Phosphorus Loading to Lake Erie: A Brief Overview, Including Recent Changes in Dissolved Reactive Phosphorus from Tributaries

David B. Baker, Heidelberg College, February 28, 2007

I. Background

A. Phosphorus entering Lake Erie occurs in two basic forms:
   1. Dissolved phosphorus (passes through a 0.45 micron filter)
   2. Particulate phosphorus (trapped on a 0.45 micron filter; associated primarily with inorganic sediments; lesser amounts in organic particulate matter or incorporated into living organisms, such as algae or bacteria)
   3. Together, these forms comprise <u>total phosphorus</u>, which is directly analyzed in most phosphorus loading studies.

B. The various forms of phosphorus have differing degrees of bioavailability (ability to support algal growth).
   1. Most of the dissolved phosphorus occurs as dissolved reactive phosphorus, which is 100% bioavailable.
   2. Particulate phosphorus is mostly unavailable to algae, and the portion that is bioavailable may settle to the lake bottom before being released to support algal growth. For the Maumee River, past studies (early 1980s) indicated that about 30% of the particulate phosphorus is bioavailable.

C. Phosphorus loading to Lake Erie is derived from two major types of sources.
   1. External sources (subject to direct measurements)
   2. Internal sources (released from lake sediments, relatively difficult to quantify)

D. External phosphorus loading into Lake Erie is derived from four major sources:
   1. Outflow from Lake Huron (a minor component for Lake Erie)
   2. Atmospheric deposition (a minor component for Lake Erie)
   3. Point sources (municipal and industrial)
   4. Nonpoint sources

E. Point sources have the following characteristics:
   1. They are comprised primarily of dissolved reactive phosphorus and consequently are highly bioavailable.
   2. They are, for the most part, discharged in roughly equal daily amounts throughout the year.
   3. They are relatively easy to measure.
   4. Their loading can be reduced by point source controls.
   5. About 50% of the total point sources currently entering Lake Erie come from southeast Michigan.

F. Nonpoint sources of phosphorus have the following characteristics:
   1. They are comprised primarily of particulate phosphorus.
   2. The particulate phosphorus has relatively low bioavailability.
   3. They are delivered to the Lake in pulses associated with runoff events.
   4. They are relatively difficult to quantify.
   5. Their loading is highly variable from year to year, due to weather conditions.
   6. Load reductions are achieved by adoption of "best management practices."

G. Phosphorus loading to Lake Erie and lake responses to that loading have been studied primarily in terms of total phosphorus, rather than individual or bioavailable forms.

II. Trends in total phosphorus loading to Lake Erie from all sources.

A. In the late-1960s, external total phosphorus loading, the majority of which was derived from point sources, averaged about 25,000 metric tons per year. Lake Erie suffered from extensive eutrophication problems.
B. During the 1970s major reductions in phosphorus loading from point sources were achieved through a combination of improved waste treatment and detergent phosphorus bans. However, as late as 1972, point source phosphorus loading by itself still exceeded the eventual target load of 11,000 metric tons per year from all sources.
C. By 1980, a target load of 11,000 metric tons of external phosphorus loading was set for Lake Erie, and its was recognized that reductions in both point and nonpoint loading to Lake Erie would be necessary to consistently meet the target load.
D. The target load was first met in 1981, and since that time total phosphorus loading has averaged 10,263 metric tons per year. Loads exceed the target load during years of above average nonpoint loads associated with above average discharges.
E. Since 1981 both point sources and nonpoint sources have continued to undergo slow declines.

III. Trends in nonpoint loading from Ohio tributaries: Particulate Phosphorus

A. Nonpoint source phosphorus control programs, which were planned in the 1980s and initiated in the early 1990's, focused on reducing particulate phosphorus through various erosion control programs, such as no-till and reduced-till, and through the use of buffer strips to trap suspended sediments.
B. Lesser emphasis was placed on fertilizer and manure management since responses to these management efforts were assumed to involve longer delays.
C. In general, particulate phosphorus has not been directly measured. It is calculated by subtracting either dissolved reactive phosphorus, or an estimate of total dissolved phosphorus, from total phosphorus measurements.
D. Particulate phosphorus loading from nonpoint sources in the agricultural watersheds of northwestern and north central Ohio has declined, along with generally larger declines in the loading of suspended sediments.
F. For the Maumee River, the declines in annual particulate phosphorus loads from 1975 to 2006 amount to 41.5% (linear regression) and are statistically significant (P-value = 0.030).
E. The declines are reflected in lower concentrations at all stream discharges, with larger decreases in concentrations at higher flows.

