Indiana Certified Crop Advisor Conference
Indianapolis Marriot East
Indianapolis, Indiana
December 12, 2017

Nutrients From Cropland to Lake Erie: Perspectives from Detailed River Monitoring, 1975-2016

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A quick guide to viewing this presentation --

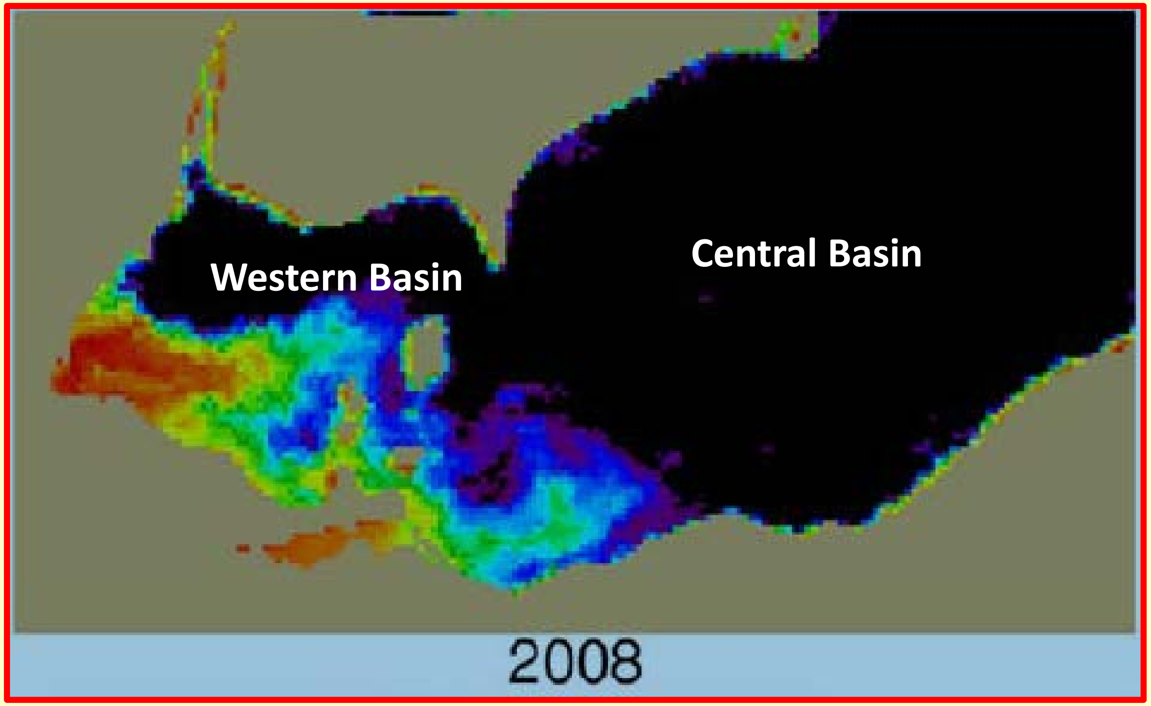
1. Many of the slides have animation to help sequence the topics included on the slide. Consequently viewing the slides as a slide show on your computer may be helpful in following the material on the slides.

2. I have added notes to many of the slides to cover my comments during the presentation or to add relevant information. To view these comments while observing the slides and related animation, it may be useful the print out the slides with the notes attached.

Selected references have been added as a last slide.

Lake Erie has been plagued by a return of harmful algal blooms in recent years.

A satellite image of the western and central basins of Lake Erie



Increased cropland runoff of dissolved phosphorus has been identified as the major cause.

But, by managing for a 40% reduction of both total and dissolved phosphorus we are likely putting too many resources on erosion control and insufficient resources on nutrient management.

Lake Erie Re-eutrophication ---

How do we know it's cropland runoff?

How do we know it's dissolved phosphorus?

Why did dissolved phosphorus loading increase so much?

What can be done about it?

<u>But first, 3 basics ….</u>

1. There are two major sources of water pollutants…

<u>Point Sources</u> – associated with <u>water use</u> for domestic and industrial purposes.

Examples – municipal sewage treatment plants.

Field Runoff in the Sandusky Watershed

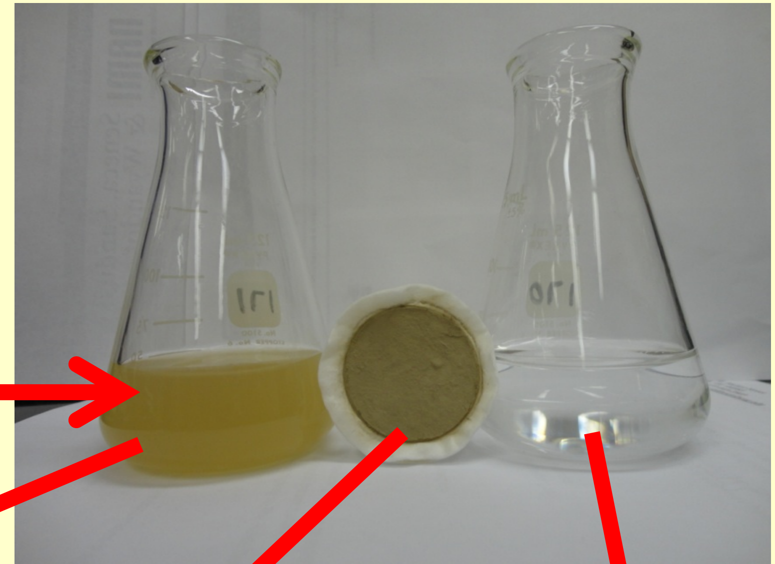
The Sandusky River in Tiffin following a rainstorm

Tiffin sewage treatment plant with discharge pipe to the Sandusky River

<u>Nonpoint Sources</u> – associated with the interaction of <u>land use</u> and <u>rainfall or snow melt events</u>.

Examples – cropland runoff, parking lot runoff

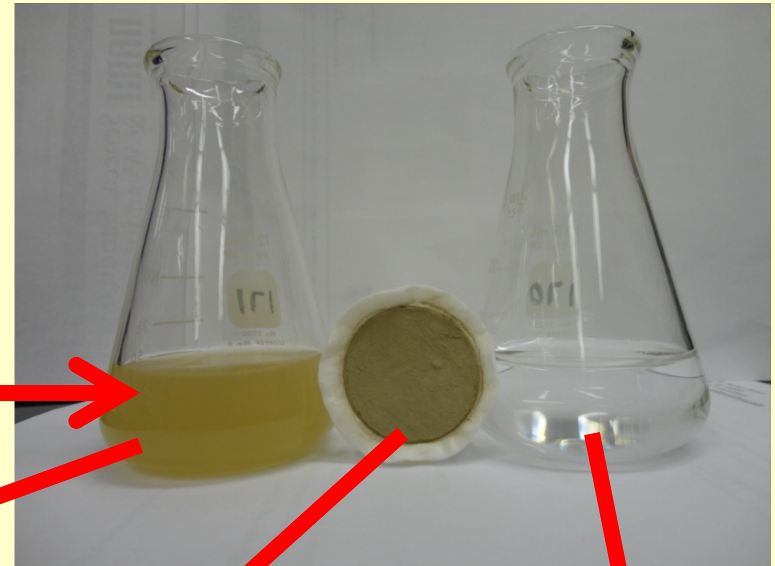
2. There are two major forms of phosphorus…



Total Phosphorus = **Particulate Phosphorus** + **Dissolved Phosphorus**

Total Phosphorus	Particulate Phosphorus	Dissolved Phosphorus
Measure	**Calculate**	**Measure**

3. These two forms differ greatly in bioavailability…



Total Phosphorus	=	Particulate Phosphorus	+	Dissolved Phosphorus
		~ 25% Bioavailable		~100% Bioavailable

Bioavailable phosphorus readily supports algal growth.

How do we know it’s cropland runoff?

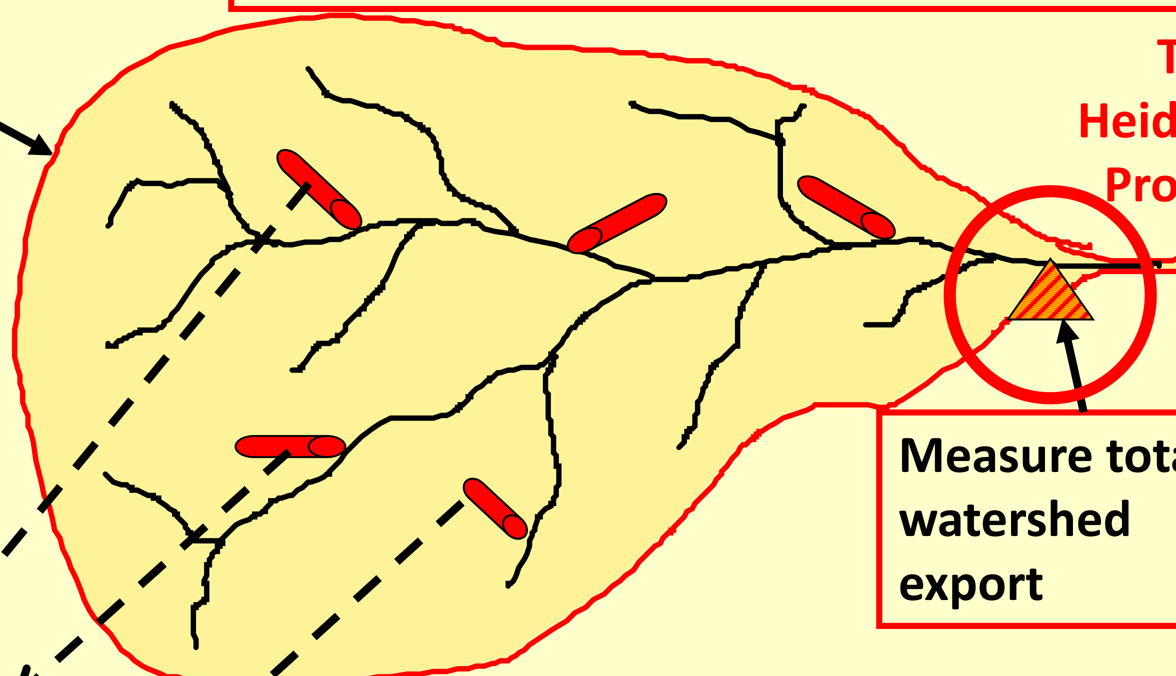
First– how is nonpoint pollution measured?

The Watershed Approach

Point source input

Stream gaging/monitoring station

Watershed boundary

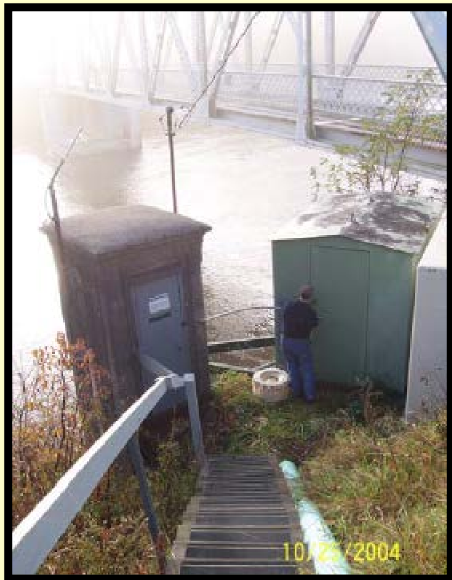


The Heidelberg Program

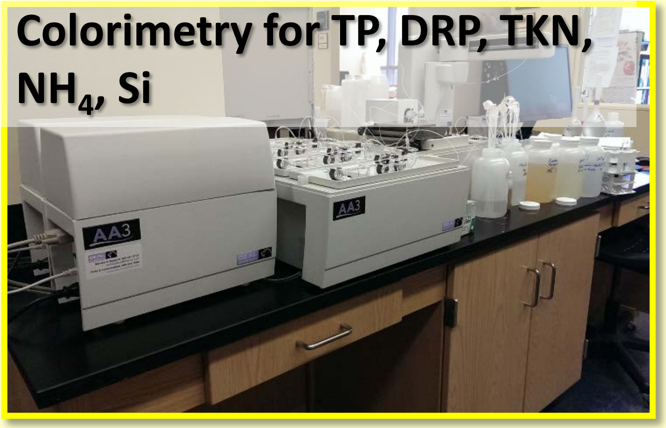
Measure total watershed export

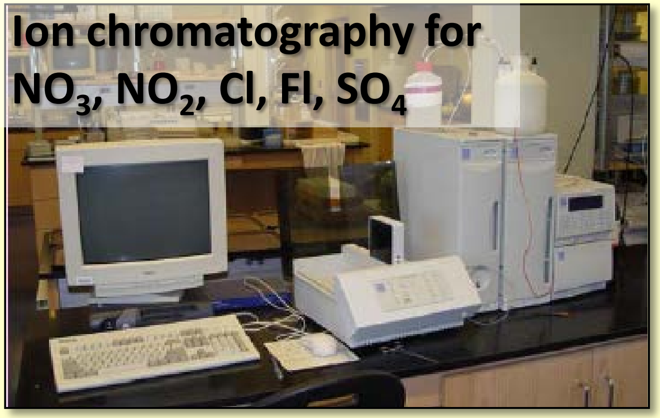
Data on point source inputs from EPA-required monitoring by dischargers.

Total watershed output
<u>- point source inputs</u>
nonpoint source output

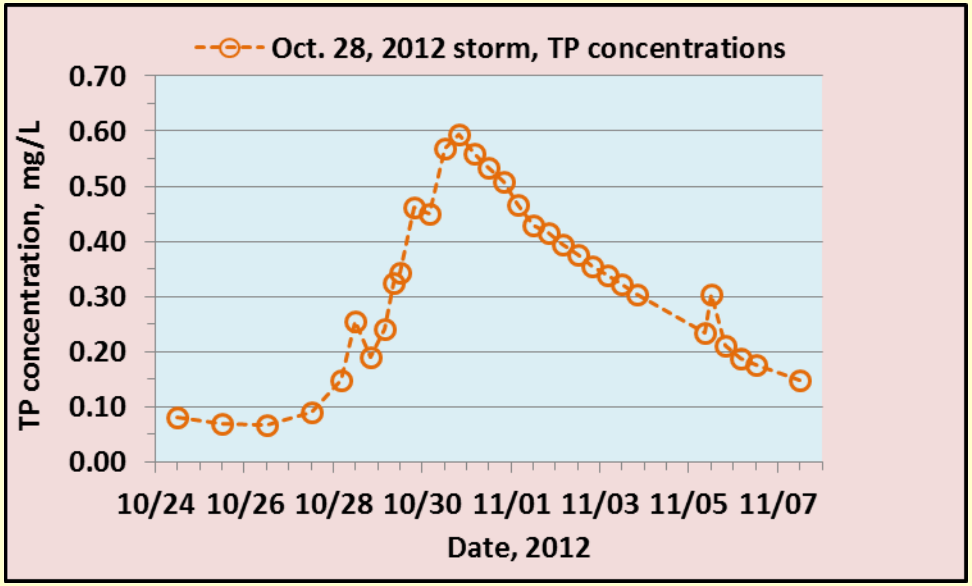








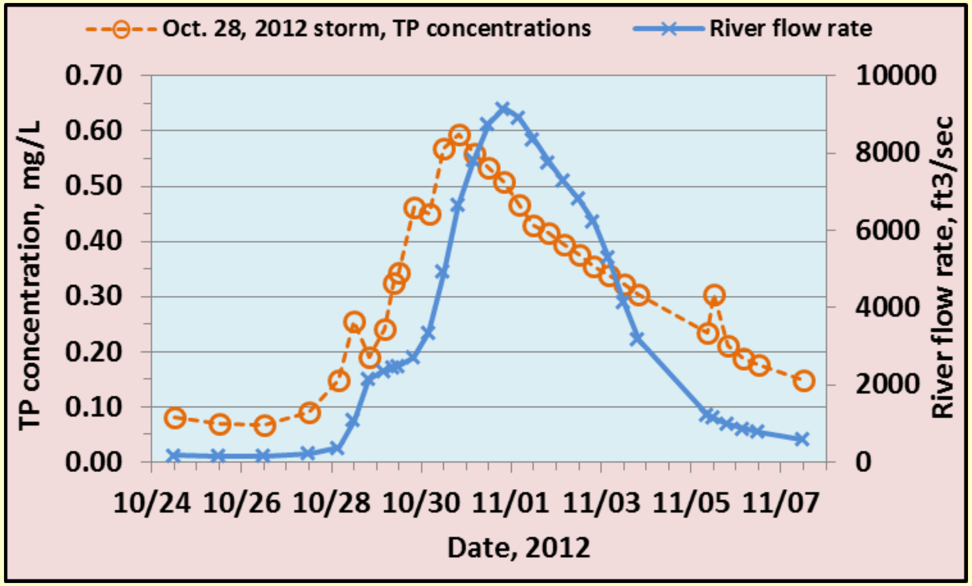
- Samples collected 3x a day
- Analyzed for all major nutrients and suspended sediments



