered sample for DRP analysis and involved the use of a suction device to pull stream water samples through a 0.45 micron filter. Samples collected during higher stream flows were difficult to field-filter due to high sediment concentrations. As such, DRP samples were often not collected due to lack of time and resources. In 2008, the Division of Surface Water began to use a syringe method for collecting DRP samples. This method has allowed for much easier and timely collection of samples across flow regimes and at higher sediment levels. This point is important because it is more likely to see the highest levels of DRP in samples collected during higher flows. Having this data helps greatly to better inform the Ohio EPA on the scenarios and landscape variables that contribute the highest phosphorus loading levels to Ohio streams and, ultimately, Lake Erie.

Although the additional DRP data will be very helpful to target actions to reduce loads, loading and concentration targets for phosphorus are still based on total phosphorus. Open lake targets are still those proposed under the Great Lakes Water Quality Agreement for a load of 11,000 metric tonnes with associated concentrations of 15 µg/L and 10 µg/L for the western and central/eastern basins, respectively. While focusing on loading reductions is a practical approach to reducing nutrients, it is the concentration of nutrients in the water that the biological community responds to.

Protocols for developing water quality criteria are typically based on identifying the numerical limits that would cause chronic or acute toxicity. The effects of high concentrations of phosphorus are usually of an aesthetic nature rather than a toxic nature which is a more subjective measure of impairment. However, there are optimal levels of phosphorus needed to support the best health of biological communities. Using this approach, the Lake Erie Lakewide Management Plan (LaMP) has proposed TP ecosystem-based targets by habitat type. The LaMP supports the existing open lake concentration targets and proposes 20 µg/L for nearshore waters, 30 µg/L for coastal wetlands, and 32 µg/L for tributaries (Lake Erie LaMP, 2009). These numbers are based on concentrations that would support a diverse algal population but not cause blooms.

The Ohio EPA has taken a similar approach in developing nutrient criteria standards. Elevated nutrient concentrations are cited frequently as a leading cause of beneficial use impairment in Ohio streams. Given Ohio EPA's long and successful history of the development and use of biological criteria as a measure of overall stream health, Ohio EPA has taken an in-depth look at the association of nutrients, habitat and the aquatic biota in Ohio streams (Ohio EPA, 1999). While U.S.EPA has provided national nutrient criteria recommendations for states, those criteria were derived from percentiles of reference sites and not cause and effect relationships. Ohio EPA has been collecting stream information to support the selection of criteria based on actual data specific to conditions in Ohio waters. Nutrient criteria will soon be proposed for small and medium sized streams. Additional sampling is underway to collect data to continue the development of nutrient criteria for large rivers.

U.S. EPA-GLNPO and the Ohio Lake Erie Commission are currently funding 7 projects to better understand the sources and causes of the increasing eutrophication in Lake Erie. The projects were selected based on the needs identified by the Ohio Phosphorus Task Force and the Lake Erie LaMP. U.S. EPA is funding projects to: 1) track if algal blooms in the lake are being "inoculated" with algae from upstream in the river watersheds or from the sediment; 2) monitoring the differences/exchange of materials between the nearshore and open lake; 3) assessing the bioavailability of phosphorus from a variety of point and nonpoint sources, and tracking the discharge from storm surges all the way to the lake; 4) linking soil test phosphorus with agricultural runoff through the use of simulated rainfall events; and 5) investigating the use of selected BMPs in their effectiveness in limiting P runoff.

The Ohio Lake Erie Commission has funded two grants to 1) track nutrient and algae loading from the Maumee and Sandusky Rivers out into Lake Erie; and 2) comparing the use and changes/trends in soil test phosphorus levels in the western Lake Erie basin over the past 15 years. A larger multi-year study funded by the Great Lakes Protection Fund is also currently underway to look more closely at phosphorus stratification in soils and develop a P Index for DRP. The results of these studies will lead to a better understanding of when, where and how algal blooms begin, the connection between DRP concentrations and algal blooms, and begin to provide an understanding of where and why DRP is increasing.

There are a number of other programs around the country exploring the nutrient and algal bloom connection. Some areas are also experiencing the "dead zone" phenomenon seen in the central basin. In addition to the environmental degradation that these conditions are causing, the increasing presence of HABs is creating a potential health hazard. In addition to Lake Erie, some of the other areas in the Great Lakes that are experiencing threats from eutrophication include: Saginaw Bay, Green Bay, areas of the western shore of Lake Michigan and Hamilton Harbor in Lake Ontario. Many inland lakes around the county are also suffering from high nutrient loads and algal blooms. Most notably in Ohio is Grand Lake St. Marys.

The Association of State and Interstate Water Pollution Control Administrators (ASIWPCA), the Association of State Drinking Water Administrators (ASDWA) and U.S. EPA recently completed a review of the status of nutrient-related pollution nationwide (State-EPA Nutrient Innovations Task Group, 2009). The findings noted that: nutrient pollution significantly impacts drinking water supplies, aquatic life, and recreational water quality; a common framework of responsibility and accountability for all point and nonpoint sources is needed; current tools for better nutrient management are underused and poorly coordinated; current regulations disproportionately address certain sources in a watershed (e.g. municipal WWTP) at the exclusion of others contributing similar pollutants to the same watershed; and that specific aspects of state nonpoint source programs have been highly successful in addressing individual sources of nutrients, but their broader application has been undercut by the absence of a common multi-state framework of mandatory point and nonpoint source accountability within and across watersheds.

The report identified many of the same problems as the Ohio Lake Erie Phosphorus Task Force:

- Most agricultural manure production/application/disposal is unregulated
- Near-stream impacts are significant, but we also need to keep far-field impacts in mind
- Climate change can expand dead zones and potentially double the rate of runoff and erosion
- BMPs are available but aren't used consistently enough because policy and institutions don't require it
- Focus voluntary efforts on priority watersheds
- Implement the right practices in the right areas
- Most program dollars are still too broadly dispersed to get water quality results
- Avoid spreading manure on frozen ground
- Setback crops from waterways
- Eliminate unrestricted and unmanaged livestock access to streams

The Western Lake Erie Basin (WLEB) program led by NRCS and the US Army Corps of Engineers has been addressing nonpoint issues, outreach and solutions in the drainage to the western basin. Ohio EPA continues to work with U.S. EPA in managing Clean Water Act 319 funds to address nonpoint source related problems in Ohio. In addition to its other technical and incentive programs such as EQIP, the Ohio NRCS supports a Conservation Reserve Enhancement Program (CREP) focused on projects in the Lake Erie watershed, particularly in the western and western/central basins. A number of watershed action plans, TMDLs and the Maumee, Black and Cuyahoga River Area of Concern remedial action plans also continue to identify and address nonpoint source nutrient related improvement projects.

Changing weather patterns are another issue that may be influencing the current conditions in Lake Erie. Heidelberg University reports that river discharge has become flashier over time suggesting the increasing occurrence of shorter but more intense storm events. In recent decades a noticeable increase in average temperatures has been observed in the Midwest, despite the strong year-to-year variations. Heavy downpours are now twice as frequent as they were a century ago. Both summer and winter precipitation has been above average for the last three decades, the wettest period in a century (US Global Change Research Program). Other studies also show that precipitation has been increasing in the long term, particularly in the fall (USGS, 2007; Magnuson et al., 1997).

Section 8 — Discussion

The Task Force took a broad-based approach in analyzing the potential contributing factors related to the observed increasing dissolved phosphorus and the resurgence of algal blooms in the western basin of Lake Erie. The complexity of the dynamics of phosphorus as it moves over and through the land surface and its transport through water systems became readily apparent to the Task Force. As the group equipped itself with deeper knowledge about the interactions of phosphorus with soil and water, the group analyzed different sources of phosphorus and their potential for contribution to the algal blooms. While no modeling or monitoring efforts were undertaken on behalf of this analysis, the Task Force was able to assess different sources utilizing existing data and information to identify their relative contributions.

The following is a series of key observations made by the Task Force to support the conclusions included within this report. Much of what follows is detailed in the full narrative of this report. The following list intends to capture those elements believed to be critical to understanding the current situation and those elements that will have the greatest impact in reducing the delivery of DRP into the western basin of Lake Erie.

Relative Contributions

1. Point source discharges have remained consistent after a rapid drop in the 1970s. Historical discharge monitoring reports do not indicate any increases in phosphorus loadings. Point source loadings are not a major contributor to the increase in DRP.
2. Certain garden care products can contain high sources of phosphorus and can be potentially available to runoff to streams and watercourses. However, most products designed for lawn care have relatively low phosphorus levels. The runoff potential from any of these products is also highly dependent on management practices. Industry reductions in phosphorus content, better package labeling and improved application devices are all serving to minimize this potential even further. Lawn care products may be a contributing source with the potential for local impacts, but overall are not a significant contributor to algal blooms.
3. The invasive species of zebra and quagga mussels have altered the internal phosphorus cycle in the lake. Research continues to quantify this impact as models are being revised to account for the influence of mussels in the lake. While mussels may be having an influence on the internal cycling, the mussels are processing phosphorus input coming in from the rivers draining into Lake Erie. Once we realize reductions in phosphorus loadings, mussels may delay the response in the Lake, but researchers expect their influence will be short-lived.
4. While there are multiple contributors to phosphorus loading, currently the most significant is the result of runoff from agricultural nutrient applications. There is a lack of evidence that differentiates the relative contribution of commercial fertilizers and the land application of manure. Commercial fertilizer usage varies from year to year and its use outweighs the land application of manure or biosolids by a factor of two to one. Considering that agriculture accounts for about 59% of the land use in the Ohio Lake Erie basin, it follows that agricultural sources would contribute the greatest load. The significance is even more pronounced in the Maumee watershed where agricultural row crop land use ranges as high as 82%.

Agriculture

1. Overall, agricultural inputs are down (total number of animal units and lower sales of commercial fertilizer) yet the increases in dissolved reactive phosphorus tell us we need to manage the inputs we are putting into the system differently. There have been a multitude of changes in agriculture, all having an influence on the methods, amount, form, placement and timing of nutrient applications. The Task Force concludes that those recommendations that focus on the timing, amount and method of application of nutrient applications, will have the greatest beneficial potential for reducing the algal blooms in the western basin.
2. Although there are agronomic standards for the amount of phosphorus that soils need for fertility and crop yields, there is no database to track the frequency of soil tests and how the results are used to guide fertilizer application rates. The Task Force concluded that tools and indices need to be refined to account for crop fertility needs as well as environmental risk. Strategies that will improve nutrient management and reduce the runoff potential include improved soil test methodology, targeted education, consistent recommendations to producers and better follow-through on the recommendations made for phosphorus application.
3. Precision nutrient management utilizing management zones prepared from geo-referencing of crop production yield maps, soil maps and soil testing data has the potential to more accurately apply phosphorus where needed and to minimize over-application of phosphorus fertilizer.
4. There is no single agricultural practice that will result in a lowering of nutrient runoff. The reduction of DRP will require a system of best management practices that address the amount of commercial fertilizers and manures applied to fields, the methods of application and the practices that inhibit runoff delivery to local streams. The Task Force has developed a list of priority BMPs that have been identified as pivotal to reducing DRP. The list is included in Appendix B.