IV. Trends in nonpoint loading from Ohio tributaries: Dissolved Reactive Phosphorus

A. Dissolved reactive phosphorus declined much more quickly than particulate phosphorus between 1975 and 1995, with declines approaching 80%.

B. Since 1995, dissolved reactive phosphorus loading has increased, and by 2006, was comparable to the dissolved reactive phosphorus loading in the late 1970s.
C. With the decreasing loads of particulate phosphorus and the recent increases in loads of dissolved reactive phosphorus, and assuming that about 30% of the particulate phosphorus is bioavailable, the bioavailable loading in the form of dissolved reactive phosphorus now exceeds the bioavailable loading from particulate phosphorus from northwestern Ohio tributaries.
D. If substantial portions of the particulate phosphorus settle out of the water column prior to release of bioavailable particulate phosphorus, the long-term trends in the delivery of dissolved reactive phosphorus to Lake Erie during storm events could be particularly important to open lake phosphorus trends and associated algal productivity.

V. Additional Background Information and Context (Question and Answer Format)

A. Of the total phosphorus export for Lake Erie tributaries, what percentage can be accounted for by point source inputs upstream from the sampling stations?

- Maumee River -- 7.5%
- Sandusky River -- 4.2%
- Honey Creek -- 3.0%
- Rock Creek -- <1%
- Cuyahoga River -- 58.5%
- Grand River --1.6%

(Total loading is the average of annual loads for the five year period including the 2002 – 2006 water years. Point source inputs are based on data provided by Dave Dolan for the 2002 Water Year. We assume that point sources have not increased during the past five years and that point sources have 100% delivery through the stream system.)

B. How do the current unit area loads (export) of total and dissolved phosphorus compare among Ohio's Lake Erie tributaries?

River	Total Phosphorus, lbs/acre (average 2002-06)	Dissolved Reactive Phos. lbs/acre (average 2002-06)
Maumee	0.998	0.243
Sandusky	1.258	0.277
Honey Creek	1.150	0.329
Rock Creek	1.230	0.223
Cuyahoga	1.516	0.238
Grand	0.694	0.078

(All values based on data from Heidelberg College's Ohio Tributary Loading Program. Note that the Maumee, Sandusky, Honey Creek and Rock Creek watersheds are primarily agricultural while the Cuyahoga is primarily urban/forested and the Grand is primarily forested.)

C. If the average dissolved phosphorus loads for 2002-2006 are expressed as a percent of the average loads for 1992-1996, how much have dissolved reactive phosphorus loads changed in Ohio's Lake Erie tributaries?

- For the Maumee River – 195%
- For the Sandusky River – 325%
- For Honey Creek – 321%
- For Rock Creek – 333%
- For the Cuyahoga River – 253%
- For the Grand River – 346%

(See Appendix Table 1 for comparable changes for suspended solids, total phosphorus and dissolved reactive phosphorus.)

D. For Lake Erie as a whole, what is the relative importance of various external phosphorus sources? (average annual loads – 1998-2002)

- Direct point sources loads.........1,464 metric tons.....................16.3%
- Indirect point source loads...........512 metric tons........................5.6%
- Monitored nonpoint sources .....3,596 metric tons.....................40.1%
- Unmonitored nonpoint sources .1,682 metric tons.....................18.8%
- Lake Huron outflow.................1,080 metric tons.....................12.0%
- Atmospheric deposition ....535 metric tons........................7.1%
- Total External load...................8,968 metric tons
- Ratio total nonpoint phosphorus:direct point source phosphorus = 3.6:1.0

(Values taken from data of Dolan and represent the average annual loads for a 5 year period from 1998-2002 water years. Direct point sources are those that discharge downstream from tributary monitoring stations, into unmonitored streams, or directly into the lake. Indirect point sources discharge upstream from monitoring stations. Monitored nonpoint sources are from monitoring stations after subtraction of upstream point sources (indirect point sources). Unmonitored nonpoint sources are based on extrapolation from nearby monitored tributaries to unmonitored land areas.)