Sandusky River

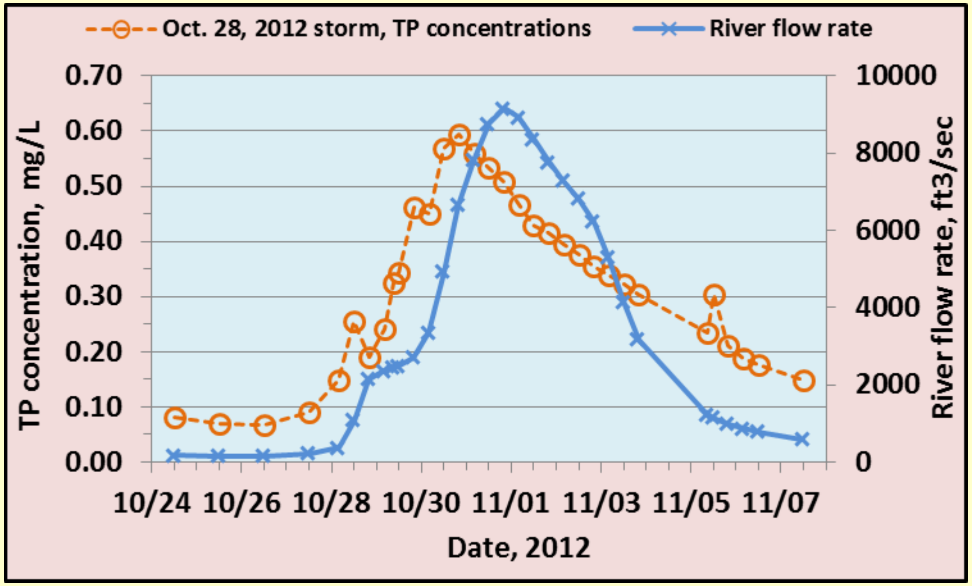
Start out with concentration data…

mg/L



Add river flow rate data from U.S. Geological Survey…

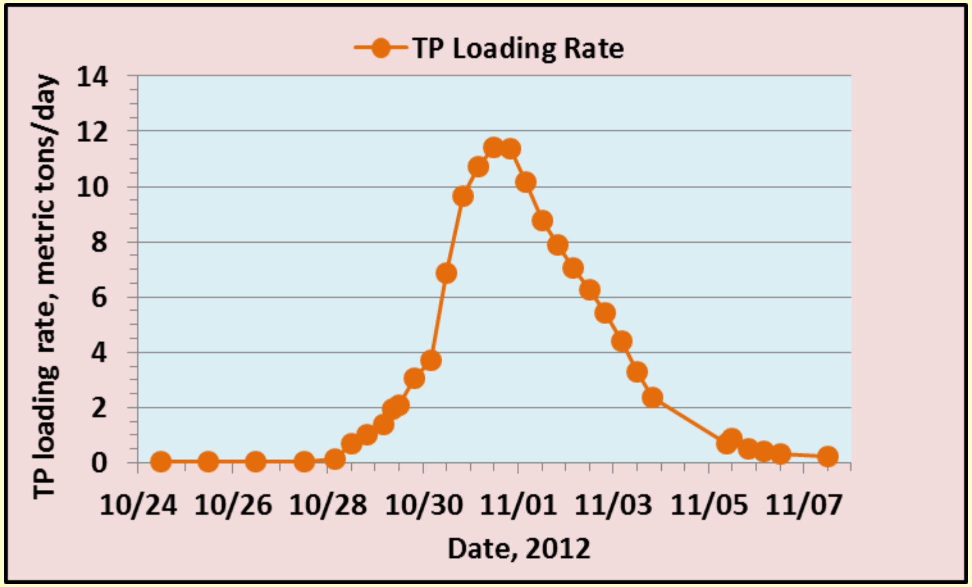
cubic feet/second



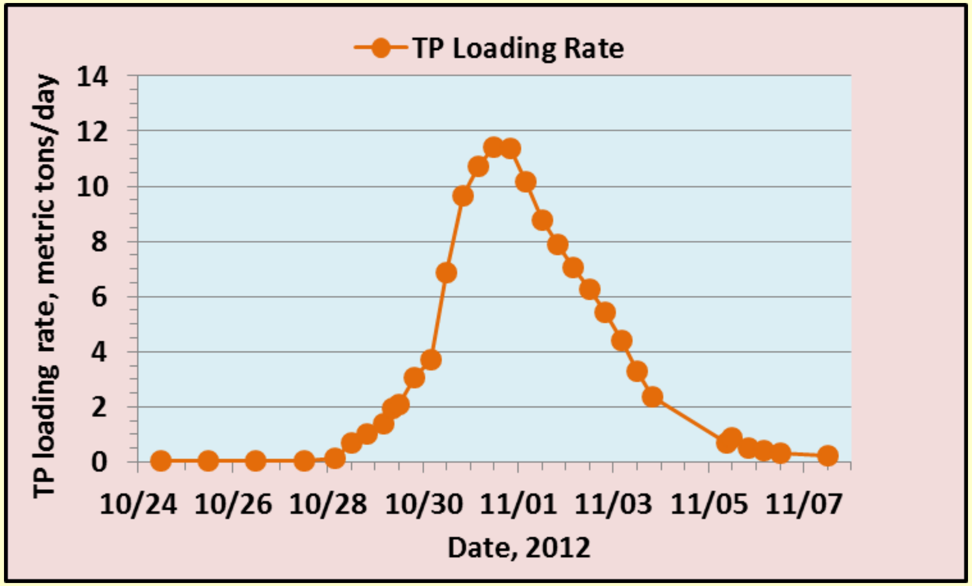
Calculate the loading rate…
Amount time

amount/unit time = amount/unit volume x volume/unit time

(loading rate) = (concentration) x (flow rate)

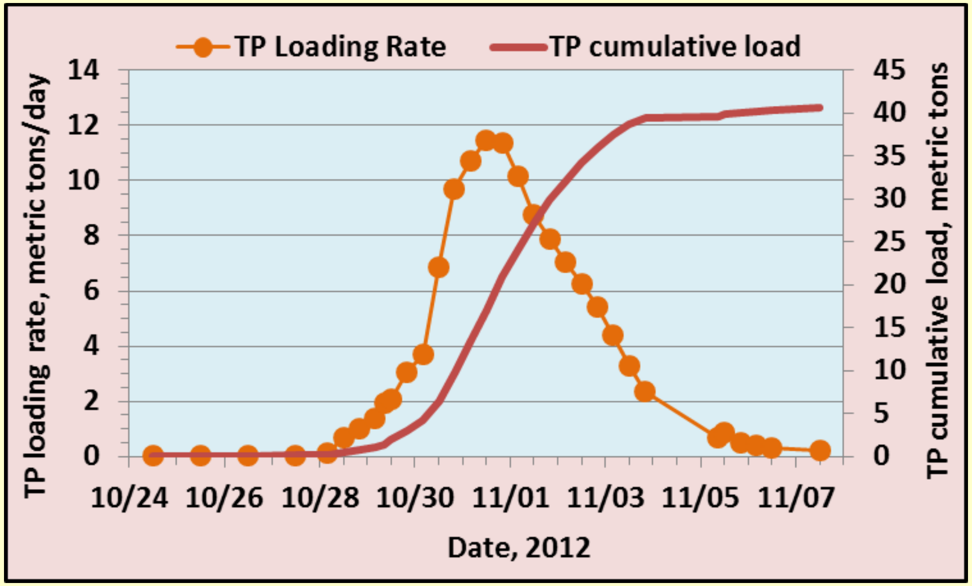


Here is the TP loading rate in units of metric tons per day



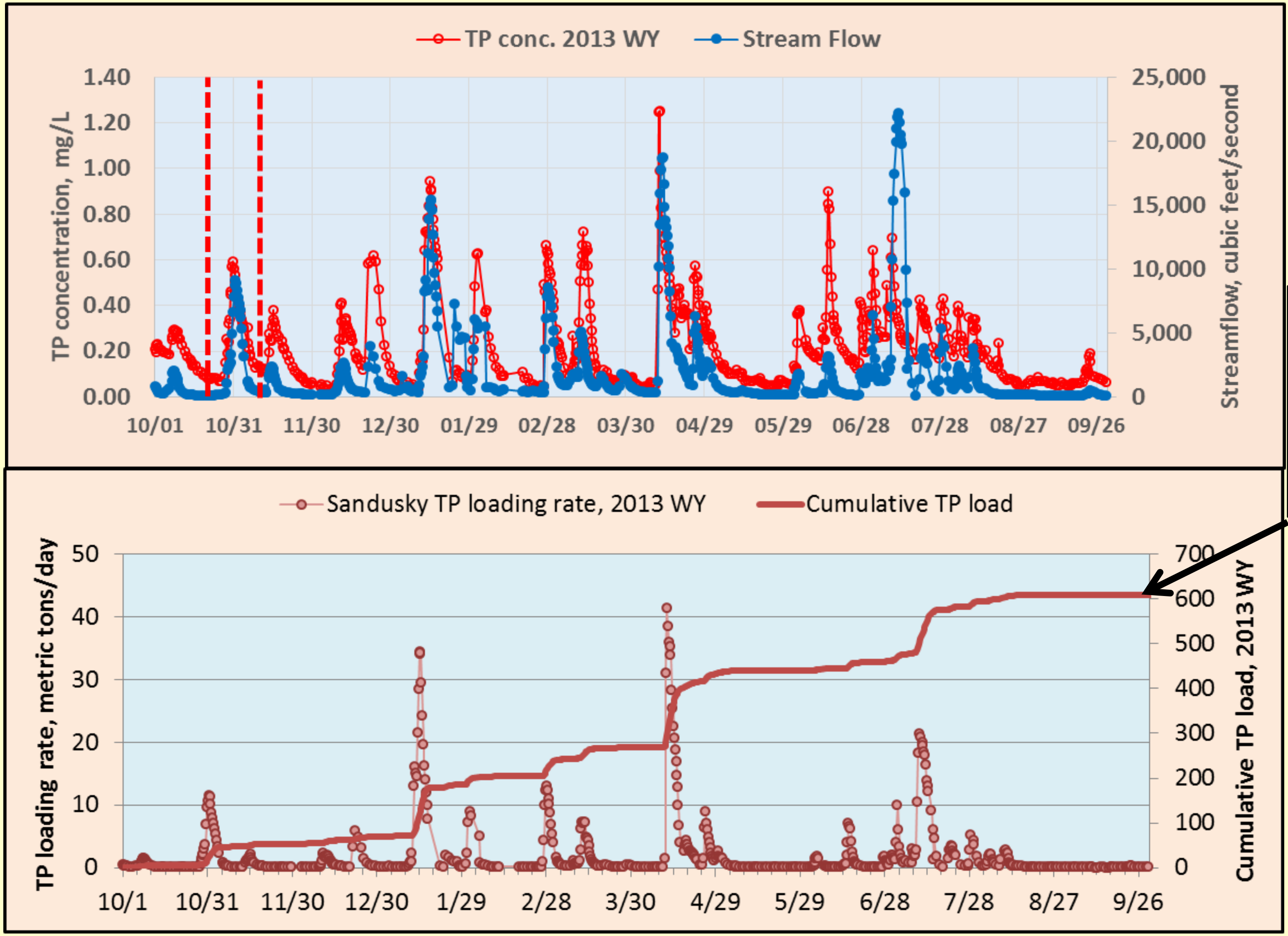
Calculate TP load over a particular time period

metric tons = metric tons/day x days



Add in each successive day to obtain cumulative loads for time period

Apply the above procedures to data for an entire year
Here the 2013 Water Year (10/01/2012 – 09/30/2013)



605 samples were analyzed for the 2013 Water Year

610 metric tons of Total Phosphorus

Adjust for missing samples … 617 metric tons

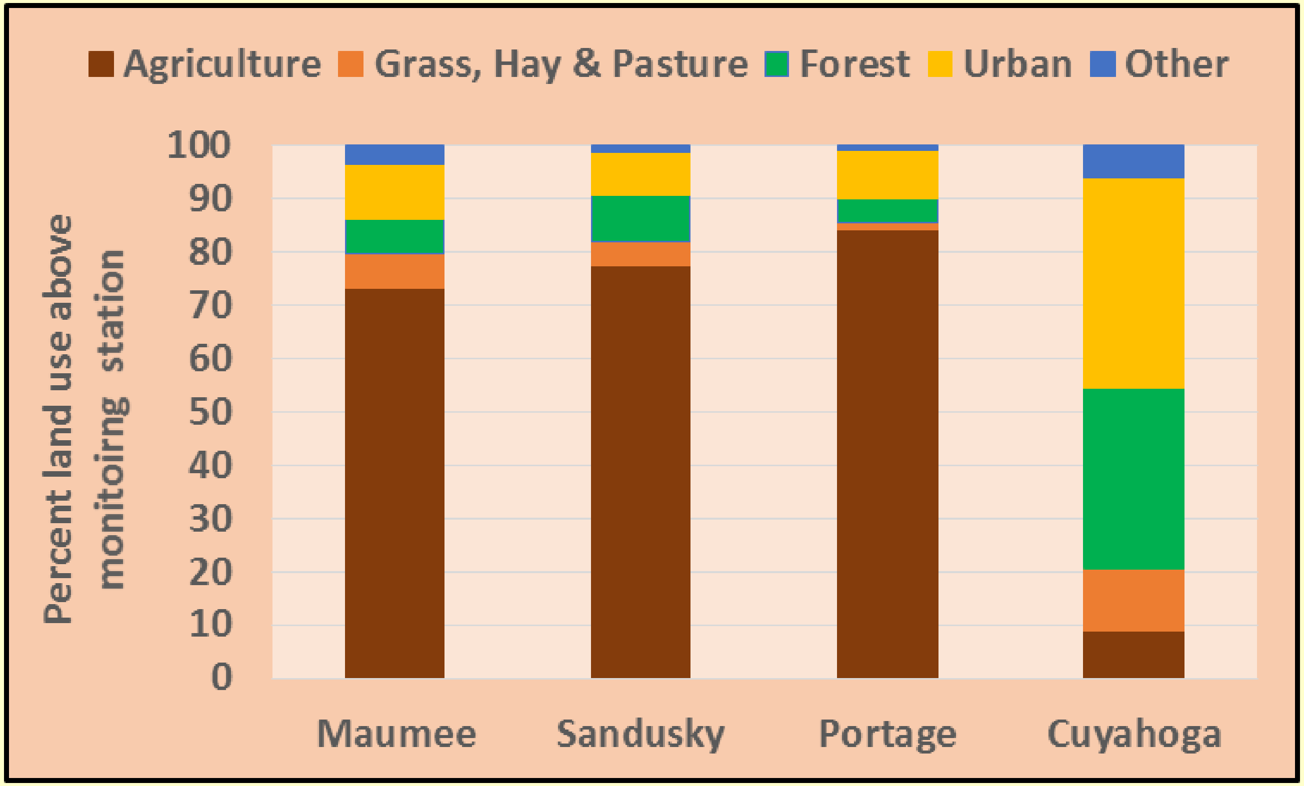
Sandusky Monitoring Station above Fremont, OH

OEPA Phosphorus Mass Balance (2013 Water Year)