Other

1. DRP loading to Lake Erie has been increasing by large amounts since the mid-1990s and is now reaching historical highs after dropping substantially during the late 1980s and early 1990s. While there has not been any significant change in rainfall, there have been significant increases in fall and winter runoff. There has been less snow so that now a moderate winter rain can generate significant runoff as a result of frozen ground and little to no plant uptake. Changing seasonal patterns of rainfall and runoff have thus contributed to the increased runoff of dissolved phosphorus to Lake Erie.
2. Stream corridors can provide assimilative capacity for the uptake of in-stream nutrients in stream runoff, but these are primarily localized benefits to stream condition. There are no specific recommendations on developing the assimilative capacity through the restoration of stream corridors. The focus of the Task Force was to address the increase in algal blooms and the Task Force has concluded that addressing upland measures will yield the most beneficial results.
3. Although DRP is increasing in other monitored tributaries in Ohio (e.g., the Cuyahoga and Grand Rivers), the much higher loads from the Maumee and Sandusky make them higher priority watersheds for reducing impacts to Lake Erie. The concentrations and loads from the Maumee and Sandusky are higher than most other monitored tributaries in the entire Midwest region.
4. Based on historical evidence, we know that whenever we can reduce the DRP loads into the system, the conditions in Lake Erie will respond accordingly. Reductions in DRP inputs could result in near-term responses in ecosystem condition, particularly in the nearshore. Open lake responses may take longer (up to 10 years).

Section 9 — Recommendations

9.1 — Matrix

As an outcome of the deliberations and findings over the past two years, the Task Force has developed a myriad of recommendations, primarily focusing on upland measures that will better manage phosphorus inputs into the system. These recommendations are presented in the action matrix on the following pages.

	TOPIC	ISSUE	RECOMMENDATION	IMPLEMENTATION
Point Sources				
1	Point Source Dischargers	Point source dischargers are required to meet discharge limits under the provisions listed in NPDES permits. Ohio EPA issues the NPDES permits by Water Quality Standards, reviewing discharge data, reviewing records, doing inspections, considering the targets set in the GLWQA (0.5 to 1 mg/l TP), and the recommendations in TMDL reports.	A. Maintain effective permit compliance and enforcement program for NPDES permitted facilities. B. Continue to pursue progress with regard to Long Term Control Plans (LTCP) for Combined Sewer Overflows (CSOs) and Sanitary Sewer Overflows (SSOs). C. Maintain timely issuance of discharge permits. D. Evaluate need to reduce Phosphorus concentration limits in individual NPDES permits based on findings in TMDL reports or other action plans (WAP, RAP, LaMP).	Ohio EPA
2	Home Sewage Treatment Systems	Data collected by the Ohio Department of Health in 2008 indicate that 23% of the household sewage treatment systems are failing with an additional 13% projected to fail within the next 5 years. Soil limitations, substandard or poor designs, space limitations, system age, shallow seasonal water tables and poor operation and maintenance were reported as most common reasons for system failure.	A. A successful household sewage treatment system program for Ohio should be based on the establishment of statewide minimum standards/rules to provide program continuity across all 88 counties in Ohio. B. To protect public health and the environment, household sewage treatment systems must be designed to ensure the proper treatment (not disposal) of household sewage. C. Proper household sewage treatment system siting, design (based on the soil and site characteristics) and installation combined with an inspection and maintenance program will ensure system long-term sustainability and protect public health and the environment. D. The use of off-lot discharge for household sewage treatment systems should be minimized. E. A training and continuing education program for household sewage treatment system designers, installers, inspectors, regulators, maintainers and operators must be established.	Ohio Department of Health and Local Health Districts

	TOPIC	ISSUE	RECOMMENDATION	IMPLEMENTATION
Nonpoint Sources: Agriculture				
3	Current agronomic recommendations (Vitosh et al. 1996).	The current agronomic recommendations for rates of P usage are considered to be valid; however, it is apparent that some fraction of the farming community is either over- applying or applying P without proper consideration to timing or methods of application, contrary to Tri-state fertilizer recommendations for corn, soybeans, wheat, and alfalfa (Vitosh et al., 1996).	A. Agricultural agencies and crop consultants need to emphasize (and producers need to follow) the prescriptions called for in the Tri-State recommendations (Vitosh et al. 1996). B. Reinforce through increased training of agency staff, producers, crop consultants, etc. C. Update recommendations as needed, with special emphasis on timing and method application.	ODA, NRCS, OSU, Fertilizer dealers, Crop Advisors, producers
4	Soil Tests – increase usage	There is limited usage of soil tests for environmental purposes. Insufficient use of soil tests for agronomic purposes results in uncertainty as to how much cropland in Ohio is regularly soil tested.	A. Develop incentives to encourage more soil testing. B. Promote wider adoption of soil testing with a goal of getting a higher % of cropland tested C. Expand soil test procedures to include water extractable solubility, P-saturation and stratification in order to expand the base of knowledge and gain additional data sets to understand risks of P transport.	• Conservation Stewardship Program (CSP) • Special projects to emphasize nutrient management (e.g., EQIP) • Broader outreach (watershed groups, SWCDs, Extension, CCAs)
5	Linkage of soil test results to fertilizer recommendations and actual application.	Basis for recommendations from soil labs and crop consultants to guide decisions by producers with respect to P application rates and methods are currently unknown.	Conduct needs assessment of the soil labs, CCAs and others (Extension, landowners, unaffiliated consultants) to learn the basis of P recommendations given with soil test results	Currently funded by the Lake Erie Protection Fund

	TOPIC	ISSUE	RECOMMENDATION	IMPLEMENTATION
6	Reliability, availability and comparative usefulness of soil test laboratory results	Reliability of some soil test results remains questionable in the absence of sampling technique standardization • In order to validate program effectiveness, we need more access to soil test data from laboratories • We also need access to collection methods data to analyze them as one factor in soil test reliability	Encourage and support development and implementation of a soil P analytical lab certification program A. Establish a central clearinghouse of soil test results to: • analyze trends and levels • identify number and location by watershed of tests taken utilizing GIS capabilities • identify problem areas and targeted watersheds B. Standardize collection methods C. Standardize analytical methods D. In the absence of a state-sponsored certification program, the agencies should consider requiring data come from certified labs allowing the industry (laboratories) the flexibility of implementing their own certification requirements. E. Review the Wisconsin "discovery farm" experience (*www.uwdiscoveryfarms.org*) and the Ontario example.	TBD
7	P-runoff risk screening tool for farmers (expansion of Soil Test Risk Assessment Procedure in the NRCS *Section 1, Field Office Technical Guide*)	There is a need for development of a simple tool to be used in the field for a rapid determination of risk of P transport to surface water. A screening tool would serve as a precursor to the more detailed analysis of the P Index.	Develop and implement a P-Risk Screening Tool that includes: • potential for off-site P transport; • seasonality/weather conditions; • runoff and erosion potential to surface waters; • distance/connectivity to surface inlets and subsurface drainage systems to surface waters; • P solubility; and • soil test data (including stratified data where available).	USDA NRCS Recommendations #6 and #7 are to be considered together for purposes of developing and providing the most effective tools for consultants and landowners to make field application decisions that address crop yields and environmental concerns

	TOPIC	ISSUE	RECOMMENDATION	IMPLEMENTATION
8	Phosphorus Index (as defined in the NRCS *Section 1, Field Office Technical Guide*	The current phosphorus index in use by the NRCS is a comprehensive tool that is in need of updating.	A. Recommend revisions as needed to the P Index to NRCS if warranted based upon: • data from last 10 years • the need to make the P-Index more quantitative to risk of P runoff from site • include a dissolved P component B. Validate as specific to Ohio	USDA NRCS; project team underway
9	Promotion of phosphorus management using improved assessment tools	How to get P runoff assessment tools used more often and to be more useful.	A. Emphasize incorporation of fertilizer and manure B. Discourage application of manure and P-containing fertilizer unless P-Index/Soil Test Risk Assessment Procedure score is below a value that is determined to be acceptable. C. Promote the use of the P runoff risk assessment tools in nutrient management plans D. Promote potential economic benefit of Phosphorus management E. Develop incentives in State and Federal programs to increase usage of updated assessment tools such as: • Tax/rebates associated with P sales • Incentives directed at crop consultants	
10	Promotion of Recommended BMPs (see Appendix B)	Priority practices for nutrient management are currently available with existing cost share programs. However, these BMPs are not fully optimized by producers. Recommended BMPs for nutrient management need to be more strongly advocated with alternative approaches.	Recommend that cost-share agencies develop innovative approaches to agricultural programs such as: • linking the use of the P Index and/or a screening tool to allocating funds for adoption of BMP practices • explore on farm challenge projects (e.g., American Farmland Trust BMP Challenge Program) • identify options to more fully support Recommended BMPs that address nutrient management	Cost-share agencies and other technical assistance entities include: FSA, USDA-NRCS, DNR-DSWC, TSPs, CCAs, OSU-Extension Available agricultural agency resource concerns are significant. Other financial mechanisms to promote implementation of Recommended BMPs in targeted areas.

	TOPIC	ISSUE	RECOMMENDATION	IMPLEMENTATION
Nonpoint Sources: Urban and Residential				
11	Contributions of P from dishwasher detergent	SB 214 has been introduced to the Ohio legislature. If adopted, SB 214 would ban phosphorus from dishwasher detergents.	The P Task Force recommends passage of this legislation.	Legislation passed in 2009, effective as of July 1, 2010
12	Lawn care fertilizers	The Task Force considers P contributions to increasing algal blooms in Lake Erie from lawn care fertilizers to be low, but contributions could be locally significant as a result of the misapplication of lawn care products.	Identify opportunities to support low-P lawn care products and proper stewardship of product recommendations. A. Develop an MOU between the State of Ohio and lawn care manufacturers and service providers to achieve a reduction in pounds of phosphorus applied in lawn care products for all 88 Ohio counties. B. Support education and outreach targeted to homeowners to implement appropriate stewardship practices in the use of lawn care fertilizers.	<u>Recommended Lawn-Care BMPs</u> 1) <u>Select low or no P fertilizer</u>: Apply a product with an N-P-K formulation of 26-0-3. 2) <u>Choose fertilizer designed for lawns</u>**.** The word “lawn or turf” should be on the label. “All purpose” formulations should be avoided for lawn use. 3) <u>Read and follow label directions</u>**.** Reduce spreader setting to that recommended on product label. Over application can harm water quality and the lawn health. 4) <u>Keep fertilizer off of walks and driveways to reduce loss to storm sewers and streams.</u> Use drop spreader with deflector to keep fertilizer on lawn. 5) <u>Mow lawn at the highest setting and leave the grass clippings on the lawn.</u> Mowing high allows the grass to develop a deep root system that retains and uses water more efficiently. Returning clippings recycles nutrients. 6) <u>Fertilize in spring after first cutting and in the fall after Labor Day and before Halloween</u>**.** Only apply fertilizer when grass is growing enough to be mowed, and before dormancy. 7) Soil tests can help determine if other nutrients are needed.