E. For Lake Erie, how does dissolved reactive phosphorus loading from tributaries and land runoff compare with the dissolved reactive phosphorus loading from direct point sources?

- From direct point sources – 1,464 metric tons (enters in equal daily amounts)
- From tributary loading – 1,279 metric tons (enters in storm event pulses)

(Assumptions: For point sources, uses annual average Lake Erie direct point sources for 1998-2002 and assumes that total phosphorus inputs from point sources is 100% dissolved reactive phosphorus; for nonpoint sources uses average annual total nonpoint phosphorus loads plus indirect point source loads for 1998-2003 and assumes that dissolved reactive phosphorus represents 22.2% of the total phosphorus. The 22.2% was taken from the average % DRP for tributaries in the Heidelberg monitoring program for the 2002-2006 water years.)

Appendix Table 1. Comparisons of average annual discharge and pollutant loads for two 5-year periods, 1992-1996 water years and 2002-2006 water years. For dissolved reactive phosphorus, flow weighted mean concentrations (FWMCs) are also shown.

River (drainage area)	WaterYears	Average Annual Discharge	Ave. Annual Suspended Solids	Ave. Annual Total Phosphorus	Ave. Annual Dissolved R. Phosphorus	Ave. Annual Dissolved R. Phosphorus		DRP as percent TP		Unit Area, TP	Unit Area DRP, lbs/acre
km^2		million m^3	metric tons	metric tons	metric tons	FWMC, mg/L		% DRP/TP		lbs/acre	lbs/acre
Raisin	1992-96	714.2	44,380.0	109.6	14.0	0.0195		12.7%		0.363	0.046
2,699 km^2	2002-06	682.2	68,091.3	129.4	25.8	0.0379		20.0%		0.428	0.085
	Percent*	95.5%	153.4%	118.1%	185.1%	193.8%					
Maumee	1992-96	4,926.2	801,600.0	1,806.0	228.4	0.0464		12.6%		0.984	0.124
16,395 km^2	2002-06	5,386.9	743,894.3	1,831.5	445.3	0.0827		24.3%		0.998	0.243
	Percent*	109.4%	92.8%	101.4%	195.0%	178.3%					
Sandusky	1992-96	1,042.2	210,600.0	403.2	31.0	0.0297		7.7%		1.110	0.085
3,245 km^2	2002-06	1,234.8	199,205.5	457.1	100.7	0.0816		22.0%		1.258	0.277
	Percent*	118.5%	94.6%	113.4%	324.9%	274.2%					
Honey Creek	1992-96	121.4	18,780.0	46.7	4.4	0.0366		9.5%		1.080	0.103
386 km^2	2002-06	137.1	15,241.1	49.7	14.2	0.1039		28.6%		1.151	0.329
	Percent*	112.9%	81.2%	106.6%	320.7%	284.0%					
Rock Creek	1992-96	27.8	8,320.0	13.3	0.7	0.0243		5.1%		1.318	0.067
90 km^2	2002-06	29.0	6,405.8	12.4	2.3	0.0776		18.1%		1.230	0.223
	Percent*	104.2%	77.0%	93.4%	332.8%	319.5%					
Cuyahoga	1992-96	861.6	195,000.0	208.0	19.3	0.0224		9.3%		1.013	0.094
1,834 km^2	2002-06	1,037.5	295,765.6	311.4	48.9	0.0471		15.7%		1.516	0.238
	Percent*	120.4%	151.7%	149.7%	253.3%	210.3%					
Grand	1992-96	876.5	100,000.0	99.0	4.4	0.0051		4.5%		0.500	0.022
1,769 km^2	2002-06	1,055.0	131,714.8	137.5	15.4	0.0146		11.2%		0.694	0.078
	Percent*	120.4%	131.7%	138.9%	346.0%	287.5%					
Lake Erie river tribs (excludes Honey and Rock Creek), for 2002-2006				2,867.0	636.2			22.2%			
*Percent is the 2002-2006 average divided by the 1992-1996 average multiplied by 100.											