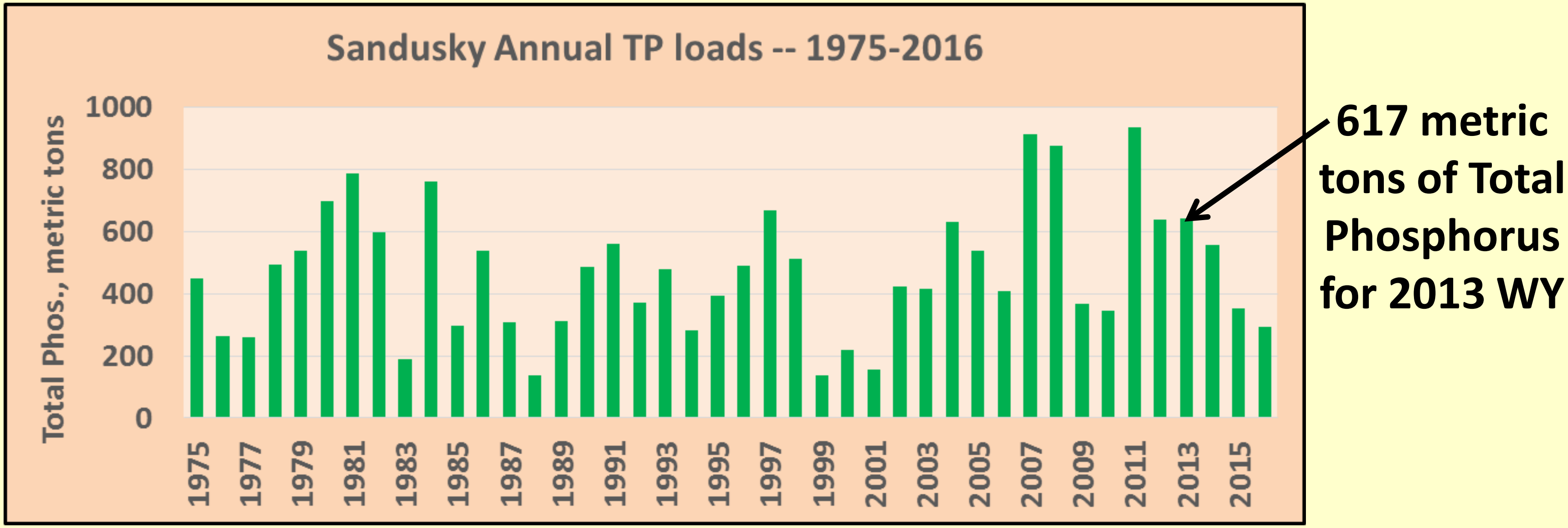
		Total Phosphorus metric tons	
Total Watershed Export		**616.7**	
Point Source inputs			
National Pollutant Discharge Elimination System (NPDES) data			
Major Wastewater Sewage Treatment Plants		6.4	
Smaller Wastewater Sewage Treatment Plants		9.4	
Industrial Dischargers		0.1	
Wet weather flows		3.8	
Home Sewage Treatment Systems	**Maumee**	13.2	
Total Point Source Inputs	**10.4%**	**- 32.9**	**(5.3%)**
Nonpoint Source Export	**89.6%**	**583.8**	**(94.7%)**

Unit Area Nonpoint TP Load = 1.8 kg/ha (1.6 lbs/acre) Sandusky Watershed

Land Use in major Ohio watersheds in the Heidelberg Tributary Loading Program



Row crop agriculture dominates land use in Ohio tributaries draining into the Lake Erie Western Basin and Sandusky Bay

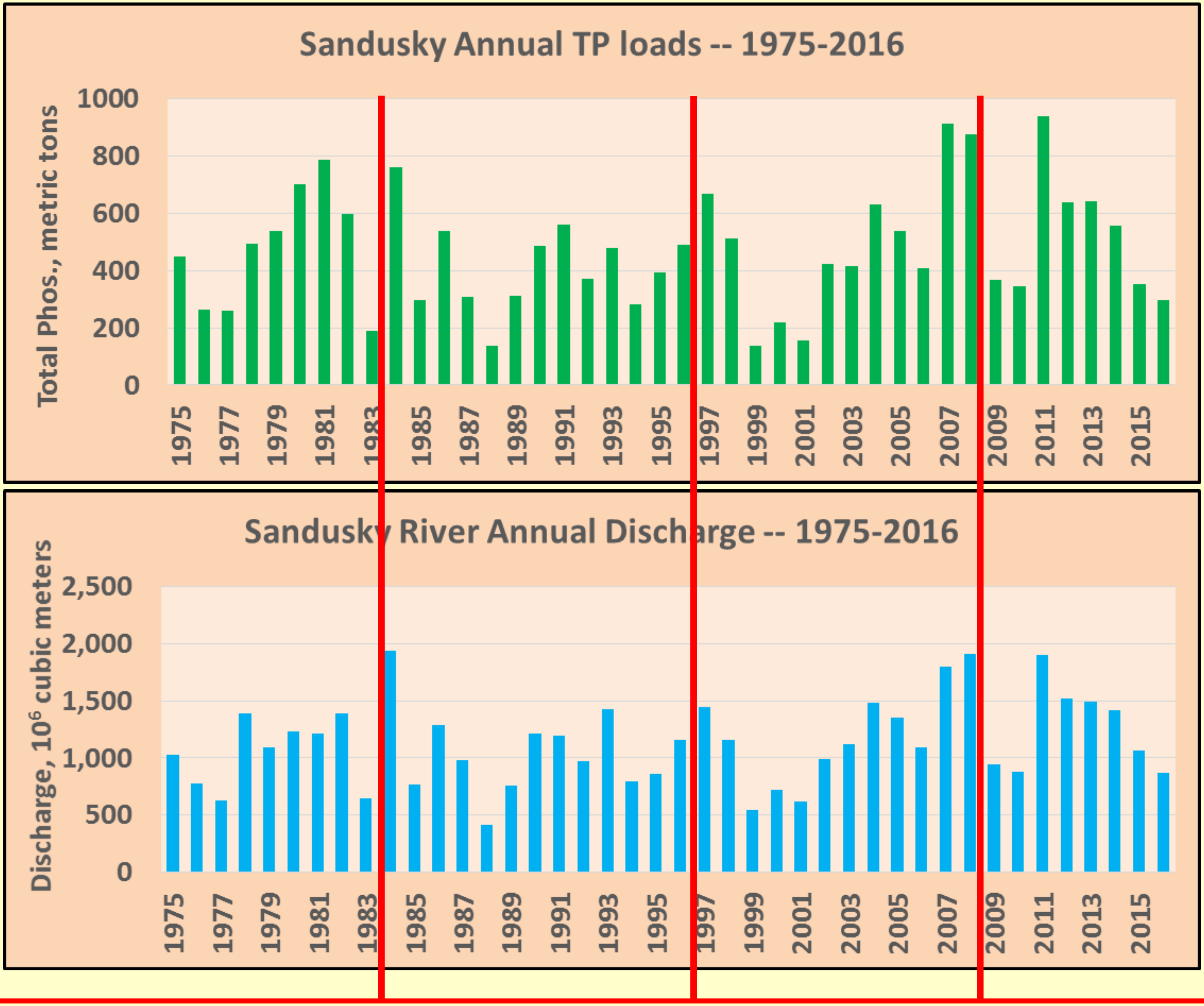


The Sandusky Fremont data set through the 2017 Water Year

- **43 Water Years (1975-2017)**
- **20,099 samples analyzed**

Note the large annual variability in TP loading.

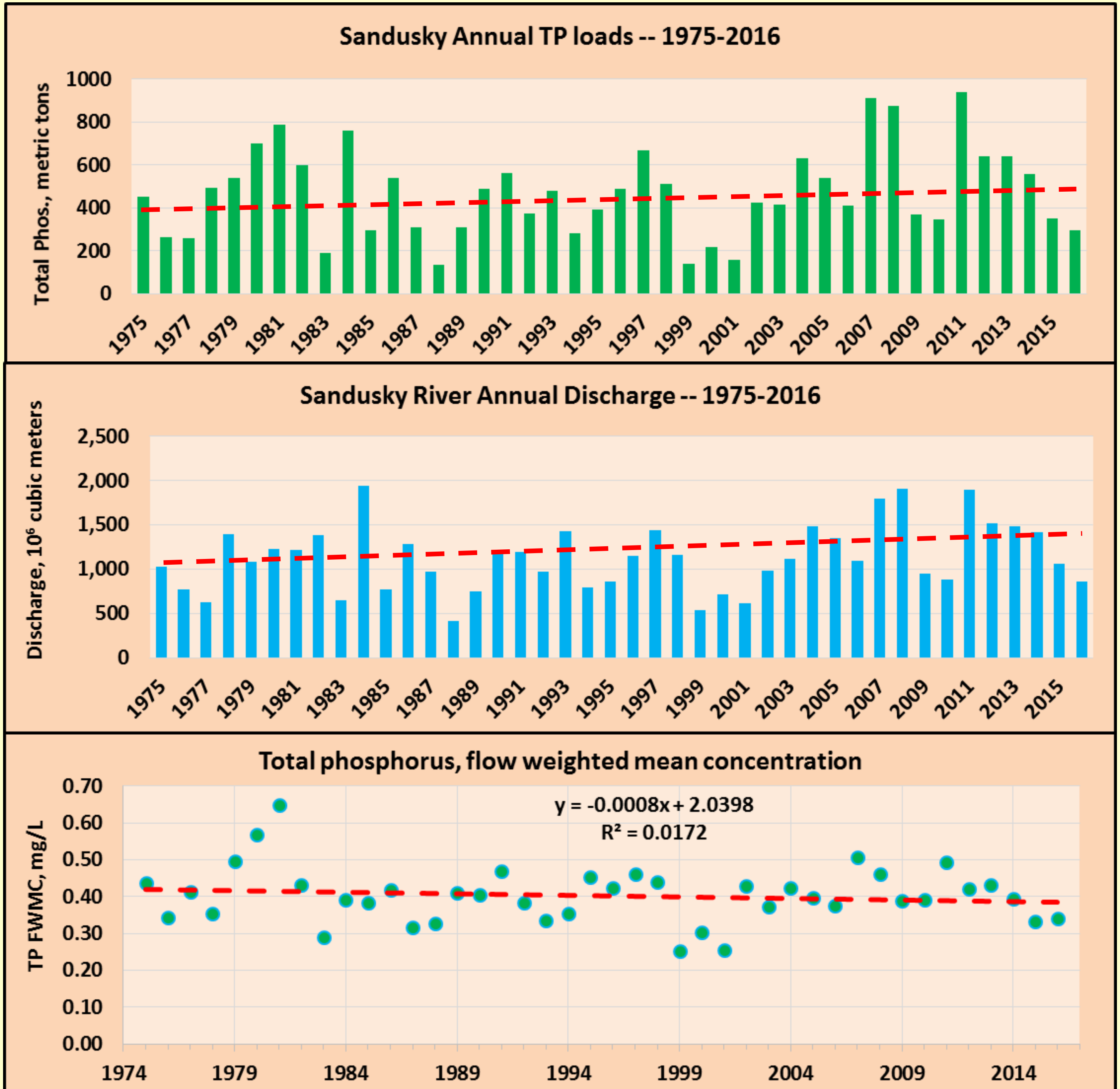
This variability complicates detection of loading trends in relation to BMP adoption.



Annual TP loads

Annual River Discharge

This variability is primarily due to annual variations in discharge.
Years with more rainfall and stream flow have higher TP loads.



Trends

1975→2016

+26%

TP **Load**

+33%

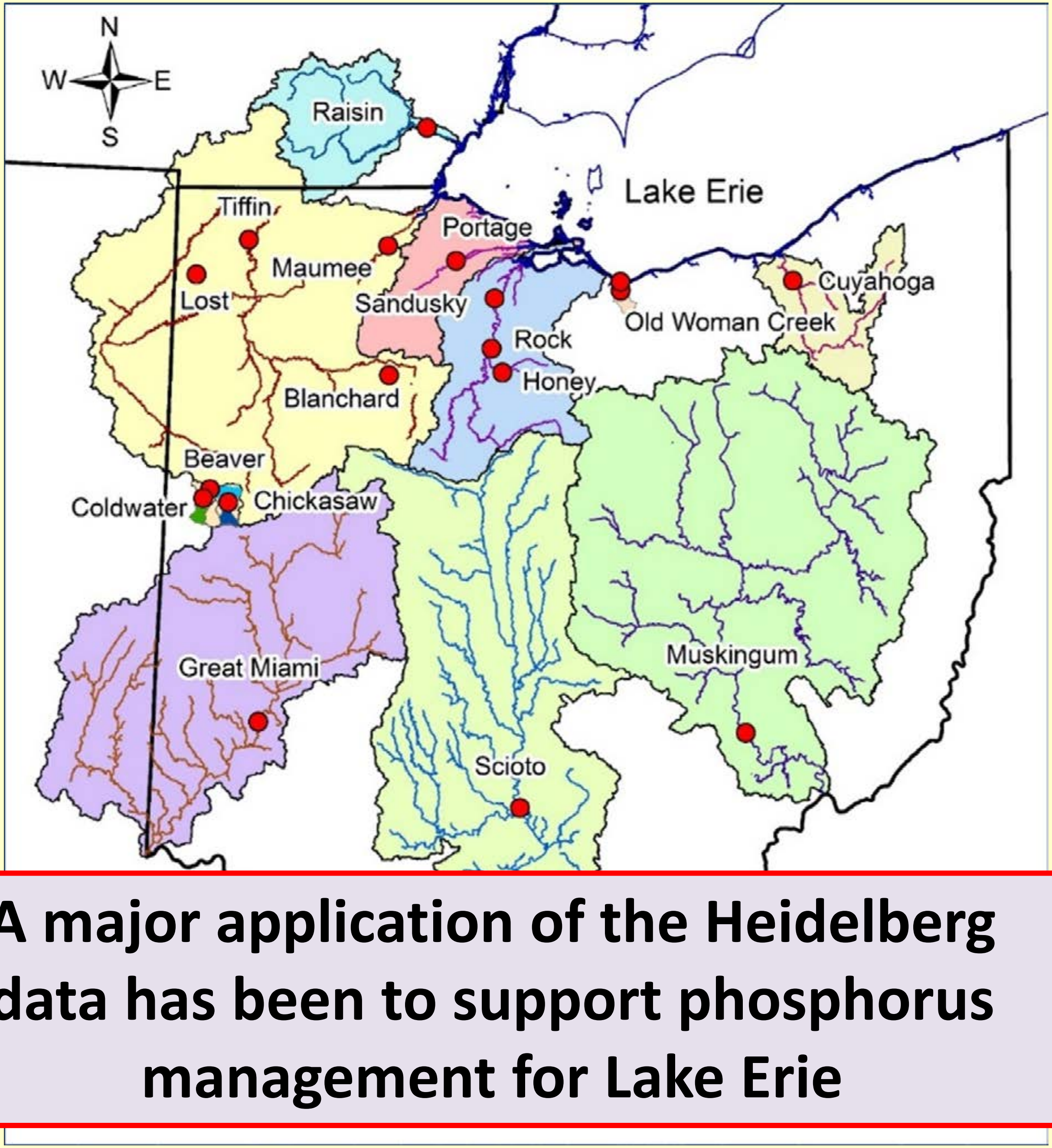
Water Volume

-7%

TP

FWMC

The Heidelberg University Tributary Loading Program



Currently 18 Stations

Every sample is analyzed for:

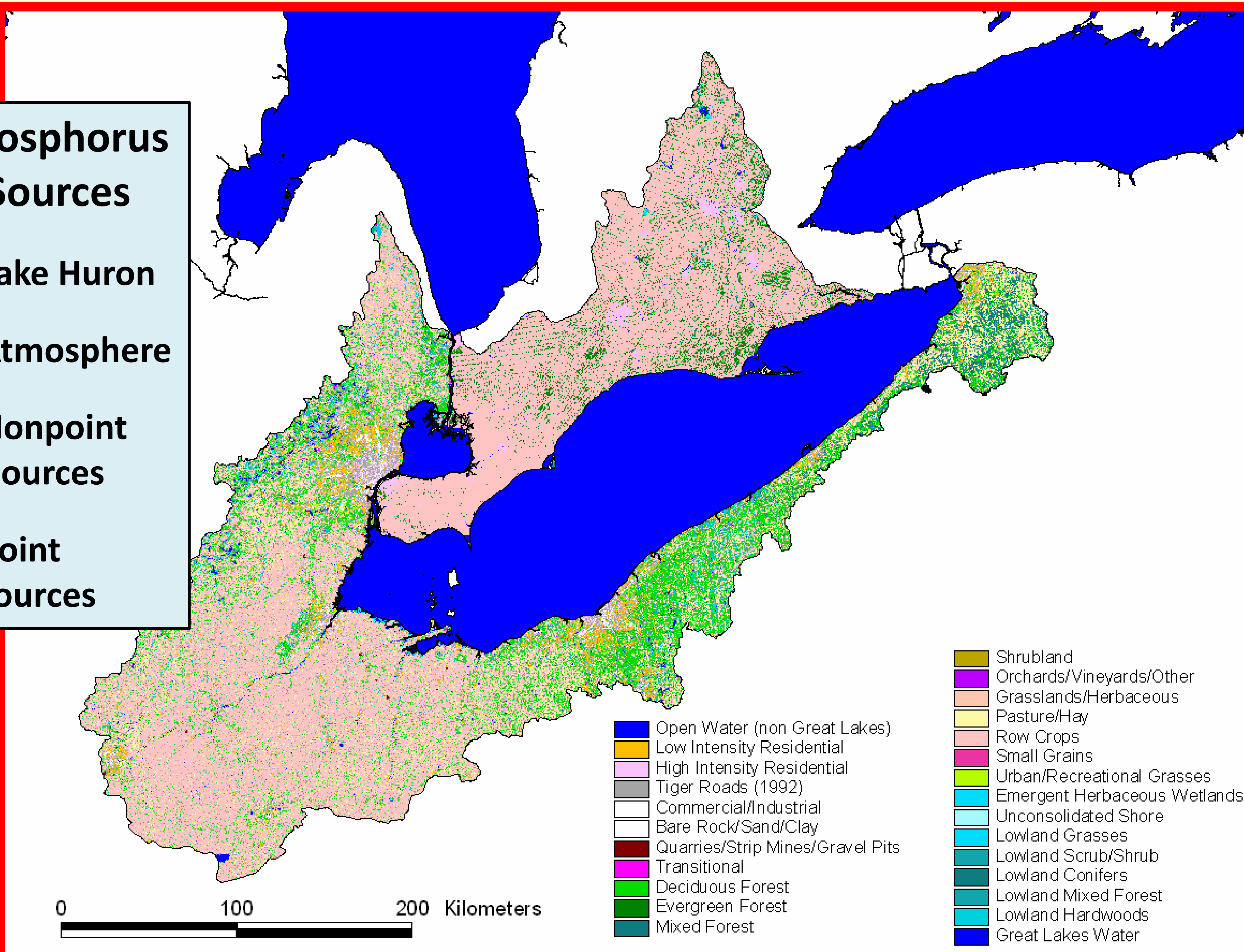
1. Suspended Sediments
2. Total Phosphorus
3. Dissolved Reactive Phosphorus
4. Nitrate
5. Total Kjeldahl Nitrogen
6. Nitrite
7. Ammonia
8. Chloride
9. Silica
10. Sulfate
11. Conductivity

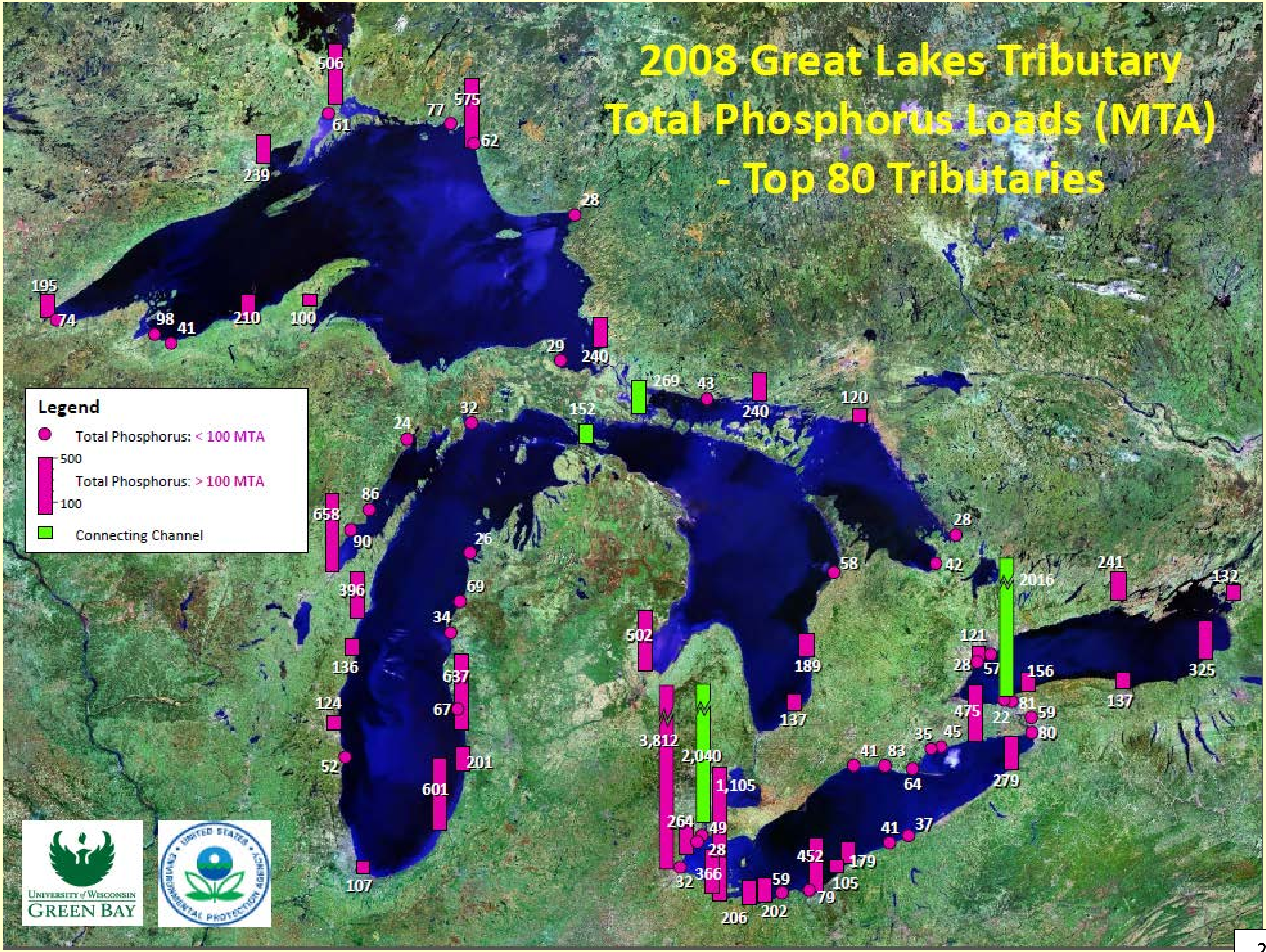
A major application of the Heidelberg data has been to support phosphorus management for Lake Erie

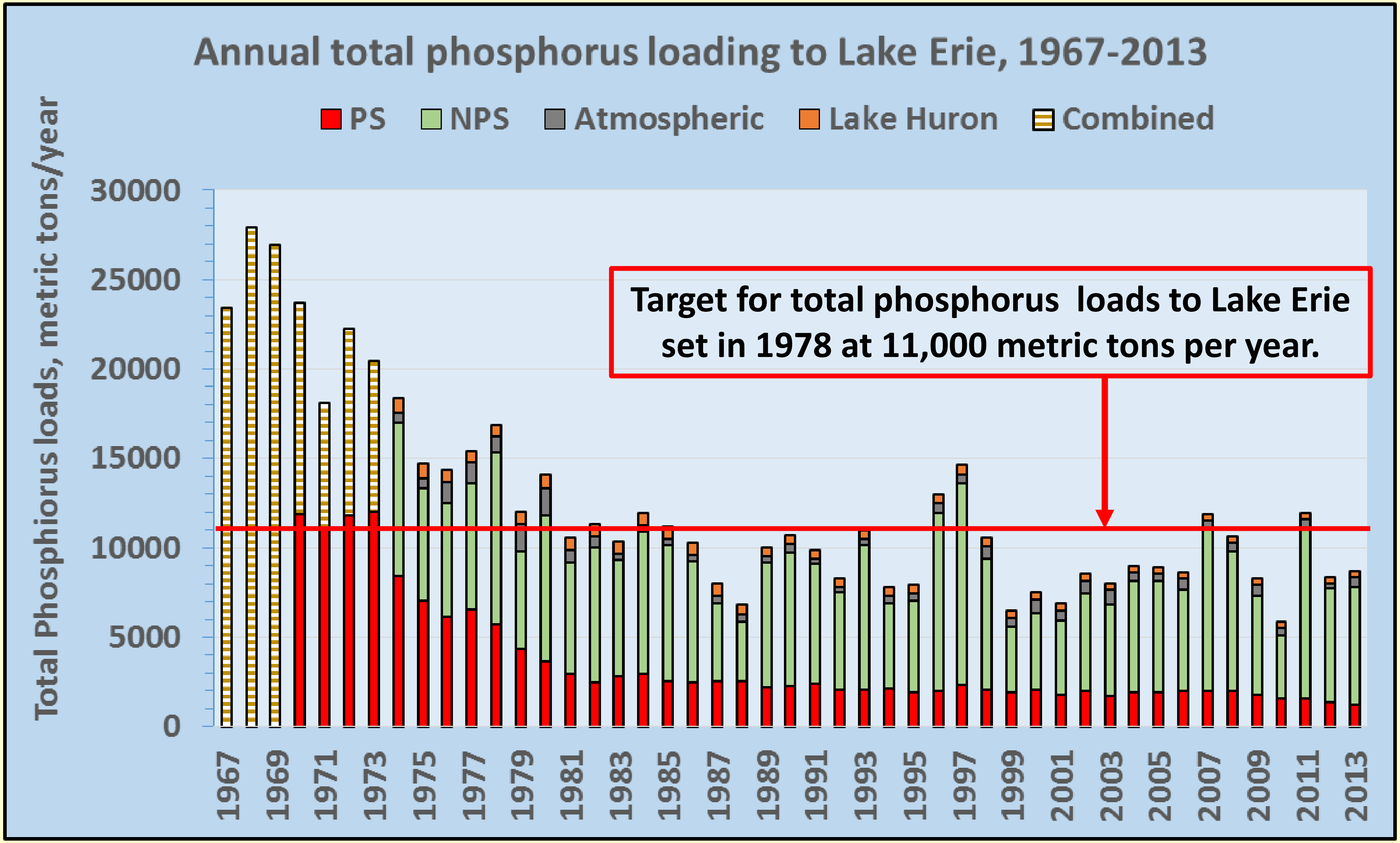
The Lake Erie Watershed: Sources of Phosphorus Loading

Phosphorus Sources

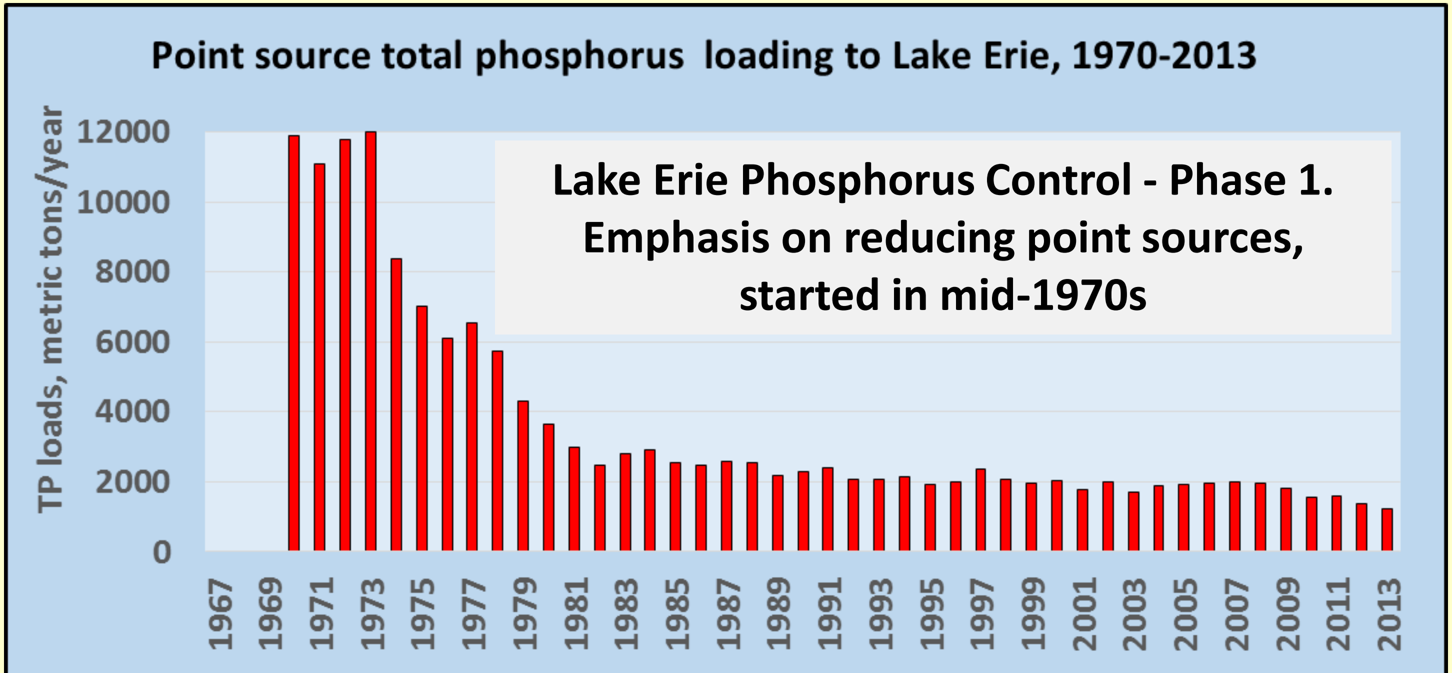
1. Lake Huron
2. Atmosphere
3. Nonpoint Sources
4. Point Sources

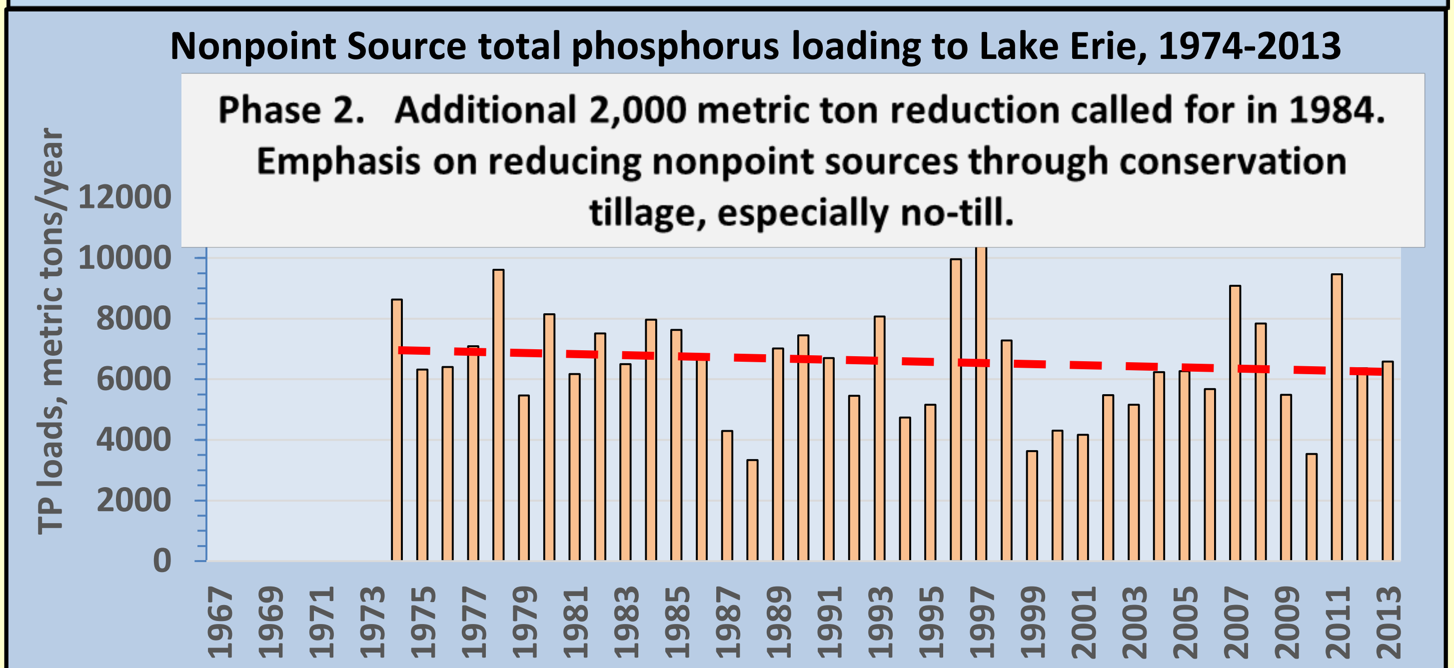



2008 Great Lakes Tributary
Total Phosphorus Loads (MTA)
- Top 80 Tributaries
Legend
Total Phosphorus: < 100 MTA
500
Total Phosphorus: > 100 MTA
100
Connecting Channel
506
61
77
575
62
239
28
195
74
98
41
210
100
29
240
269
43
240
120
152
24
32
86
658
90
26
69
396
34
136
637
67
124
52
201
601
107
502
189
137
3,812
2,040
1,105
264
49
28
32
366
206
202
59
452
79
179
105
41
37
41
83
64
35
45
28
58
42
2016
121
28
57
156
81
22
475
59
80
279
241
132
325
137
University of Wisconsin Green Bay
United States Environmental Protection Agency



The target load was met for the first time in 1981.