	TOPIC	ISSUE	RECOMMENDATION	IMPLEMENTATION
13	Transport Mechanisms	Subsurface drainage, surface drainage and channelized streams and ditches -are contributing factors to the transport of DRP. Lack of available data prevents a thorough analysis of the relative contribution.	A. Support the recommendations of the Ohio Rural Drainage Committee. B. Promote/encourage complementary practices to surface and subsurface drainage practices to address potential delivery of DRP to streams. C. Conduct data collection on drainage intensity via the ag census and/or survey. D. Conduct research on sampling discharges from tile drain systems. E. Further develop BMP effectiveness analysis to guide BMP selection.	State and federal agricultural agencies
Other				
14	Public Education and Involvement	Education of residents about harmful algal blooms and local actions needed to address this problem on a long term basis.	A. Ohio EPA should work with sister agencies to coordinate the delivery of Phosphorus Task Force recommendations for public outreach and education utilizing current programs to the extent possible. Where gaps exist, funding should be sought to fulfill identified needs. B. Ohio EPA and ODNR should seek funding that will result in the development and implementation of new Watershed Action Plans and updates to existing plans to fully address Phosphorus Task Force recommendations in the Lake Erie basin.	Ohio EPA and ODNR; other state, academic and local partners

	TOPIC	ISSUE	RECOMMENDATION	IMPLEMENTATION
15	Research agenda for Ohio	Current research projects underway will yield valuable results in understanding the science and mechanisms in the movement of phosphorus and its impact to Lake Erie. The Task Force recommends an integrated, interdisciplinary approach to current and future projects to maximize the application of results to an adaptive management approach in addressing phosphorus delivery to Lake Erie.	A. Develop a research agenda designed to: • identify specific P reduction targets for the western basin; • identify nearshore targets; • identify potential linkages of DRP levels with rainfall intensity; • identify (any) direct linkages of DRP and harmful algal blooms; • determine extent of contributions of P from internal cycling; and • impacts of P stratification in soil. B. Develop a Discovery Farm and/or Watershed in Ohio (based upon the Wisconsin model) to demonstrate results from research (both agricultural and environmental) and linkages between land and water. C. Expand soil test procedures to include water extractable solubility, P-saturation and stratification in the soil to expand base of knowledge and data set to estimate the risk of P transport from a given site. D. Develop and implement a P-Risk Screening Tool (as described in #6). E. Validate the P-Index (as developed in #7). F. Develop new BMPs to minimize Phosphorus movement from the landscape where risk of P transport is known to be high.	See Section 10
16	Phosphorus Water Quality Standards for streams	Need WQ standards for TP and DRP; Need to consider loading standards vs. concentration standards.	A. Ohio EPA should monitor or require monitoring for dissolved phosphorus. B. Adopt and update nutrient standards for water quality. C. Develop standard operating procedures for dissolved phosphorus samples in runoff.	Ohio EPA and U.S. EPA
17	Create an Ohio Research Advisory Committee	The State of Ohio would benefit from a coordinated effort among researchers and program managers to assess research needs in Ohio	Form a committee of applied interdisciplinary researchers (including managers, users, academia).	This committee would address the research needs identified in Recommendation #15 above

Section 10 — Research Needs, Organization and Approaches

10.1 — Introduction and Background

TP loading to Lake Erie declined rapidly with the implementation of phosphorus removal programs at WWTPs, and met the GLWQA target load of 11,000 metric tonnes for the first time in 1981. Supported by the widespread adoption of soil erosion control BMPs, TP loads continued to decrease, with targets exceeded only in years of high rainfall and the associated increases in agricultural runoff. The Lake Erie phosphorus removal programs led to major improvements in water quality and are viewed as a major success story in large scale environmental management (Matisoff and Ciborowski, 2005). However, since the mid-1990s, the problems of eutrophication have returned to the Lake. Similar eutrophication problems are occurring in many other coastal areas and inland lakes and are often associated with nutrient runoff from intensive agricultural land use. These problems are particularly severe in the Gulf of Mexico and Chesapeake Bay, and exasperated by agricultural activities far up in the watersheds.

Examination of pollutant loading data for Lake Erie's major U.S. tributaries suggests that the problem stems not from any increase in the total amount of phosphorus entering the Lake, but instead from changes in the forms of phosphorus entering the lake from its large agricultural watersheds. Despite an 85% decrease in DRP from agricultural runoff between 1975 and 1995 (Richards and Baker, 2002), agricultural runoff DRP is now at its historically highest levels (Joosse and Baker 2009). This is particularly significant now as for every pound of phosphorus entering the Lake from WWTPs, three pounds are entering from nonpoint sources.

The challenges of reducing eutrophication in Lake Erie are great. As the shallowest and warmest of the Great Lakes, Lake Erie is particularly susceptible to harmful algal blooms and hypoxia. Agriculture, the dominant land use in the watershed, takes place on intensively tile-drained soils with high clay content. The tile drainage contributes to high delivery of nitrates to area streams. The high clay content contributes to rapid surface runoff during rainfall events, with that runoff carrying both dissolved pollutants and fine-grained sediments. Even though the cropland is relatively flat and has low erosion rates, and conservation programs have decreased particulate phosphorus runoff, the nitrogen and phosphorus export rates from these watersheds remain well above average for Midwestern cropland watersheds (Richards et al., in press). Yet another challenge may come from climate change. Agricultural runoff is driven by the seasonal patterns, amounts, and intensities of rainfall events. Changing seasonal patterns of rainfall and runoff have already contributed to the increased runoff of dissolved phosphorus to Lake Erie. If the weather changes predicted by most climate change models for this region do occur, the challenges will become even greater.

The Ohio Lake Erie Phosphorus Task Force has begun the diagnosis of the array of potential sources contributing to the algal blooms in the western basin, yet more needs to be fully understood to effectively manage the critical resource that is Lake Erie. Scientific analyses are needed to: understand the movement of sediment and nutrients through stream systems; target remedial measures to critical pollutant source areas at the watershed level; improve the science of watershed modeling relative to both predicting the extent of agricultural nonpoint pollution and estimating the benefits of targeted BMP adoption; and expand our understanding of the sociology of agricultural pollution abatement. More information is also needed relative to the transport and effects of nutrients and sediments as they move through estuaries, bays, nearshore zones and open lake waters during and following storm runoff events. These analyses are needed so that results can be applied to the most effective melding of modern soil conservation methods with advanced nutrient management measures and agricultural water management measures.

Researchers believe Lake Erie is well positioned for another recovery. Eighty percent of the water that enters Lake Erie is derived from Lake Huron and has very low nutrient concentrations. About 10% comes from rainfall and the remaining 10% from the tributaries draining the Lake Erie watershed. Recent increases in the costs of fertilizers should lead farmers toward more careful nutrient management. Reductions in nutrient concentrations in the Lake's agricultural tributaries should lead to relatively quick recovery since it is flushed out by clean water from the upper Great Lakes.

The unique, yet clearly defined characteristics of Lake Erie and its nutrient inputs position this water resource to serve as an important study site for environmental management and recovery. But we must better understand the dynamics of how nutrients are moving from croplands into the water pools in the watershed and its tributaries and ultimately to the lake to inform our management strategies. The interdisciplinary collaboration among the researchers, managers, agency personnel and stakeholder groups of the Ohio Lake Erie Phosphorus Task Force has sharpened our understanding of knowledge gaps and approaches we can use to fill those gaps. Solving these problems in Lake Erie will benefit similar efforts throughout the Great Lakes and the Midwest, and have significance at national and global scales.

10.2 — Research Needs as Reflected in Questions Raised During Task Force Deliberations

The research and information needs related to reducing nutrient runoff from agriculture and its subsequent impacts on the open waters of Lake Erie can be organized in terms of the sequential habitats shown in Figure 38. Many of the questions raised during the Task Force deliberations can be placed along these sequential habitats. These questions will be briefly noted and explained in this section.

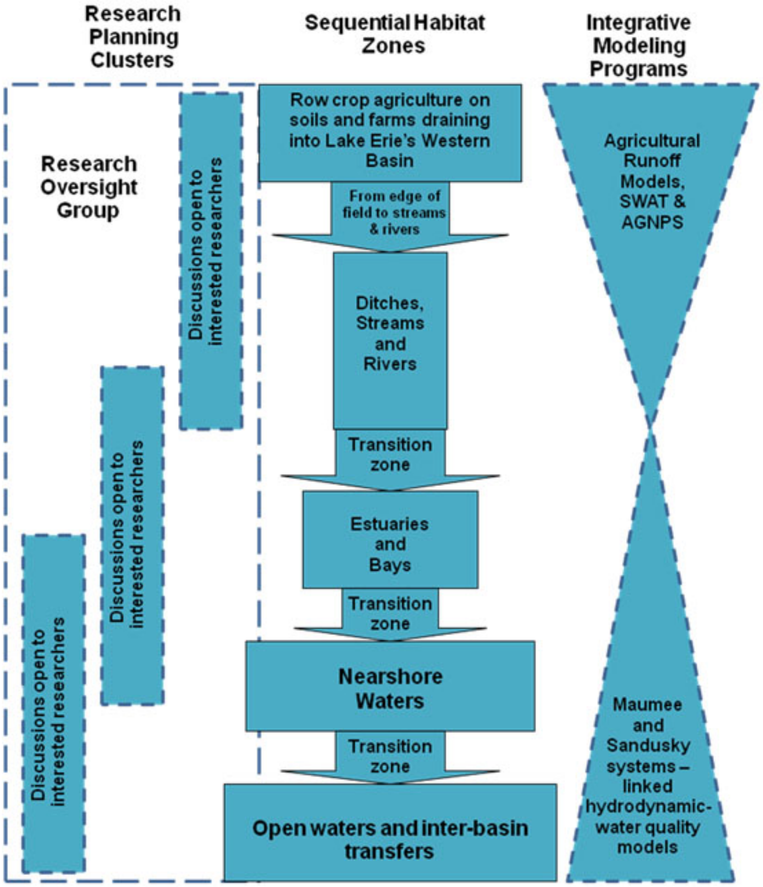


Figure 38 — Major habitats linking croplands to open waters of Lake Erie, modeling frameworks and research clusters

A. Cropland Issues (Note – the term “area cropland,” as used below, refers to cropland in northwest Ohio and adjacent portions of Indiana and Michigan that drain into the western basin of Lake Erie).

1. Are the guidelines of the Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa (Vitosh et al. 1996) adequate for today’s high yield seed varieties, relative to critical soil test values for phosphorus that will produce maximum (economic) yields?
2. If farmers were to apply drawdown rates of phosphorus fertilizer, how quickly would phosphorus soil test levels drop to the agronomic critical levels for the various soil types present in area cropland?
3. What roles do gridded soil sampling, yield monitors and variable rate fertilizer applications have for overall nutrient management in area cropland?
4. What is the relationship between surficial soil test levels and DRP concentrations in surface runoff for the various soil types present in area cropland?
5. What is the relationship between the degree of phosphorus stratification on area fields and the various combinations of tillage practices and fertilizer placement practices for the various soil types present in area cropland?
6. What proportions of DRP export from area cropland move through sub-drainage (tile systems)?
7. What guidelines can be developed for targeting programs to reduce DRP export from cropland, and how can necessary information be collected and utilized?
8. What role does the application of manure to area cropland have in the overall problem of high DRP export from area cropland?
9. What role could programs to improve soil tilth have in reducing DRP phosphorus export from cropland, and how might such improvements be achieved?
10. What role could utilization of winter cover crops play relative to reducing DRP export from area cropland?
11. What is the overall magnitude of edge-of-field nutrient losses relative to nutrient removal by harvested crops for area cropland?
12. What role can revisions to Ohio’s Phosphorus Index play in programs to reduce DRP export from area cropland?

B. From Edge-of-Field to Ditches, Streams and Rivers

1. What opportunities exist for intercepting edge-of-field nutrient and sediment losses prior to their delivery to stream systems?
2. Where, in area cropland landscapes, do opportunities exist for using field buffers, wetlands, and streamside buffers to reduce dissolved and particulate nutrient loading into area ditches and streams?
3. How can broader habitat and environmental benefits associated with buffers and wetlands be factored into programs fostering their adoption by area farmers?

C. Ditches, Streams and Rivers (Note: In this area, the term ditch generally refers to man-made extensions of the natural drainage network into cropland areas to facilitate tile drainage and increase the rate of removal of excess water.)

1. Ditches, streams and rivers constitute pollutant conveyance pathways between cropland and Lake Erie. What modifications or “processing” of nutrients and sediments occur within this drainage network that alter the amounts, forms and timing of agricultural pollutant delivery to the Lake?
2. Can these conveyance pathways be modified to enhance their assimilation capability and significantly reduce nutrient and sediment export to the Lake and are such modifications economically and socially viable?

3. Can or has the performance of such modifications been adequately evaluated relative to their effectiveness in reducing soluble nutrient transport during floods for various seasons, especially during winter periods when the bulk of DRP export occurs?
4. As important water resources in and of themselves, and as resources known to be impacted by agricultural land use in their watersheds, how will efforts to reduce nutrient and sediment export to Lake Erie from cropland interact with ambient water quality and/or flow regimes and flooding in these ditches, streams and rivers? (Ambient water quality includes uses for aquatic life, public water supply and recreation.)
5. What is the relative importance of agriculturally derived nutrients and point source derived nutrients in river eutrophication, a condition that sometimes develops in riverine habitats during low flow conditions?
6. What are the impacts of river eutrophication, and possible release of toxicants from algal blooms, on riverine biota and on drinking water supplies?

A special note on ditches, streams and rivers: Ditches, streams and rivers provide the only practical locations where quantitative measurements of pollutant transport can occur. At watershed outlets, tributary loading stations provide information on the cumulative pollutant export from upstream land uses, including both point and nonpoint sources. Such stations also provide information on the total amounts of pollutants exported to downstream receiving waters from watersheds. Tributary loading stations on rivers draining large watersheds provide the basis for tracking pollutant loading into Lake Erie, and for documenting the effectiveness of pollutant loading abatement programs. Pollutant transport studies on rivers require both continuous discharge measurements, such as those provided by the U.S. Geological Survey, and frequent sample collection for chemical analysis, such as those of the Heidelberg University National Center for Water Quality Research. It is not feasible to measure edge-of-field transport on a continuous basis for a large number of fields, nor is it feasible to accurately and continuously measure pollutant fluxes in estuarine environments. The Ohio portion of the Lake Erie Watershed is the home to the most detailed and longest-term pollutant transport studies in the Great Lakes Basin and the Midwest, thus it is uniquely positioned for addressing the questions posed herein.

D. Estuaries and Bays (Note: Wind driven seiches in Lake Erie create estuarine-like conditions in the lower sections of rivers near the lake. These constitute fresh water estuaries. Two major bays occur in the western basin of Lake Erie – Maumee Bay and Sandusky Bay.)

1. Estuaries and bays represent depositional environments for suspended sediments and particulate phosphorus that are exported from rivers during runoff events. What proportions of the sediments and particulate phosphorus delivered to estuarine portions of rivers during runoff events pass through these environments and reach nearshore and/or open lake systems, and how do these proportions change in relation to the size of runoff events and/or floods?
2. Under low flow conditions in rivers, what proportion of the nutrients entering the estuarine and bay environments come from river inflows and what proportion from point sources discharges and/or urban storm water runoff from adjacent land uses?
3. What roles do algal communities that develop in estuarine and bay environments have in subsequent algal bloom developments in nearshore and/or open lake environments?
4. Do bottom sediments in estuaries and bays serve as significant sources of dissolved phosphorus and/or bioavailable phosphorus for algal community development in overlying water?
5. What proportion of dissolved phosphorus and nitrate entering estuaries and bays from rivers during runoff events is taken up by algal growth and/or is otherwise removed by physical and chemical processes and what proportion passes through to nearshore and open lake environments?
6. What are the environmental impacts of eutrophication in the estuaries and bays?

E. Nearshore Zone (Note: The nearshore zone and associated shorelines of Lake Erie represent the major interface between humans and the Lake. The proximity to the land can result in high pollutant concentrations, their shallowness can allow for wave induced re-suspension of pollutants, and that same shallowness can support development of attached algal growths such as *Cladophora* and *Lyngbya*. The nearshore zone can moderate nutrient transport to open water habitats (the nearshore shunt). These areas also include biologically important coastal wetlands.)

1. What is the source of nutrients that support the development of excessive growths of benthic algae, such as *Lyngbya* and *Cladophora*, in nearshore zones? (What are the relative roles of storm derived agricultural nutrients and local point sources and urban runoff sources?)
2. What is the role of wave and/or current induced sediment re-suspension in nearshore algal bloom development?
3. What role, if any, do nearshore attached algae play in subsequent developments of harmful algal blooms in off-shore waters of the Lake?
4. Can nutrient loads from the land be reduced enough to eliminate nuisance benthic algal growth? If so, what level of load reduction is needed?
5. What are the broader impacts of toxins released by algae on aquatic life and, through contact recreation, food chains and drinking water pathways, on human populations?
6. How do inorganic nutrients interact with other environmental factors that influence the species composition and population densities of algal communities in the nearshore zone?
7. How do nutrient inputs and associated algal community responses affect benthic and fish communities in the nearshore zone?
8. Do nearshore zones interact with open lake waters such that they serve as “kidneys” that filter out nutrients from open lake waters?
9. What are the interactions between open lake hypoxia and nearshore benthic communities during seiche events?

F. Open Lake Waters (Note: These are the broad expanses of open waters that support the bulk of the fishing and boating activities in the Lake. These are the zones where problems of hypoxia have their greatest and most prolonged impacts.)

1. What is the appropriate balance of nutrient inputs that support a productive fishery in Lake Erie and nutrient inputs that avoid and/or minimize harmful and nuisance algal blooms?
2. What are the relative roles of internal phosphorus loading from bottom substrates and seasonal inputs from nonpoint sources in creating environments for harmful algal bloom development?
3. Within the western basin of Lake Erie, how does phosphorus release from dredging activities compare with phosphorus release from wind driven re-suspension of bottom sediments?
4. Do current levels of eutrophication in open waters warrant reinvestigation of target loads for total phosphorus?
5. Should target loads of phosphorus be set for bioavailable phosphorus? … for DRP?
6. Do direct point source phosphorus inputs, with their constant daily loads, have the same impact on open water nutrient levels as nonpoint derived loads which are delivered in large pulses?
7. Can the establishment of phosphorus standards be utilized in efforts to reduce harmful algal blooms, and, if so, should they be for concentrations or loading rates, for various seasons, for high flow or low flow, or for some combinations of the above? How could compliance with standards be judged or enforced?

8. Are there other controllable environmental inputs that could be modified so as to manage algal communities such that they better support fisheries food chains.

10.3 — Integrated Research Planning and Modeling

A. Research Planning Process

Since the overall objectives of the research programs relate to addressing the problem of harmful algal blooms in Lake Erie, it is essential that researchers communicate with each other along the habitat zones shown in Figure 38. We suggest that sets of overlapping research planning clusters be formed such as those shown in Figure 38. Such clusters should review, refine and prioritize the questions that have been posed relative to the habitats included in each cluster. Participation in these clusters should be open to all interested researchers, including those in governmental agencies, universities and the private sector. Invitations for participation should extend beyond those who have participated in the Ohio Lake Erie Phosphorus Task Force meetings.

Products of a first round of meetings would be detailed outlines of the research, monitoring and information collection that would be undertaken, along with summary descriptions of the methods to be employed and the cost estimates associated with the work. These products would be submitted to an oversight committee for approval. Detailed proposals would then be developed in accordance with oversight committee recommendations and with the endorsement of the oversight committee. Proposals would be submitted to a variety of funding agencies funded under the Great Lakes Restoration Initiative or other appropriate funding sources.

B. Integrative Modeling

Much of the research, monitoring and data collection from the above research efforts can be incorporated into modeling efforts such as those shown in Figure 38. In part, the models can guide some of the research and monitoring efforts, and in part, the research and monitoring data can help to evaluate and refine the models. The models can then be used to extrapolate results to neighboring watersheds or coastal systems.

Both the Sandusky watershed and the Maumee watershed have been the sites for extensive model applications. Likewise, linked hydrodynamic-water quality modeling has been developed for both Sandusky Bay and Maumee Bay. These models include lower food web components. Since these two bay systems differ greatly in their watershed area to bay volume ratios, comparative analyses of these two systems may prove valuable.

10.4 — Spatial Aggregation, Implementation and Adaptive Management

A. Spatial Aggregation

Much of the research outlined at the farm and field level could most efficiently be accomplished through the establishment of a set of demonstration or “discovery” farms for representative soils and farming situations in this region. Discovery farms have been used in other parts of the Midwest to advance applied research in those areas. Such farms provide critical links between land grant operated research farms and the working farms that populate large agricultural watersheds.