Metric Ton Reductions

Point Source

~ 10,000

~ 84%

Nonpoint source

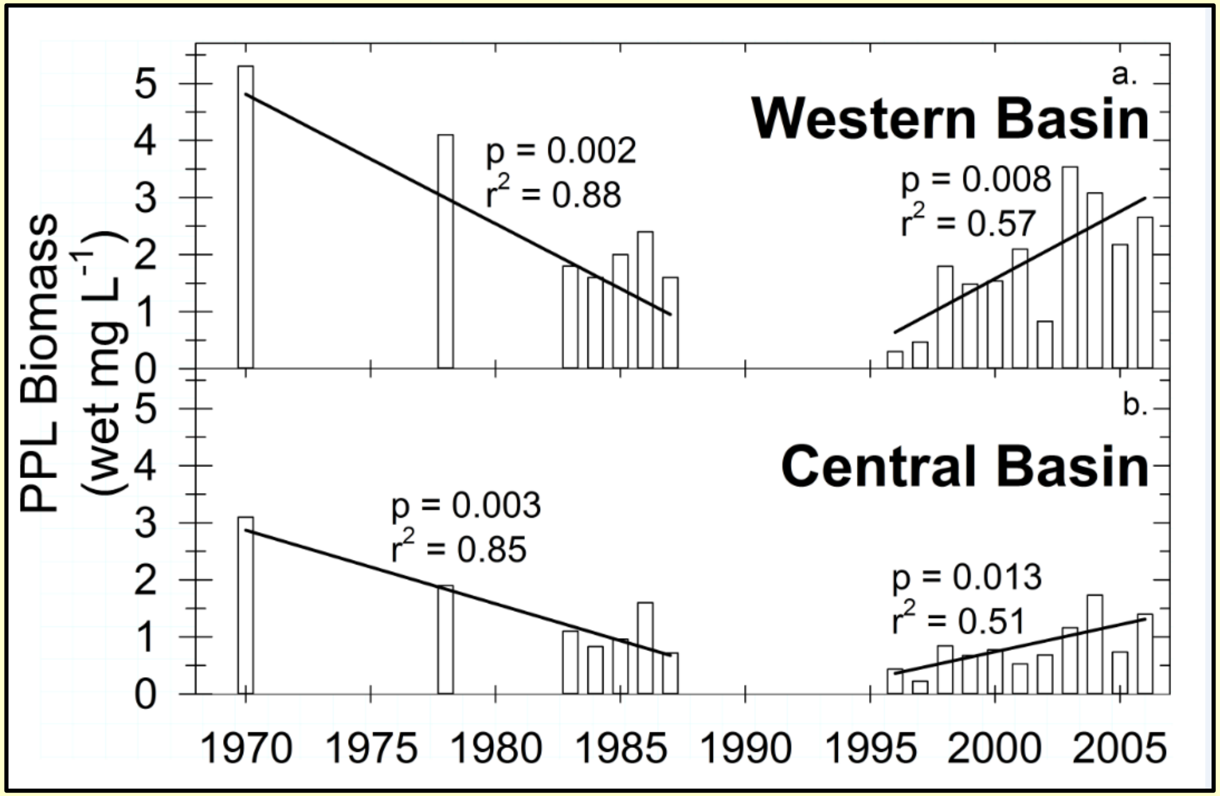
~ 900

~ 13%

If total phosphorus loading has not increased in recent years, how can we blame re-eutrophication of Lake Erie on phosphorus loading?

Algal Biomass

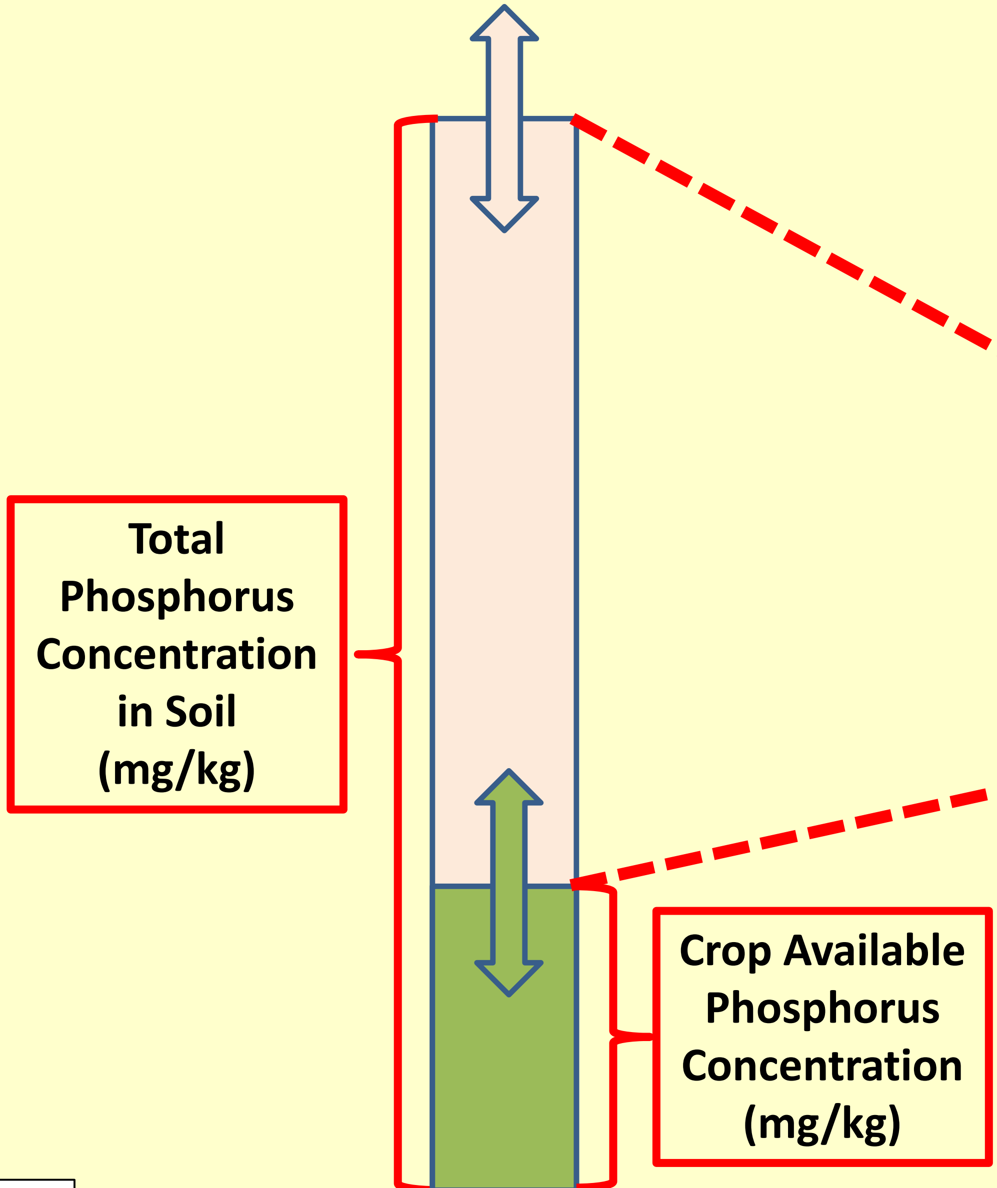
(Kane et al., 2014)



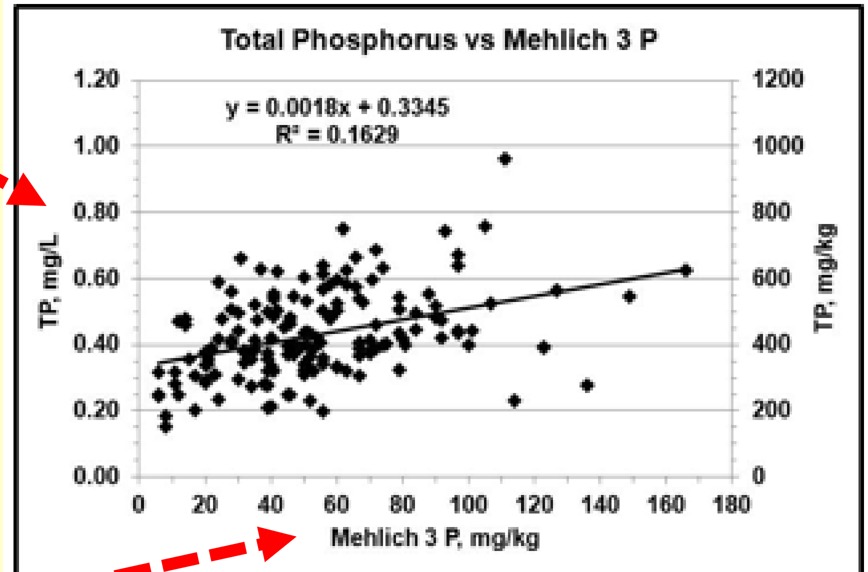
We have to look at two characteristics of TP loading

1. **Separate the trends in particulate and dissolved phosphorus.**
2. **Consider the relative bioavailability of the two forms.**

<u>Agronomic</u> Phosphorus Management



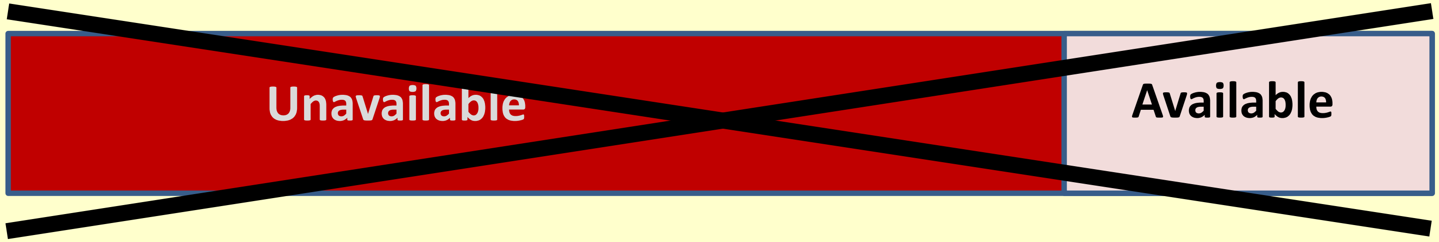
Relationship between total phosphorus content of soils and Mehlich 3 P STP



Agronomic management is based on "bioavailable" phosphorus as indicated by phosphorus soil test values.

Total phosphorus content of soil

Incorrect concept of "available" phosphorus as a discrete fraction in the soil



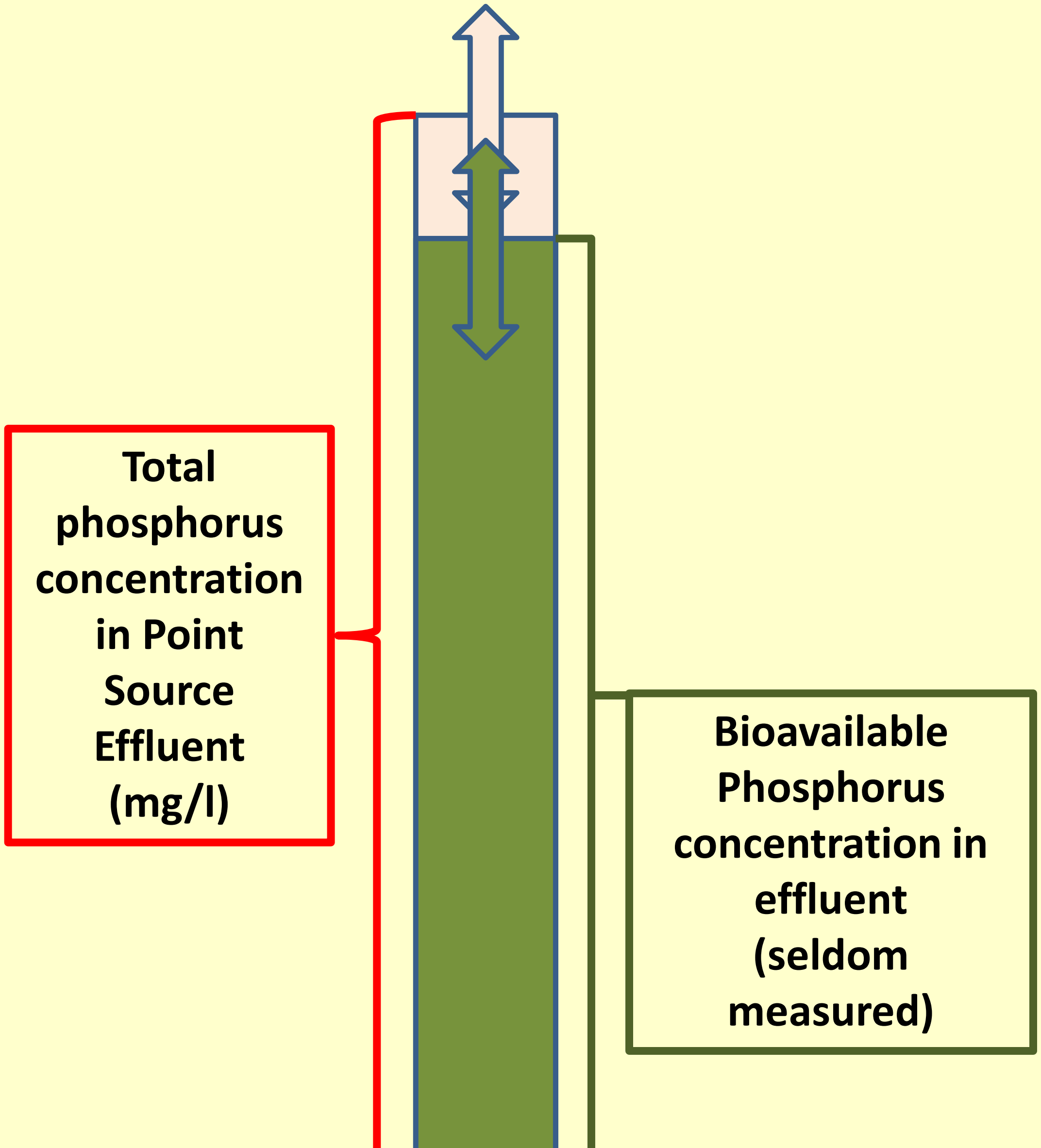
Correct concept of phosphorus availability as a continuum in the soil