In addition, applied research can also be advanced through the establishment of research watersheds. Within research watersheds, monitoring programs are established to carefully track both human and climatic inputs, as well as watershed outputs. Research watersheds provide locations for evaluating the effectiveness of nonpoint source pollution reduction programs and for evaluating and refining watershed models. Research watersheds also pose favorable locations for studies related to the transport and processing of pollutants as they move through stream systems. Monitoring programs that support pollutant export at the watershed level can also help support assessments of stream processing.

B. Implementation Programs

Implementation of measures to reduce DRP loading to Lake Erie need not wait for results from the research programs described above. Management efforts inevitably proceed within the limits of the "best management practices" available at that time. The Lake Erie watershed is poised for large scale investments in nutrient reduction programs as part of the Great Lakes Restoration Initiative.

Implementation programs provide researchers who operate at the large watershed scale with the nearest thing to "controlled experiments" that they are likely to be able to afford. In fact the research can assume, among other things, the role of assessment of the effectiveness of the implementation programs. This is particularly true when the implementation occurs within the boundaries of established research watersheds.

Implementation and assessment efforts at watershed scales do not yield benefits that can be assessed in the short term. However, it is only when accomplished at large watershed scales that the goals of reducing nutrient loading to Lake Erie will be realized. Thus we must recognize the necessity of long-term efforts for both implementation and assessment. If implementation programs focus only on those problems that can be fixed and assessed in the short term, it is unlikely that we will be addressing the big problems that face Lake Erie.

C. Adaptive Management

In a changing world, and the Lake Erie basin is changing in many respects, Adaptive Management should be the *modus operandi* of environmental management. It simply involves: careful problem identification; addressing those problems through implementation of "best" technology and/or practices available and affordable at that time; monitoring to assess the effectiveness of those implementation programs and to identify emerging problems and/or tradeoffs; and research and development related to new "best" technologies and practices for reducing adverse environmental impacts associated with our ever more intensive uses of our land and water resources.

Adaptive management has worked for Lake Erie in the past and we trust that it will be applied and work in the future.

Section 11 — References

Alexander, R.B. and R.A. Smith. 2006. Trends in the nutrient enrichment of U.S. rivers during the late 20th century and their relation to changes in probable stream trophic conditions. Limnology and Oceanography, 51(1, part 2): 639–654.

Alexander, R.B., R.S. Smith, G.E. Schwartz, E.W. Boyer, J.V. Nolan and J.W. Brakebill. 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River basin. Env. Science and Tech. 42:822–830.

Addiscott, T.M. and D. Thomas. 2000. Tillage, mineralization and leaching: phosphate. Soil Tillage Research 53: 255-273.

American Farmland Trust BMP Challenge Program. *www.bmpchallenge.org/*.

Andraski, T.W., and L.G. Bundy. 2003. Relationships between phosphorus levels in soil and in runoff from corn production systems. J. Environ. Qual. 32:310-316.

Baker, D.B. 2007. Phosphorus Loading to Lake Erie: A Brief Overview, Including Recent Changes in Dissolved Reactive Phosphorus from Tributaries. *www.epa.ohio.gov/portals/35/lakeerie/ptaskforce/BakerBullets.pdf* .

Baker, D.B. and R.P. Richards. 2002. Phosphorus budgets and riverine phosphorus export in northwestern Ohio watershed. Journal of Environmental Quality 31:96-108.

Bartish, T. 1984. Thermal stratification in the western basin of Lake Erie: its characteristics, mechanisms of formation, and chemical and biological consequences. Ohio Sea Grant Publication TB-OHSG-21. The Ohio State University.

Bast, L., R. Mullen, I. O'Halloran, D. Warncke and T. Bruulsema. 2009. Phosphorus balance trends on agricultural soils of the Lake Erie drainage basin. Better Crops 93(1):6-8.

Bedford, K.W. and V. Velissariou. 1999. Integrated analysis of the impact of unconfined placement activities on nearshore sensitive areas. Executive Summary. Dept. of Civil Eng. and Geodetic Science, The Ohio State University. Prepared under Contract DACW39-95-K-0018 with the U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Benning, J.L. and C.S. Wortman. 2005. Phosphorus indexes in four Midwestern states:

An evaluation of the differences and similarities. Journal of Soil and Water Conservation 60:221-227.

Black, A. 1980. Experience with Phosphorus Removal at Existing Ontario Municipal Wastewater Treatment Plants. P. 329-353. In R.C. Loehr et al. (Ed) Phosphorus Management Strategies for Lakes, Ann Arbor Science, Ann Arbor, MI.

Bolsenga, S.J. and C.E. Herdendorf (editors). 1993. Lake Erie and Lake St. Clair Handbook. Wayne State University Press. Detroit.

Brady, N.C. and R.R. Weil. 2002. The nature and properties of soils, 13th ed. Prentice Hall.

Brannan. S. 2009. Rounding up the evidence. Ohio State University Sea Grant. Twineline 31(1):11. (*www.ohioseagrant.osu.edu/_documents/twineline/v31i1.pdf*).

Bray, R.H., and L.T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59: 39-45.

Brockman, C. S. and J.P. Szabo. 2000. Fractures and their distribution in the tills of Ohio. Ohio J Sci 100 (3/4):39-55, 2000. *https://kb.osu.edu/dspace/handle/1811/23855*.

Burton, G.A. Jr., and R. Pitt. 2001 Stormwater Effects Handbook: A Tool Box for Watershed Managers, Scientists, and Engineers. CRC Press, Inc., Boca Raton, FL.

Canavan, R.W. 2006. Biogeochemical Cycling of Nutrients and Trace Metals in the Sediment of Haringvliet Lake: Response to Salinization. Ph.D. dissertation, Utrecht University. 159 pp.

Canavan, R. W., C. P. Slomp, P. Jourabchi, P. Van Cappellen, A. M. Laverman, and G. A. Van Den Berg. 2006. Organic matter mineralization in sediment of a coastal freshwater lake and response to salinization. Geochimica et Cosmochimica Acta 70**:** 2836-2855.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley and V.N. Smith. 1998. Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen. *Ecology Applications* 8, 559.

Chang, R. 1991. Chemistry, 4th ed. McGraw-Hill, Inc.

Chapra, S.C. 1977. Total phosphorus model for the Great Lakes. Proc. Amer. Soc. Civil Engr. 103 (EE2): 147-162.

Dayton, E.A. and N.T. Basta. 2005. Use of drinking water treatment residuals as a potential best management practice to reduce phosphorus risk index scores. J. Environ. Qual. 34:2112-2117.

DePinto, J.V., T.C. Young and S.C. Martin. 1981. Algal availability of phosphorus in suspended sediments from lower Great Lakes tributaries. J. Great Lakes Research. 7(3):311-325.

Di Toro, D.M. and J.P. Connolly 1980. Mathematical models of water quality in large lakes. Part 2: Lake Erie. U.S.EPA Report #EPA-600/3-80-065.

Di Toro, D.M. 2001. Sediment Flux Modeling. Wiley Interscience, New York.

Dodson, S. 2005. Introduction to limnology. McGraw Hill.

Dolan, D. M., and K. P. McGunagle. 2005. Lake Erie Total Phosphorus loading analysis and update: 1996–2002. *J. Great Lakes Res.* 31(Suppl. 2):11–22.

ECOFORE. 2006. Ecological Forecasting: Hypoxia Assessment in Lake Erie. University of Michigan, Cooperative Institute for Limnology and Ecosystem Research (*http://sitemaker.umich.edu/ecoforelake.erie/home*.

Easton Z.M., P. Gerard-Marchant, M. Todd Walter, A.M. Petrovic, and T.S. Steenhuis. 2007. Identifying dissolved phosphorus source areas and predicting transport from an urban watershed using distributed hydrologic modeling. Water Resource Research, Vol. 43: W11414.

Edsall, T. and M. Charleton. 1997. Nearshore waters of the Great Lakes. Prepared for the State of the Lakes Ecosystem Conference 1996, U.S.EPA, EPA 905-R-97-015a, and Environment Canada, Cat. No. En40-11/35-1/1997E. 152pp.

Environment Ohio and Environment Ohio Research and Policy Center. 2007. Sewage overflows: Billions of gallons of sewage contaminate Lake Erie.

Gächter, R., and B. Müller. 2003. Why the phosphorus retention of lakes does not necessarily depend on the oxygen supply to their sediment surface. Limnology and Oceanography 48**:** 929-933.

Garn, H.S. 2002. Effects of lawn fertilizer on nutrient concentration in runoff from lakeshore lawns, Lauderdale Lakes, Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 02–4130, 6 p.

Hecky, R.E., R.E.H. Smith, D.R. Barton, S.J. Guildford, W.D. Taylor, M.N. Charlton, T. Howell. 2004. The nearshore phosphorus shunt: a consequence of ecosystem engineering by dreissenids in the Laurentian Great Lakes. *Can. J. Fish. Aquat. Sci*. 61:1285-1293.

Hiriart-Baer, V.S. Watson, T. Howell, J. Vincent and M. Charlton. 2008. Status of Nutrients in the Lake Erie Basin. Draft final report to the Lake Erie Work Group of the Lake Erie Lakewide Management Plan.

Higgins, S.N., E.T. Howell, R.H. Hecky, S.J. Guildford, and R.E. Smith. 2005. The wall of green: the status of Cladophora on the northern shores of Lake Erie's eastern basin, 1996-2002. J. Great Lakes Res. 31:547-563.

Hooda, P.S., A.R. Rendell, A.C. Edwards, P.J.A. Withers, M.N. Aitken and V.W. Tresdale. 2000. Relating soil phosphorus indices to potential phosphorus release to water. J. Environ. Qual. 29:1166-1171.

House, W. A. 2003. Geochemical cycling of phosphorus in rivers. Applied Geochemistry 18**:** 739.

Hyacinthe, C., and P. Van Cappellen. 2004. An authigenic iron phosphate phase in estuarine sediments: composition, formation and chemical reactivity. Marine Chemistry 91**:** 227-251.

International Joint Commission. 1978. Environmental Management Strategy for the Great Lakes Systems, Final report to the International Joint Commission from the International Reference Group on Great Lakes Pollution from Land Use Activities. PLUARG. Windsor, Ontario.

International Joint Commission. 1980. Pollution in the Great Lakes Basin from Land Use Activities. An IJC Report to the Governments of the United States and Canada, Windsor, Ontario.

Joosse, P.J. and D.B. Baker. 2009. The re-emergence of eutrophication in the Great Lakes: a context for renewed concern regarding nonpoint agricultural source phosphorus. Canadian J. Soil Sci. (Submitted as an invited paper introducing the Great Lakes Phosphorus Forum, Windsor, ON, July 2009).

Kelly, J. 2008. Nutrients and the Great Lakes Nearshore, Circa 2002-2007. In U.S. Environmental Protection Agency and Environment Canada, Nearshore Waters of the Great Lakes. Draft background paper prepared for the State of the Lakes Ecosystem Conference 2008.

Kim, E.K. 2007. Use of soil texture analyses to predict fracturing in glacial tills and other unconsolidated materials. Dissertation, The Ohio State University, 313 pages. *http://etd.ohiolink.edu/view.cgi?acc_num=osu1196080474*.

Kleinman, P.J., A.N. Sharpley, B.G. Moyer and G.F. Elwinger. 2002. Effect of mineral and manure phosphorus sources on runoff phosphorus. J. Environmental Qual. 31:2026 – 2033.

Kleinman, P.J., A.N. Sharpley, L.S. Saporito, A.R. Buda and R.B. Bryant. 2008. Application of manure to no-till soils: phosphorus losses by sub-surface and surface pathways. Nutr.Cycl. Agroecosyst. 84:215-227.

Knight, R. L. 1997. Successful interagency rehabilitation of Lake Erie walleye. Fisheries 22(7):16-17.

Lake Erie LaMP. 2009. Draft Nutrient Management Strategy. Prepared for the Lake Erie LaMP Management Committee. (July 19, 2009 Draft).

Lemunyon, J.L., and R.G. Gilbert. 1993. Concept and need for a phosphorus assessment tool. Journal of Production Agriculture 6: 483-486.

Lindsay, W.L. 1979. Chemical equilibria in soils. The Blackburn Press. Caldwell, N.J.

Ludsin, S.A., M.W. Kershner, K.A. Blocksum, R.L. Knight, and R.A. Stein. 2001. Life after death in Lake Erie: nutrient controls drive fish species richness, rehabilitation. Ecological Applications 11:731-746.

Magnuson, J., K. Webster, R. Assel, C. Bowser, P. Dillon, J. Eaton, H. Evans, E. Fee, R. Hall, L. Mortsch, D. Schindler and F. Quinn. 1997. Potential effects of climate changes on the aquatic systems: Laurentian Great Lakes and Precambrian Shield Region. Hydrological Processes, Vol. 11: 825-871.

Mallarino, A.P. and M.U. Haq. 2009. Runoff phosphorus loss shortly after applying fertilizer and animal manure without incorporation into the soil. Iowa State University Extension. Agronomy Extension Soil Fertility Web Site *www.agronext.iastate.edu/soilfertility/*.

Matisoff, G. and J.H Ciborowski. 2005. Lake Erie Trophic Status Collaborative Study. J. Great Lakes Research 31 (Supplement 2):1-10.

Meals, D.W., and L.F. Budd, 1998. Lake Champlain Basin Nonpoint Source Phosphorus Assessment. Journal of the American Water Resources Association 34:251-265.

Mehlich, A. 1984. Mehlich-3 soil test extractant: A modification of Mehlich-2 extractant. Commun. Soil Sci. Plant Anal.15:1409-1416.

Meile, C., and P. Van Cappellen. 2003. Global estimates of enhanced solute transport in marine sediments. Limnology and Oceanography 48**:** 777-786.

Milesi, C., S.W. Running, C.D. Elvidge, J.B. Dietz, B.T. Tuttle, and R.R. Nemani. 2005. Mapping and modeling the biogeochemical cycling of turf grasses in the United States. Environ. Manage. 36:426-438.

Miltner, R. 2010. A method and rationale for deriving nutrient criteria for small rivers and streams in Ohio. Environmental Management online journal publication. DOI: 10.1007/s00267-010-9439-9.

Moosmann, L., R. Gächter, B. Müller, and A. Wüest. 2006. Is phosphorus retention in autochthonous lake sediments controlled by oxygen or phosphorus? Limnology and Oceanography 51**:** 763-771.

Morris, K. 2003. The National Turfgrass Research Initiative. Enhancing America’s beauty, protecting America’s natural resources, ensuring the health and safety of all Americans. National Turfgrass Federation. Beltsville, MD.

Mortimer, C. H. 1941. The exchange of dissolved substances between mud and water in lakes. I. Journal of Ecology 30**:** 280-329.

Mullen, R. and K. Diedrick. 2009. Glyphosate and phosphorus. Crop observation and recommendation network (C.O.R.N.) newsletter 2009-23. (*http://corn.osu.edu*).

National Oceanographic and Atmospheric Administration. 2009. Center of Excellence for Great Lakes and Human Health. Harmful algal bloom event response. *www.glerl.noaa.gov/res/Centers/HABS/sampling_data.html*.

Nestor, J. 2010. Letter to the Ohio Lake Erie Phosphorus Task Force, Joe Nester, Nester Ag LLC, January 22, 2010.

Ohio Department of Health. 2008. ODH Report to the Ohio Lake Erie Phosphorous Task Force. April 18, 2008.

Ohio Department of Natural Resources. 2008. Rural drainage systems report. ODNR, Division of Soil and Water Conservation.

Ohio EPA. 1999. Association between nutrients, habitat and the aquatic biota of Ohio rivers and streams. Ohio EPA Technical Bulletin MAS/1999-1-1.

Ohio EPA. 2003. Lower Cuyahoga River Watershed TMDL, Appendix J, Final Report prepared by Ohio Environmental Protection Agency, Division of Surface Water.

Ohio EPA. 2008. Integrated water quality and assessment report. Ohio EPA. Division of Surface Water.

Ohio NRCS. 2001. Field Office Technical Guide. Section 1. Nitrogen and phosphorus risk assessment procedures. *http://efotg.nrcs.usda.gov/references/public/OH/Nitrogen_and_Phosphorous_Risk_Assessment_Procedures.pdf*.

Ohio State University Extension. 2005. Ohio Agronomy Guide, 14th Edition Bulletin 472-05.

Ohio State University. 2006. Ohio State University Bulletin 604 – Ohio Livestock Manure Management Guide. OSU Extension. Columbus, OH. *http://ohioline.osu.edu/b604/*.

Ohio State University Extension. Tri-State Fertility Recommendations for Corn, Soybeans, Wheat and Alfalfa, Bulletin E-2567, *http://ohioline.osu.edu/e2567/index.html*

Pote, D. H., T. C. Daniel, P.A. Moore, Jr., D.J. Nichols, A.N. Sharpley, and D.R. Edwards. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. Soil Science Society of America Journal 60: 855-859.

Pote, D.H., T.C. Daniel, D. J. Nichols, A.N Sharpley, P.A. Moore, Jr., D.M Miller, and D.R. Edwards. 1999. Relationship between phosphorus levels in three Ultisols and phosphorus concentrations in runoff. Journal of Environmental Quality 28: 170-175.

Rehm, G., M. Schmitt, J. Lamb, G. Randall and L. Busman. 2002. Understanding phosphorus fertilizers. University of Minnesota Extension. Published online at: *www.extension.umn.edu/distribution/cropsystems/dc6288.html*.

Richards, R.P. and D.B. Baker. 2002. Trends in water quality in LEASEQ rivers and streams (Northwestern Ohio), 1975-1995. J.Environ. Qual. 31:90-96.

Richards, R.P., D.B. Baker, J.P. Crumrine, and A.M. Stearns. (in press). Unusually large loads in 2007 from the Maumee and Sandusky Rivers, tributaries to Lake Erie. Accepted by Journal of Soil and Water Conservation 2010.

Rural Drainage Advisory Committee. 2008. Rural drainage systems. Agencies and organization reach consensus on ways forward. ODNR. Division of Soil and Water Conservation.

Schroeder, P.D., D.E. Radcliffe, M.L. Cabrera and C.D. Belew. 2004. Relationship between soil test phosphorus and phosphorus in runoff: Effects of soil series variability. J. Environ. Qual. 33:1452-1463.

Sharpley, A.N. 1985. Depth of surface soil-runoff interaction as affected by rainfall, soil slope, and management. Soil Science Society of America Journal 49: 1010-1015.

Sharpley, A.N. 1995. Dependence of runoff phosphorus on extractable soil phosphorus. J. Environ. Qual. 24:920-926.

Sharpley, A.N. 2006. Lesson 34. Agricultural phosphorus management: Protecting production and water quality. Livestock and Poultry Environmental Stewardship (LPES) Curriculum, USDA-Agricultural Research Service, Midwest Plan Service, Iowa State University, Ames, Iowa.

Sharpley, A.N. and J.K. Syers. 1979. Phosphorus inputs into a stream draining an agricultural watershed: II. Amounts and relative significance of runoff types. Water Air Soil Pollut. 11:417–428.

Sharpley, A.N., T. Daniel, J.Sims, and D Pote. 1996. Determining environmentally sound soil phosphorus levels. Journal of Soil and Water Conservation 51: 160-166.

Sharpley, A.N. and A.D. Halvorson. 1994. The management of soil phosphorus availability and its transport in agricultural runoff. p. 1-84. *In* R. Lal (ed.) Soil processes and water quality. Advances in Soil Science. Lewis Publ., Boca Raton, FL.

Sharpley, A.N., J.L. Weld, D.B. Beegle, P.J. Kleinman, W. J. Gburek, P.A. Moore, Jr. and G. Mullins. 2003. Development of phosphorus indices for nutrient management planning strategies in the United States. Journal of Soil and Water Conservation 58: 137-152.

Sharpley, A.N., P.J. Kleinman, A.L. Heathwaite, W.J. Gburek, G.J.Folmar, and J.P Schmidt. 2008. Phosphorus loss from an agricultural watershed as a function of storm size. J. Environ. Qual. 37:362-368.

Shipitalo, M.J., W.A. Dick, W.M. Edwards. 2000. Conservation tillage and macropore factors that affect water movement and the fate of chemicals. Soil Tillage Research 53: 167-183.

Shuman, L.M. 2001. Phosphate and nitrate movement through simulated golf greens. Water Air Soil Pollut. 128:1-11.

Shuman, L.M. 2003. Fertilizer source effects on phosphate and nitrate leaching through simulated golf greens. Environ. Pollut. 125:413-421.

Sims, J.T., R.O. Maguire, A.B. Leytem, K.L. Gartley and M.C. Paulter. 2002. Evaluation of Mehlich 3 as an agri-environmental soil phosphorus test for the Mid-Atlantic United States of America. Soil Sci. Soc. Am. J. 66:2016-2032.

Sims, J.T., A.C. Edwards, O.F. Schoumans and R.R. Simard. 2000. Integrating soil phosphorus testing into environmentally based agricultural management practices. J. Environ. Qual. 29:60-71.

Slomp, C. P., J. F. P. Malschaert, and W. Van Raaphorst. 1998. The role of adsorption in sediment-water exchange of phosphate in North Sea continental margin sediments. Limnology and Oceanography 43**:** 832-846.