Soil Test Extractants

Fertilizers add highly available phosphorus to the soil

After CAST, Issue Paper #15, June 2000

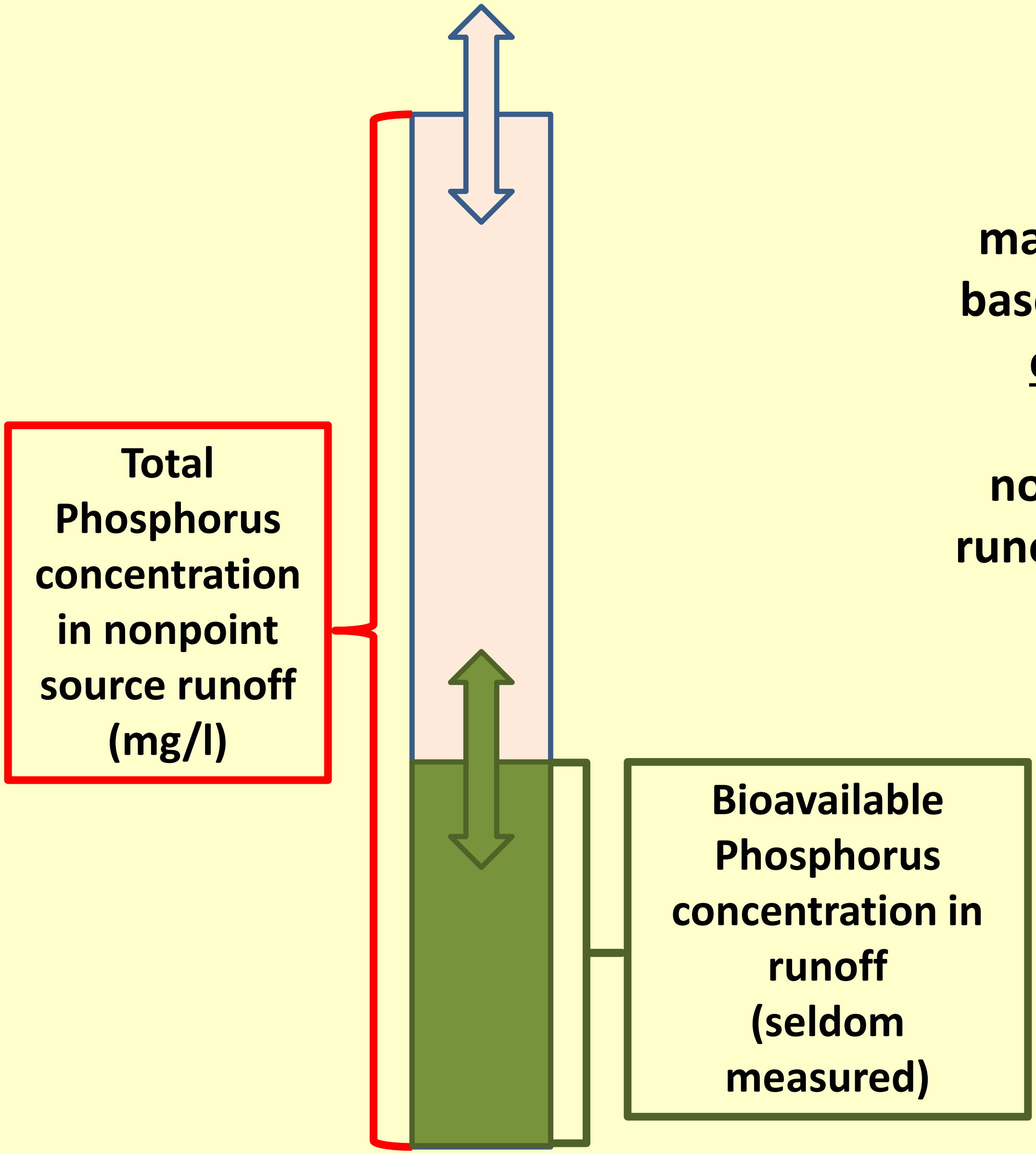
Environmental Phosphorus Management: Point Sources



Point source management based on <u>total phosphorus concentration</u> measurement since most of the phosphorus in the effluent is bioavailable.*

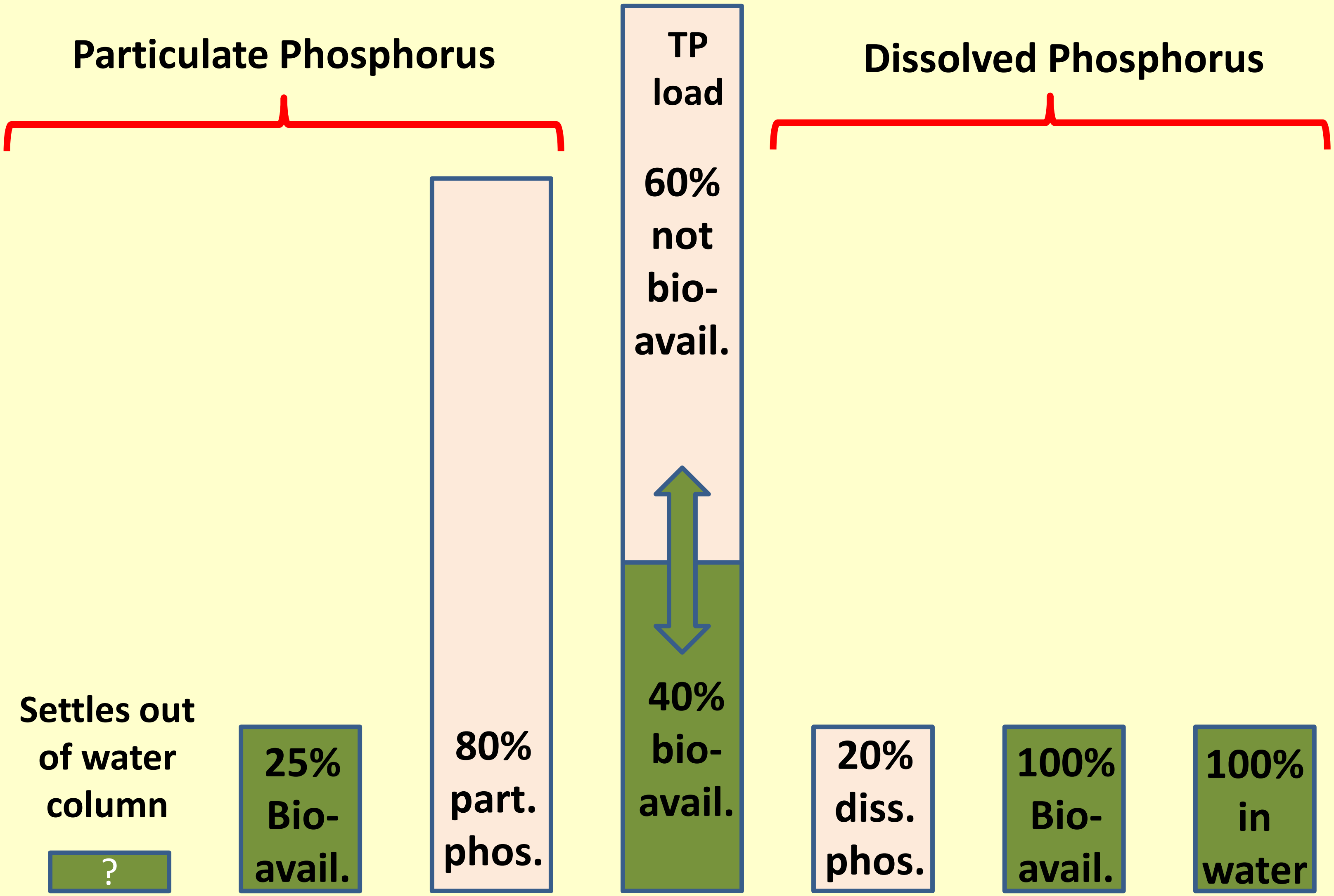
**** The percent bioavailability decreases as the amount of P removal increases.***

Environmental Phosphorus Management: Nonpoint Sources

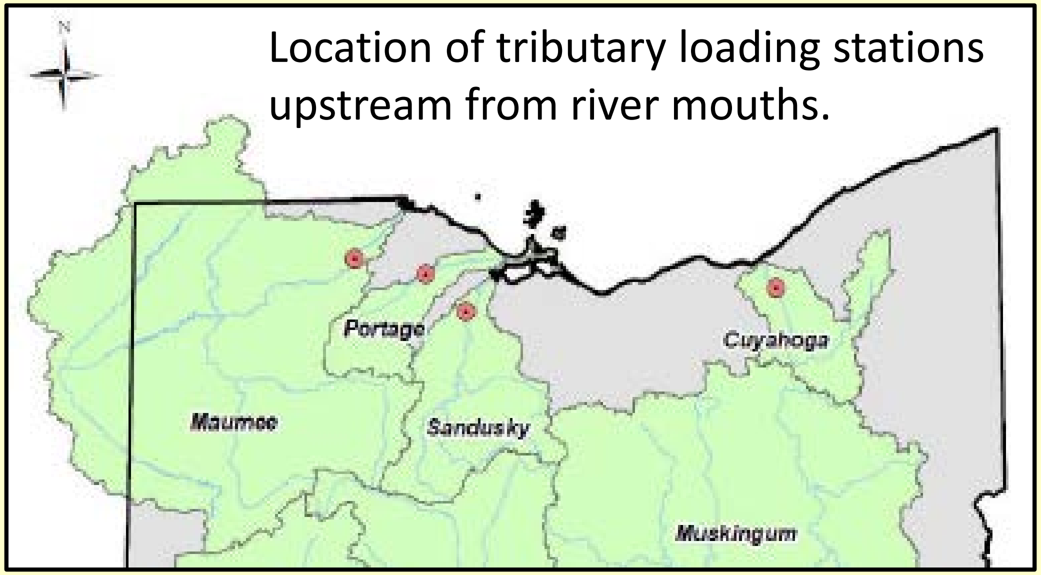


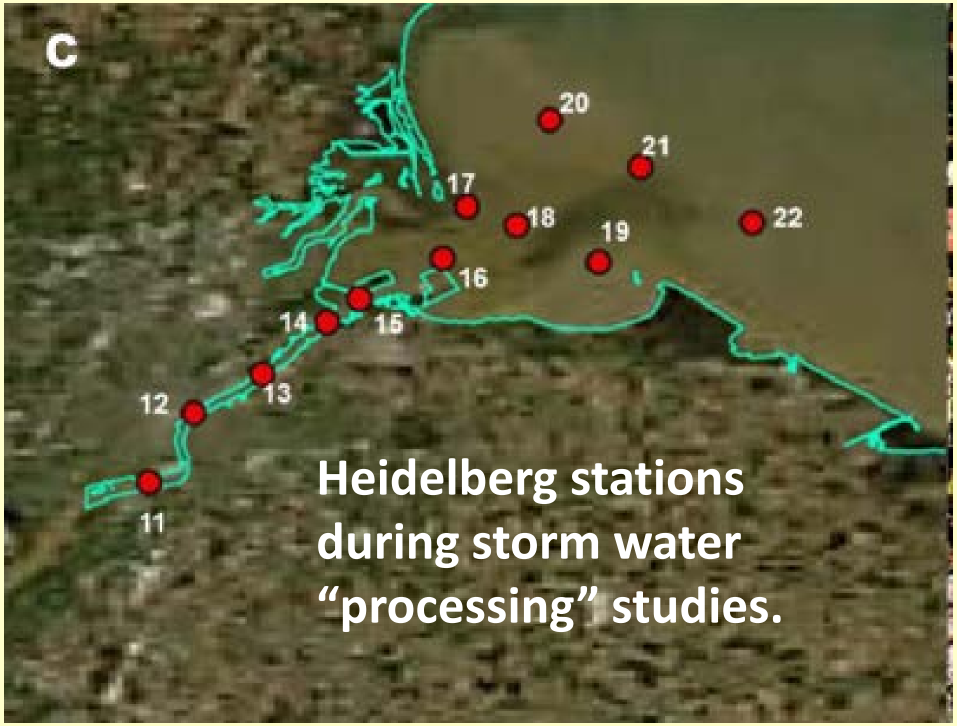
Nonpoint source management is generally based on total phosphorus concentrations even though most of the nonpoint phosphorus in runoff in not bioavailable.*

Bioavailability of Total Phosphorus in Nonpoint Runoff: A closer look (approximate percentages, actual values vary)



Positional bioavailability





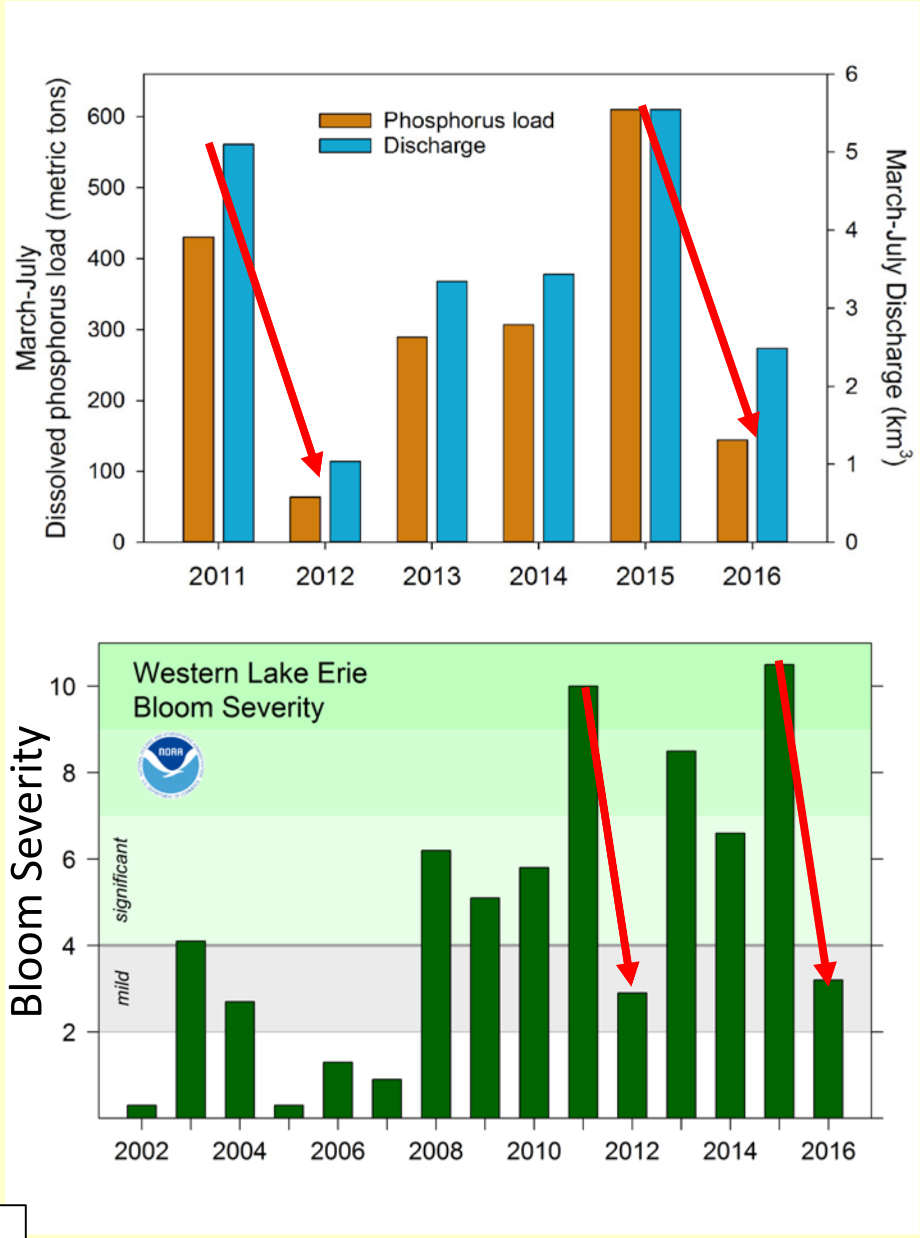
The tributary monitoring stations are upstream from the lake. For example, the Maumee Waterville station is 26 river miles from the river mouth at Maumee Bay.

During floods, are DRP and PP transported with equal "efficiency" between the sampling station and the river mouth? (i.e. equal locational bioavailability?)

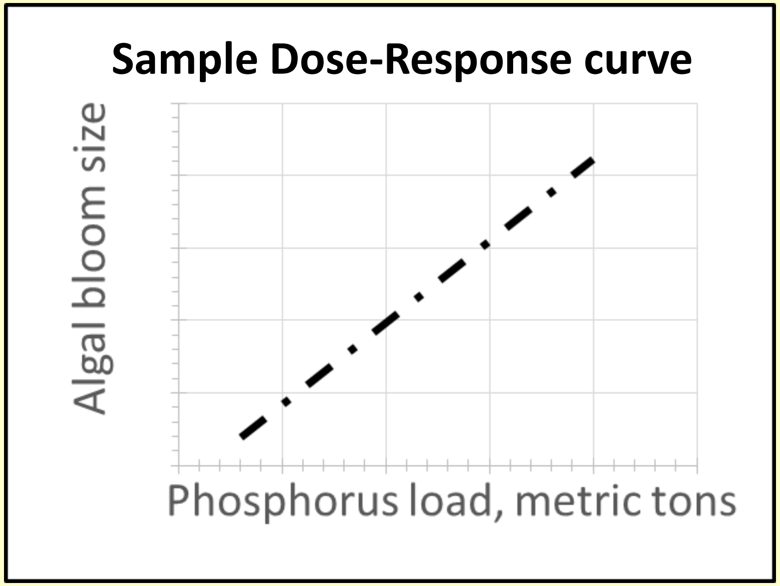
Our studies of storm water moving through the river and into the Lake suggest that much of the particulate phosphorus settles out of the storm water before reaching the river mouth, while DRP is unchanged.

The models used to set target loads use Waterville data directly as daily input to the Lake, ignoring "locational" bioavailability.

40% Reduction in TP based on correlation between algal bloom severity and discharge/phosphorus loads

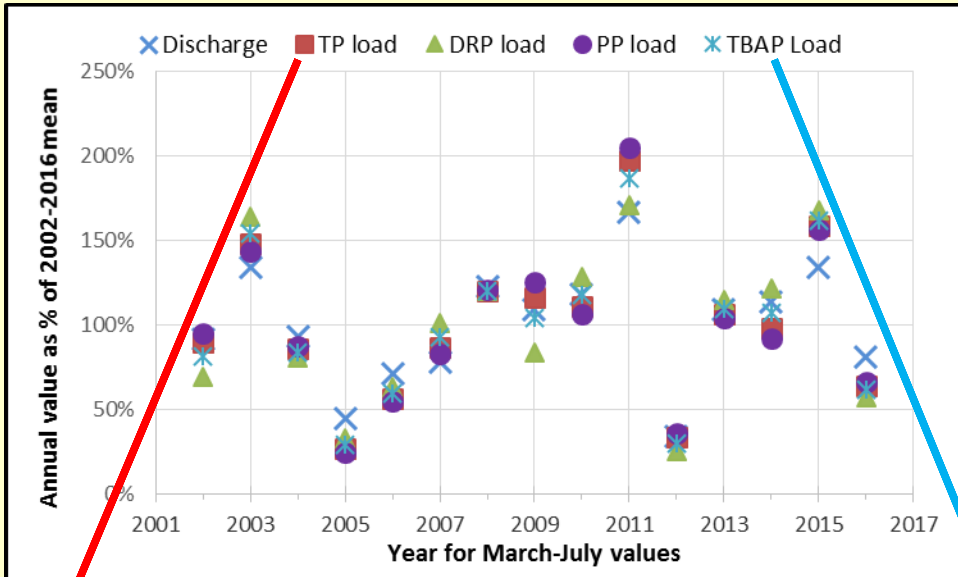


The correlations between phosphorus loads and bloom severity are used to set the target loads for phosphorus.

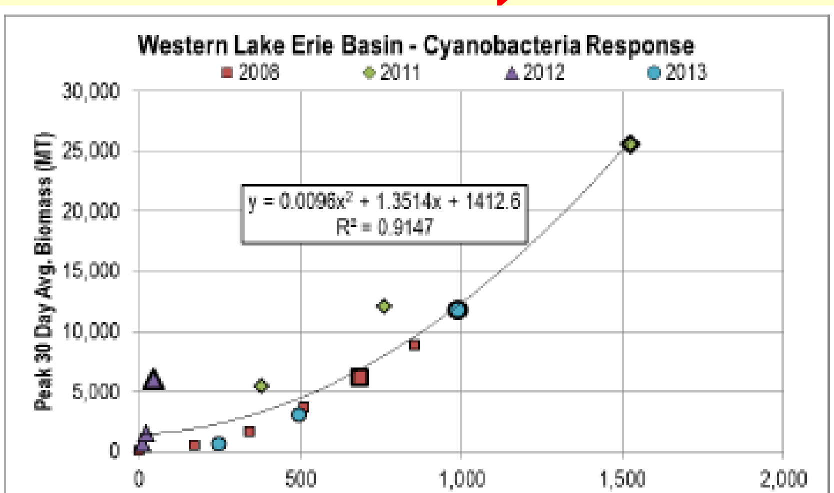


But… what form of phosphorus should be on the X-axis?

Y-axis is annual value as a percentage of mean 2002-2016 value for each parameter. Covariance is due to role of discharge in load calculations.

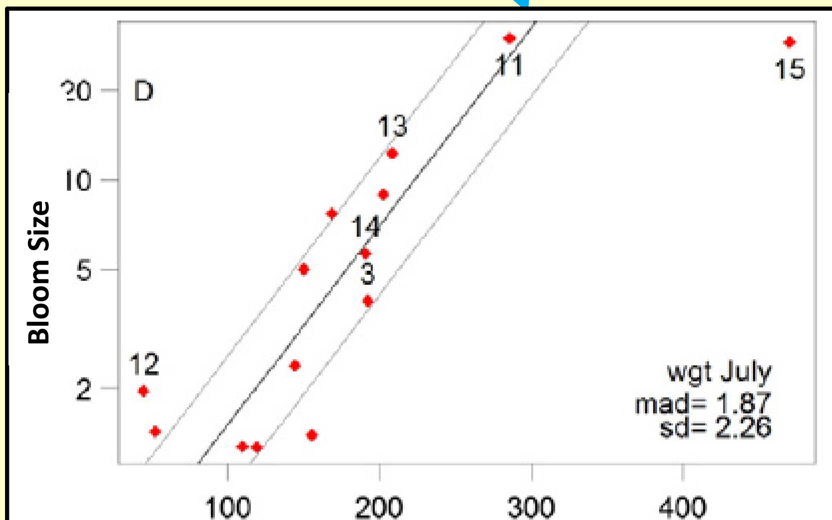


Management recommendations vary greatly depending on choice of x-axis phosphorus form.



Maumee spring total phosphorus load

Western Lake Erie Ecosystem Model



Maumee total bioavailable phosphorus load

NOAA Western Lake Erie Model

(Stumpf et al., 2016)

Annex 4 Ensemble Modeling Report Appendix B7-33

The targets of 40% reductions in both TP and DRP were based on models that used total phosphorus as the "dose" parameter at the monitoring station.

Using Total Phosphorus for the X-axis

Phosphorus Form	Total Phosphorus	Dissolved Phosphorus	Particulate Phosphorus
		--- metric tons ---	
2008 loads (base year)	1433	310	1123
Target for acceptable bloom (40% reduction)	860	186	674
Reduction to meet target	573	124	449

Modelers noted that reducing dissolved phosphorus to zero would be insufficient to meet targets for TP reduction. So Annex 4 reduced both DP and PP by 40%.

Using Total Bioavailable Phosphorus for the X axis

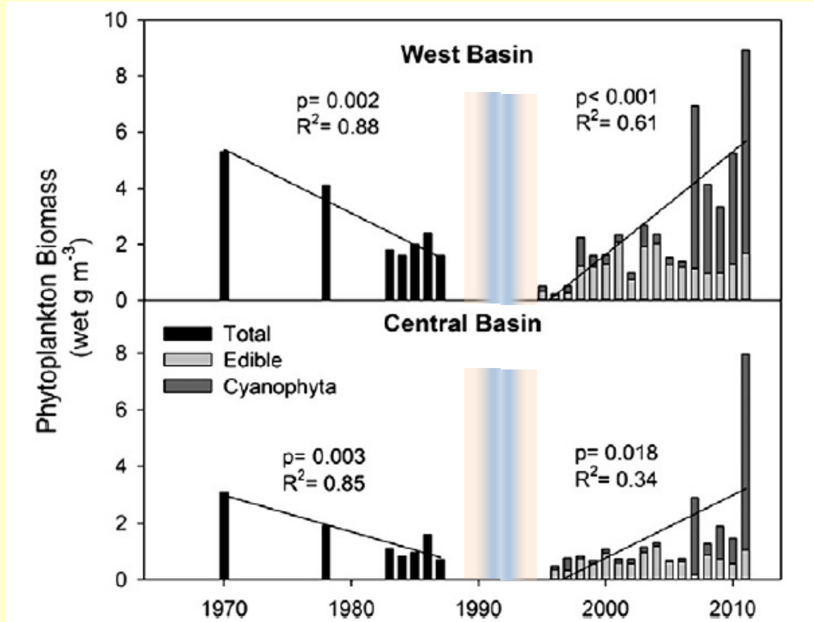
Phosphorus Form	Total Bioavailable Phosphorus	Bioavailable Dissolved Phosphorus	Bioavailable Particulate Phosphorus
		--- metric tons ---	
2008 loads (base year)	591	310	281
Target for acceptable bloom (40% reduction)	348	186	162
Reduction to meet target	243	124	119

But if the X-axis is bioavailable phosphorus, reducing DP to zero is more than enough to reduce bioavailable P loading by 40%.

Which version fits the historical data?

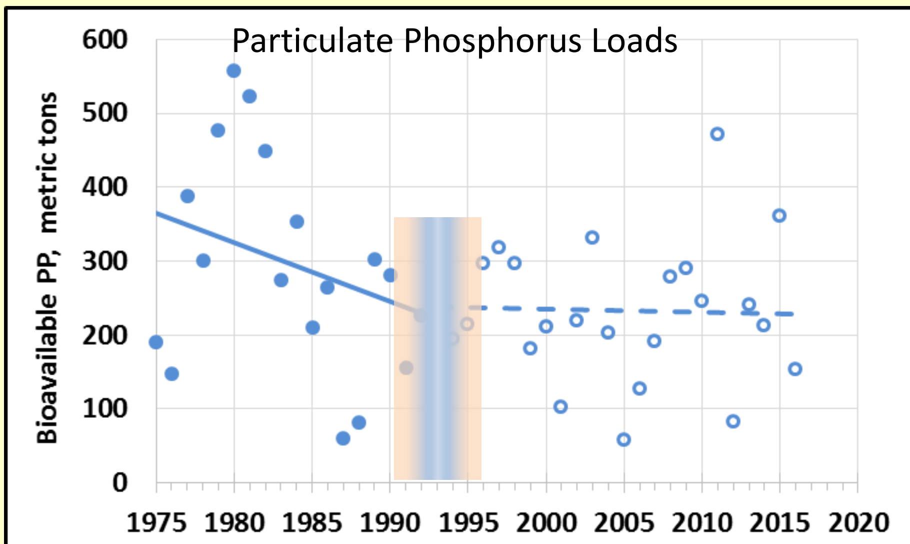
During the early 1990s, Lake Erie was viewed as a poster child for eutrophication control. During re-eutrophication, particulate P loads did not increase while DRP loads increased dramatically. Furthermore, much of the PP doesn't make it to the Western Basin.

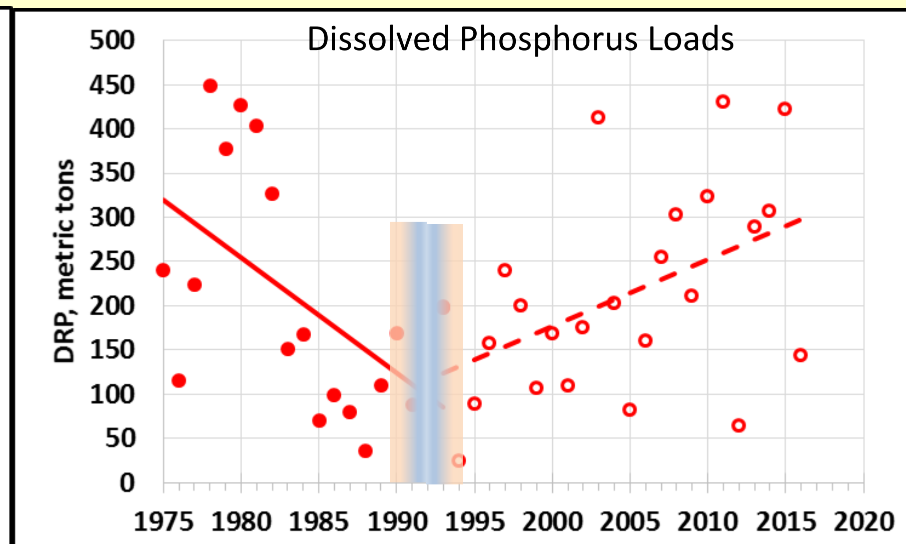
De-eutrophication—recovery– Re-eutrophication



Should we base our management plans on models that suggest a need to reduce current loading of both particulate P and dissolved P by equal amounts (40%) to move toward conditions present in the early 1990s?

We think not …. Much more emphasis should be placed on reducing dissolved P.





Trends in spring (March-July) phosphorus concentrations from the Maumee River

3. Why did dissolved phosphorus loading increase so much?

4. What can be done about it?

… but first, another basic!