Soldat, D.J and A.M. Petrovic. 2008. The fate and transport of phosphorus in turfgrass ecosystems. Crop Science, Vol. 48, Nov.-Dec.:2051-2065.

Sondergaard, M., J. P. Jensen, and E. Jeppesen. 2003. Role of sediment and internal loading of phosphorus in shallow lakes. Hydrobiologia 506**:** 135-145.

Sonzogni, W., S. Chapra, D. Armstrong and T. Logan. 1982. Bioavailability of phosphorus inputs to lakes. J. Environ. Qual., Vol. 11(4):555-563.

State-EPA Nutrient Innovations Task Group. 2009. An urgent call to action – Report of the State-EPA Nutrient Innovations Task Group. Available online at *www.epa.gov/waterscience/criteria/nutrient/nitgreport.pdf*.

Szabo, J.P. 2006. Textural and mineralogical characteristics of tills of northeastern and north-central Ohio. Ohio J. Sci. 106 (2):9-16, 2006. *https://kb.osu.edu/dspace/handle/1811/36449*.

Terry, D.L. 2006. Fertilizer tonnage reporting in the U.S.—Basis and current need. Better Crops 90(4):15-17.

Tornes, L.A., K.E. Miller, J.C. Gerken and N.E. Smeck. 2000. Distribution of soils in Ohio that are described with fractured substratums in unconsolidated materials. Ohio J Sci 100 (3/4):56-62, 2000. *https://kb.osu.edu/dspace/handle/1811/23856*.

University of Wisconsin. Discovery Farm experience. *www.uwdiscoveryfarms.org*.

U.S. Army Corps of Engineers. 1975. Lake Erie wastewater management study, preliminary feasibility report. 3 volumes, Corps of Engineers, Buffalo District, Buffalo, New York.

U.S. Army Corps of Engineers. 1979. Lake Erie Wastewater Management Study, Final Report. Corps of Engineers, Buffalo District, Buffalo, NY. 225 pages.

U.S. Army Corps of Engineers. 1983. Summary report of the Lake Erie Wastewater Management Study. U.S. Army Corps of Engineers, Buffalo District, Buffalo, NY.

USDA-National Agricultural Statistics Service. 2007. Ohio Statistics. Available at: *www.nass.usda.gov/Statistics_by_State/Ohio/index.asp*. USDA-NASS, Washington, DC.

USDA, NRCS. 2007. Conservation practice decision support tool, conservation practice physical effects (CPPE) matrix ranking by Ohio NRCS.

USDA, NRCS. 1973. Ohio drainage guide. Ohio Agricultural Research and Development Center, the Ohio State University and Ohio Department of Natural Resources.

US Global Change Research Program. 2010. *www.globalchange.gov*.

US Geological Survey. 2007. Historical changes in precipitation and streamflow in the U.S. Great Lakes basin, 1915-2004. National Water Availablity and Use Program, Scientific Investigations Report 2007-5118.

Van Cappellen, P., and Y. F. Wang. 1996. Cycling of iron and manganese in surface sediments: A general theory for the coupled transport and reaction of carbon, oxygen, nitrogen, sulfur, iron, and manganese. American Journal of Science 296**:** 197-243.

Vitosh, M.L., J.W. Johnson, and D.B. Mengel (eds). 1996. Tri-state fertilizer recommendations for corn, soybeans, wheat, and alfalfa. Ext. Bull. E-2567, Rep. August. Michigan State Univ., E. Lansing, MI).

Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, and N. Van Driel. 2001. Completion of the 1990s national land cover data set for the coterminous United States from landsat thematic mapper data and ancillary data sources. Photogrammetric Engineering and Remote Sensing. Vol. 67:650-662.

Vollenweider, R.A. 1971. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Organization for Economic Cooperation and Development, Paris, France.

Walker, J.L., Younos, T. and Zipper, C.E. 2007. Nutrients in Lakes and Reservoirs – a Literature Review for use in Nutrient Criteria Development. Walker et al. Virginia Polytechnic Institute and State University of Blacksburg Virginia.

Waschbusch, R.J., Selbig, W.R., and Bannerman, R.T., 1999, Sources of phosphorus in stormwater and street dirt from two urban residential basins in Madison, Wisconsin, 1994–95: U.S. Geological Survey Water-Resources Investigations Report 99-4021, 47 p.

Weatherington-Rice, J., A. Christy, M. Angle, R. Gehring and L. Aller. 2006. DRASTIC Hydrogeologic settings modified for fractured till: Part 2. Field observations. Ohio J Sci 106 (2):51-63, 2006. *https://kb.osu.edu/dspace/handle/1811/36430*.

Weld, J.L., D.B. Beegle, W.L. Gburek, P.J. Kleinman and A.N. Sharpley. 2003. The Pennsylvania phosphorus index: Version 1. Publ. Distribution Center, Pennsylvania State Univ., University Park.

Wersin, P., P. Hohener, R. Giovanoli, and W. Stumm. 1991. Early Diagenetic Influences on Iron Transformations in a Fresh-Water Lake Sediment. Chemical Geology 90**:** 233-252.

Wetzel, Robert. 1975. Limnology. W. B. Saunders Company.

Wilson, R. 2010. Analysis of effectiveness of Ohio NRCS Practice Standards in addressing five leading causes of water quality impairment. Ohio EPA, Division of Surface Water. *www.epa.ohio.gov/portals/35/lakeerie/ptaskforce/BMP_Effectiveness_Final030110.pdf*.

Wortman, C., M Helmers, A. Mallarino, C. Barden, D Devlin, G. Pierzynski, J. Lory, R. Massey, J Halz, C. Shapiro, and J. Kovar. 2005. Agricultural Phosphorus management and water quality protection in the Midwest. Heartland Regional Water Coordination Initiative. U.S. EPA Region 7.

Wortman, C. and D. Walters. 2006. Phosphorus runoff during four years following composted manure application. J. Environ. Qual. 35:651-657.

Appendices

Appendix A — HUC Maps and Land Use Statistics

Figure A-1 — Hydrologic units (HUC) representing individual or a combination of Ohio watersheds draining to Lake Erie. Use as a companion to Appendix Table A-1

Appendix Table A-1 — Level I land use classifications and percentages based on 2001 National Land Cover Data (NLCD). Hydrologic units from 04100001 through 04100011 drain to the Western Basin of Lake Erie. Hydrologic Units 04100012 through 04110003 drain to the Central Basin of Lake Erie

NLCD 2001 Level I	Ohio Lake Erie Tributaries	Maumee Basin	St. Joseph	St. Marys	Upper Maumee	Tiffin/ Bean
Hydrologic Unit	**Aggregate of HUCs**	**Aggregate of HUCs**	**04100003**	**04100004**	**04100005**	**04100006**
Area (sq. mi.)	**13,643**	**6,587**	**1,074**	**823**	**383**	**782**
Agriculture	65%	78%	70%	78%	78%	78%
Urban	16%	11%	10%	13%	14%	8%
Forest	13%	7%	11%	6%	5%	7%
Wetlands	3%	2%	8%	1%	1%	6%
Grassland	1%	1%	1%	1%	1%	0%
Barren	0%	0%	0%	0%	0%	0%
Shrub	0%	0%	1%	0%	0%	0%

NLCD 2001 Level I	Auglaize	Blanchard	Lower Maumee	Ottawa	Toussaint/ Portage	Sandusky
Hydrologic Unit Code	**04100007**	**04100008**	**04100009**	**04100001**	**04100010**	**04100011**
Area (sq. mi.)	**1,666**	**786**	**1,074**	**402**	**973**	**1,878**
Agriculture	82%	82%	76%	54%	76%	76%
Urban	11%	10%	14%	32%	13%	10%
Forest	5%	6%	7%	10%	4%	8%
Wetlands	0%	0%	1%	2%	4%	2%
Grassland	1%	2%	1%	1%	1%	1%
Barren	0%	0%	0%	0%	1%	0%
Shrub	0%	0%	0%	0%	0%	0%

NLCD 2001 Level I	Huron +	Vermilion/ Black/Rocky	Cuyahoga	Chagrin +	Grand	Ashtabula +
Hydrologic Unit Code	**04100012**	**04110001**	**04110002**	**04110003**	**04110004**	**04110003**
Area (sq. mi.)	**759**	**899**	**801**	**380**	**712**	**252**
Agriculture	69%	36%	16%	6%	33%	28%
Urban	9%	31%	45%	56%	11%	21%
Forest	19%	25%	31%	31%	43%	43%
Wetlands	1%	6%	3%	1%	6%	3%
Grassland	0%	1%	3%	5%	4%	3%
Barren	0%	0%	0%	0%	0%	0%
Shrub	0%	0%	0%	0%	2%	2%

Appendix B — Ohio Lake Erie Phosphorus Task Force
Recommended Agricultural Best Management Practices
for Reducing Phosphorus, Nitrogen and Sediment Loading to Lake Erie*

Nutrient Management (590) and Waste Utilization (633)

Nutrient management is the use of approved and proper prescriptions for fertilizer amounts and application methods and timing, based on proper soil testing and crop yield goals. <u>Nutrient management is one of the most important practices for reducing the export of dissolved reactive phosphorous from the watershed.</u> Nutrient management takes two forms:

- *Traditional nutrient management* involves traditional soil testing methods; and
- *Precision nutrient management* incorporates Global Positioning (GPS) Technology, combined with yield monitor maps, and Geo-referenced application methods to more precisely apply only what the crop needs and can use and only where it is needed. Precision nutrient management is state of the art conservation.

Develop and/or update Comprehensive Nutrient Management Plans Comprehensive Nutrient Management Plans (CNMPs) are documents developed to provide nutrient managers (especially manure managers in Ohio) an environmentally sound plan for proper nutrient storage, application, and agronomic utilization. CNMPs in and of themselves <u>do not</u> reduce nutrient losses in runoff, unless they are well-written, regularly updated and implemented. Water quality can incrementally improve based upon the extent that the following actions occur: CNMPs and/or Waste Utilization plans are well written and regularly updated per changes to recommendations and USDA-NRCS practice codes; a commitment to implement the CNMP exists on behalf of the nutrient manager (through training, monitoring, record keeping); and the degree with which the plan is fully implemented.

Fully <u>Implement</u> Waste Utilization and Nutrient Management practice standards

Waste utilization is the planning of a system to store, test, and apply animal waste in a manner that minimizes environmental risks and impacts. A waste utilization plan is a component of a *comprehensive nutrient management plan* and specifies the time, placement, and amounts of waste applied. It incorporates soil testing, waste testing, nutrient application prescriptions, application setbacks and restrictions, and timing prescriptions AND record keeping.

> **Management Practice:** Necessitates increased time spent for planning, oversight, and commencement of nutrient application, which can raise cost associated with additional labor, equipment, and fuel, but can reduce cost of fertilizer inputs.

Appendix B — Ohio Lake Erie Phosphorus Task Force Recommended Agricultural Best Management Practices for Reducing Phosphorus, Nitrogen and Sediment Loading to Lake Erie*

Riparian Forested Buffers (391) and Herbaceous Riparian Cover (390)

Riparian Forested Buffers are areas of native trees maintained along water courses to: control bank erosion; provide shading to keep water temperatures down and inhibit algal growth; reduce runoff rate and amount; intercept and assimilate nutrients; sequester carbon; and provide habitat. Riparian forested buffers may be the most effective buffer to protect and restore natural stream ecosystems. Herbaceous Riparian Cover buffers have similar but less effective conservation effects for water quality protection.

Buffer Practice: Generally, a cropland retirement action, which involves a Farm Bill program easement or lease payment to compensate landowner.

Wetlands: Restoration (657), Creation (658), Constructed (656), Enhancement (659)

Wetland restoration involves converting cropland and other drained areas into wetlands. Wetlands act as a buffer by providing the benefits of flow attenuation, reduced runoff, filtering of nutrients, and provide habitat.

Buffer Practice: Generally, a cropland retirement action, which involves a Farm Bill program easement or lease payment to compensate landowner.

Appendix B — Ohio Lake Erie Phosphorus Task Force Recommended Agricultural Best Management Practices for Reducing Phosphorus, Nitrogen and Sediment Loading to Lake Erie*

Drainage Water Management (554) and Structures for Water Control (587)

Drainage water management utilizes water control structures in tile drainage systems to raise the water table in crop fields during the non-crop period when improved drainage is not needed. The elevated water table reduces nutrient losses to surface waters by reducing the overall volume of water released from the tile drainage system over time.

Management Practice: Success of drainage water management is dependent upon the degree and timing with which the land-owner/operator utilizes and adjusts the structure.

Structural Practice: A permanent structure that must be installed. Costs include cost of material, labor, and any land that may be removed from production.

Filter Areas/Filter Strips (393)

Filter Areas and Filter Strips are areas that are generally placed adjacent to watercourses that are planted into perennial grasses, legumes and forbs. These areas reduce erosion, trap pollutants and nutrients, improve water quality and provide habitat.

It is important to recognize that sheet flow of runoff from field to watercourse is rare in the landscape. Therefore, filter areas that are designed to intercept and disperse runoff through the entirety of the filter area are much needed, and should become a priority for conservation planners in Lake Erie watershed county offices in Ohio. Fixed-width buffers can be improved with this rationale in mind.

There are numerous instances in Ohio where streamside buffers are called “filter strips,” but in fact, do not meet the specifications in the Filter Strip/Area practice NRCS fField Office Technical Guide standard because runoff is not dispersed through the filter, but enters surface water via concentrated flow paths and/or subsurface tiles. In these cases (e.g., where the filter strip elevation is higher than the crop field), the “filter strip” is more properly called “conservation cover.”

Buffer Practice: Generally, a cropland retirement action, which involves a Farm Bill program easement or lease payment to compensate landowner.

Appendix B — Ohio Lake Erie Phosphorus Task Force Recommended Agricultural Best Management Practices for Reducing Phosphorus, Nitrogen and Sediment Loading to Lake Erie*

Conservation Crop Rotations (328)

Conservation crop rotations improve soil structure and soil tilth by incorporating more high residue crops in the rotation, use of cover crops, and by minimizing oxidation of crop residue by tillage. Improved crop rotations decrease surface runoff volumes through better infiltrative and water holding capacities of the soil resulting in decreased runoff amounts and reduced soil erosion losses.

Management Practice: Necessitates increased time spent for planning, oversight, and commencement of land practices, which can raise cost associated with additional labor, equipment, and fuel, but can reduce cost of fertilizer inputs.

Residue and Tillage Management (Conservation Tillage): No till/strip till/direct seed (329), Mulch Till (345)

Conservation tillage is the use of crop production methods that maintain protective crop residue on the soil surface. Conservation tillage practices such as No-till, strip till and direct seed are the most effective conservation practices to control soil erosion in the Western Lake Erie Basin. Compared to traditional moldboard plow tillage, conservation tillage reduces volume and intensity of surface runoff, sequesters carbon in soil profile, and provides wildlife habitat in winter.

Management Practice: Necessitates increased time spent for planning, oversight, and commencement of land practices, which can raise cost associated with additional labor, equipment, and fuel, but can reduce cost of fertilizer inputs.

Appendix B — Ohio Lake Erie Phosphorus Task Force Recommended Agricultural Best Management Practices for Reducing Phosphorus, Nitrogen and Sediment Loading to Lake Erie*

Cover Crops (340)

Cover crops are grasses, small grains, or legumes planted after harvest to protect the soil and sequester nutrients until the next crop is planted. Cover crops prevent nutrients from leaching or leaving in runoff waters, reduce discharge volume, improve soil tilth and quality, and reduce erosion. Cover crops work in union with conservation cropping systems, and conservation tillage. Further, the benefits to water quality are multiplicative with the adoption of each practice for as long as the land continues in row crop production.

Management Practice: Necessitates increased time spent for planning, oversight, and commencement of land practices, which can raise cost associated with additional labor, equipment, and fuel, but can reduce cost of fertilizer inputs.

Grassed Waterway (412) and associated Grade Control Structures (410)

Grassed waterways control ephemeral gully erosion. They reduce sediment delivery to receiving waters and eventually to the harbor and Lake Erie. Grade stabilization structures control bank and gully erosion to improve water quality and allow for drainage water management. They are often used in the installation of grassed waterway.

Buffer Practice: Generally, a cropland retirement action which involves a Farm Bill program easement or lease payment to compensate land owner.

Structural Practice: A permanent structure that must be installed. Costs include cost of material, labor, and any land that may be removed from production.

Appendix B — Ohio Lake Erie Phosphorus Task Force Recommended Agricultural Best Management Practices for Reducing Phosphorus, Nitrogen and Sediment Loading to Lake Erie*

Field Border (386), Vegetative Barrier (601), Contour Buffer Strips (332), and Conservation Cover (327)

Field borders are plantings of perennial grasses, forbs, and legumes around the perimeters of crop fields. These plantings capture and filter nutrients in runoff, provide food and nectar for crop pollinators, and provide habitat and nesting.

Conservation covers establish perennial vegetative cover to protect soil and water resources on land retired from agricultural protection. As mentioned above, countless acres of conservation cover along streams and water courses are mistaken for and often referred to as "filter strips." Where possible these systems conservation cover should be re-evaluated and redesigned to meet the "filter area" definition described above for more effective water quality protection.

The practices described above may also be applied as in-field buffers to reduce the rate and quantity of surface runoff by acting as a physical barrier to reduce runoff velocity/energy,

> **Buffer Practice:** Generally, a cropland retirement action which involves a Farm Bill program easement or lease payment to compensate land owner.

Diversion (362): *in Association with Filter Areas (above)*

A diversion is a channel constructed across the slope generally with a supporting ridge on the lower side. That is installed to break up concentrations of water on long slopes, on undulating land surfaces, and to intercept surface and shallow subsurface flow. A diversion can be an important practice to achieve more effective benefit of designed filter areas or strips.

> **Structural Practice:** A permanent structure that must be installed. Costs include cost of material, labor, and any land that may be removed from production.

Appendix B — Ohio Lake Erie Phosphorus Task Force Recommended Agricultural Best Management Practices for Reducing Phosphorus, Nitrogen and Sediment Loading to Lake Erie*

Waste Transfer (634)

Waste transfer is a management practice that involves a system using structures, conduits or equipment (usually manure hauling vehicles) to convey byproducts (manure and other material) from agricultural operations to alternative points of storage or usage. This practice is especially important in regions or farmsteads where there is a nutrient surplus in the soil, and where there is no agronomic necessity for application of additional manure or other nutrients to the land.

Management Practice: Necessitates increased time spent for planning, oversight, and commencement of waste transfer, which can raise cost associated with additional labor, equipment, and fuel, but can reduce cost of fertilizer inputs.

Controlled Traffic System

Controlled traffic confines heavy traffic from tractor drive wheels/tracks, combine wheels, fertilizer or manure spreaders and grain carts to specific lanes in crop fields year after year. Controlled traffic systems will reduce soil compaction, increase infiltration and improve crop yields. Additional benefits include reductions in erosion, runoff and sedimentation as well as energy savings as the need for sub-soiling decreases and firm traffic tracks form for better traction. Implementation of this practice includes: limiting wheel/track traffic to no more 50% of the rows or a maximum of 50% of the trafficked area of the field; keeping wheel/track traffic the same for all passes, all equipment and years; and ensuring no track row that is greater than 20 inches wide.

Equipment Enhancement and Management Practice: For full width tillage Geographic Positioning System (GPS) is required to maintain the designated traffic lanes. For narrow width or drilled crops, a skip row system or GPS is required. Some systems use GPS to steer tractor and are accurate to within an inch.

Appendix B — Ohio Lake Erie Phosphorus Task Force Recommended Agricultural Best Management Practices for Reducing Phosphorus, Nitrogen and Sediment Loading to Lake Erie*

Other recommended practices that can affect water quality improvement where applied to address farm specific concerns:

The following practices are included on this list because they have been documented to provide water quality benefit, but it is recognized that there may be limited participation in the Lake Erie Basin, or on acres where site specific needs dictate their adoption:

1. **Critical Area Planting (342):** Planting vegetation such as trees, shrubs, vines, grasses, or legumes on highly erodible or critically eroding areas with the purpose to: stabilize sheet, rill, and gully erosion, minimize sedimentation on and offsite, and improve wildlife habitat and visual resources.
2. **Pasture and Hay Planting (512):** Establishing and re-establishing long-term stands of adapted species of perennial, biennial, or reseeding forage plants for the purpose of reducing erosion, to produce high quality forage and to adjust land use on existing pasture and hayland or on land that is converted from other uses.
3. **Prescribed Grazing (528):** Managing the harvest of vegetation with grazing and/or browsing animals for the purpose of improving or maintaining surface and/or subsurface water quality and quantity, improving or maintaining riparian and watershed function, reducing accelerated soil erosion, and maintaining or improving soil condition.

* Photographs obtained from USDA-NRCS and lftseed.com. Numbers refer to specific NRCS practice standards listed in the NRCS Field Office Technical Guide. (Ohio NRCS, 2001)

Cover Image:
Lake Erie, Sept. 4, 2009
Thomas Archer, Columbus, Ohio

Ohio Environmental Protection Agency
Division of Surface Water
P.O. Box 1049
Columbus, Ohio 43216-1049
www.epa.ohio.gov
(614) 644-2001