DRP runoff concentrations increase with increasing soil test levels

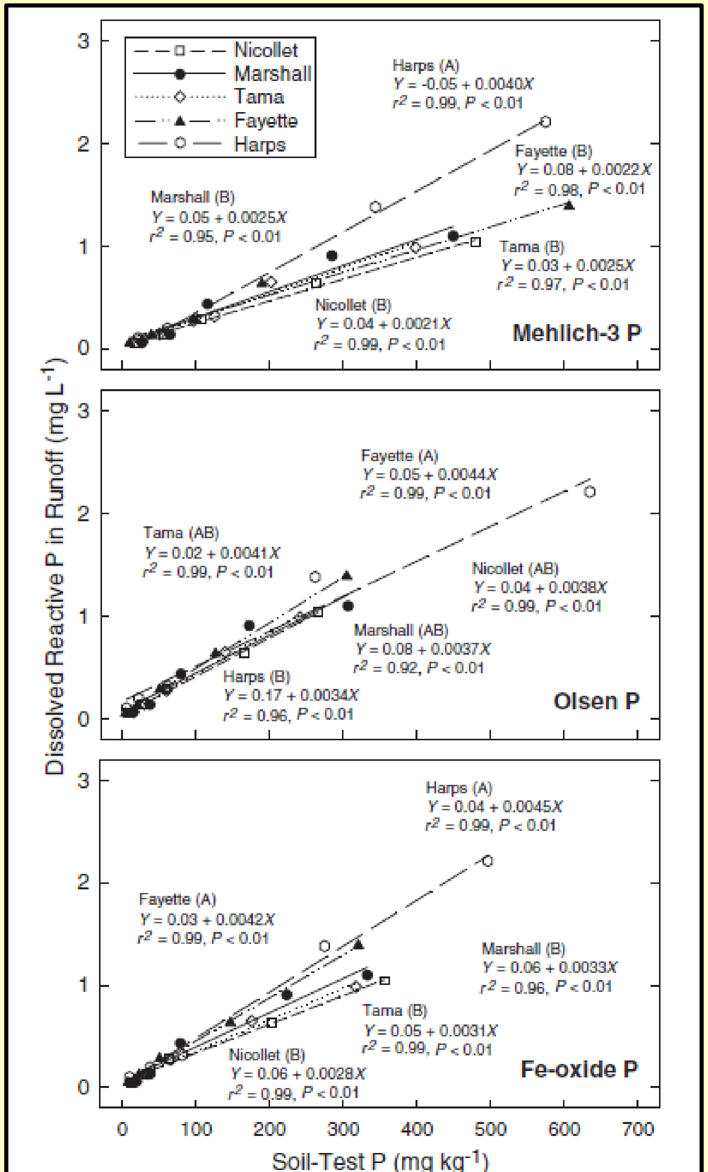
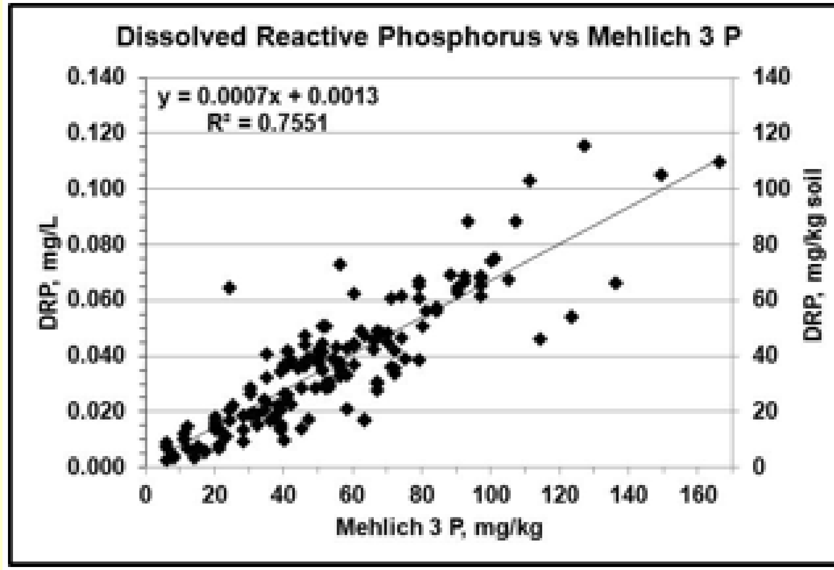
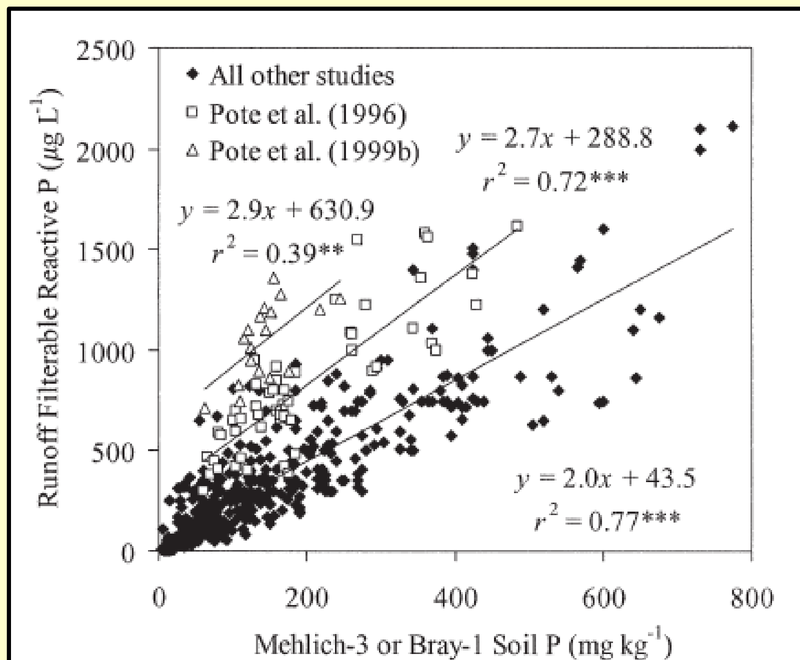


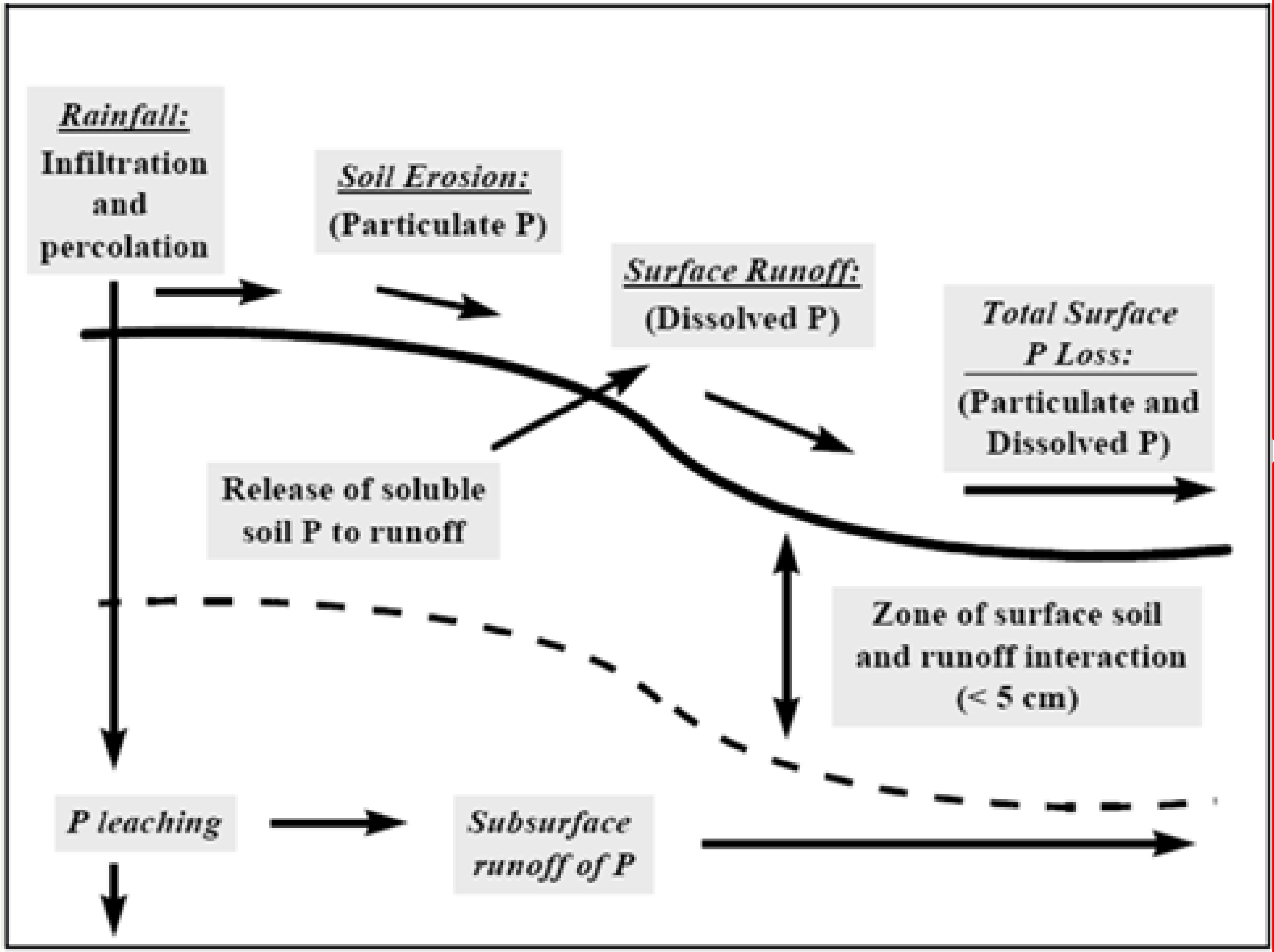
Fig. 5. Relationship between soil-test P and dissolved reactive P in runoff. Different letters by the soil names indicate significantly different ($P < 0.05$) linear coefficients between soils for each soil test.





How does phosphorus move from cropland to streams, rivers and lakes?

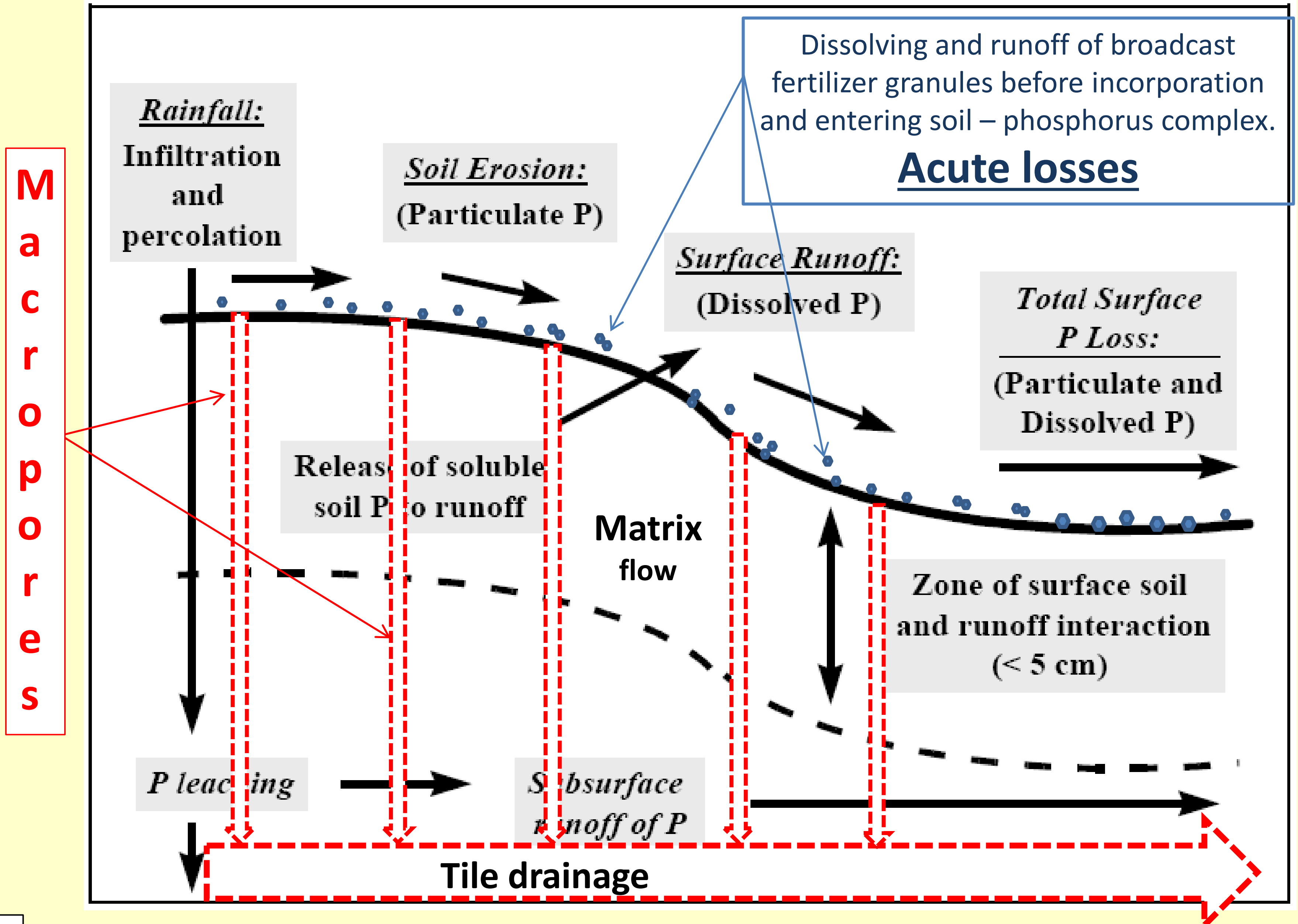
A diagram from the 1970s …



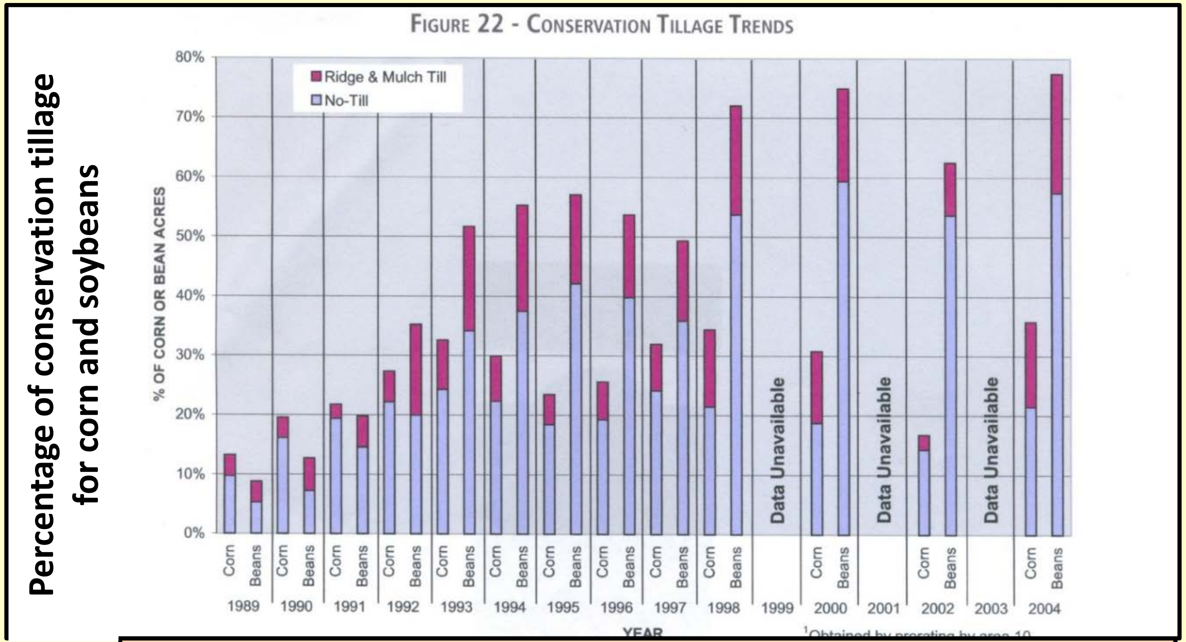
The concentration of dissolved P in cropland runoff is related to the phosphorus soil test levels in the zone of interaction.

Dissolved P released from soil in the zone of interaction represents "chronic losses" of "legacy" phosphorus.

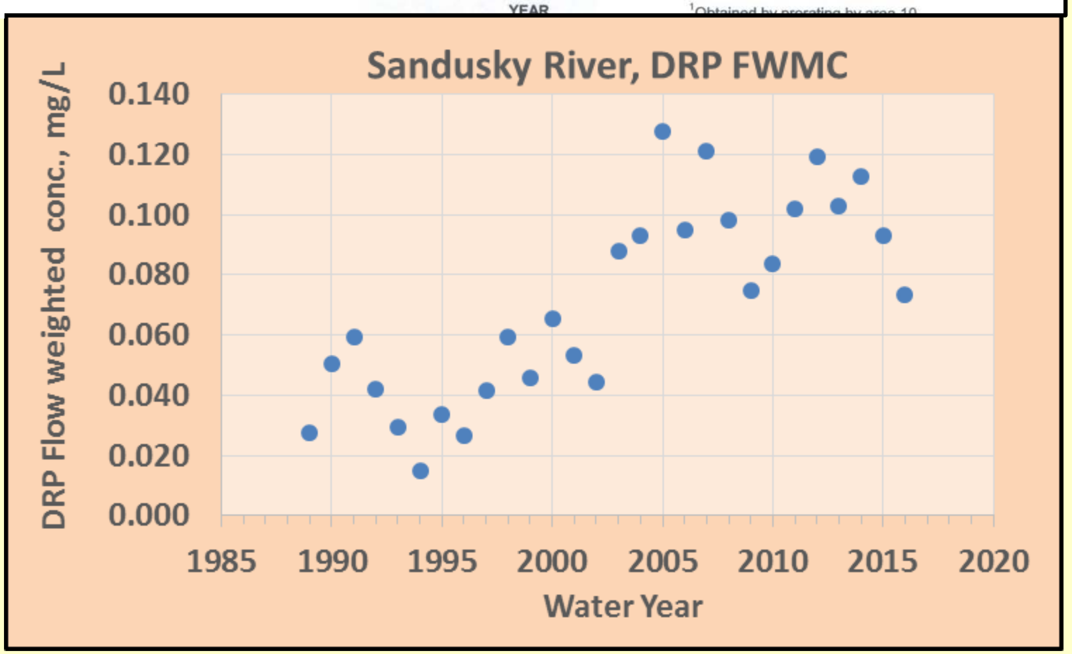
Have views of phosphorus pathways to water changed?



What changes in crop management correlate with DRP loading trends?

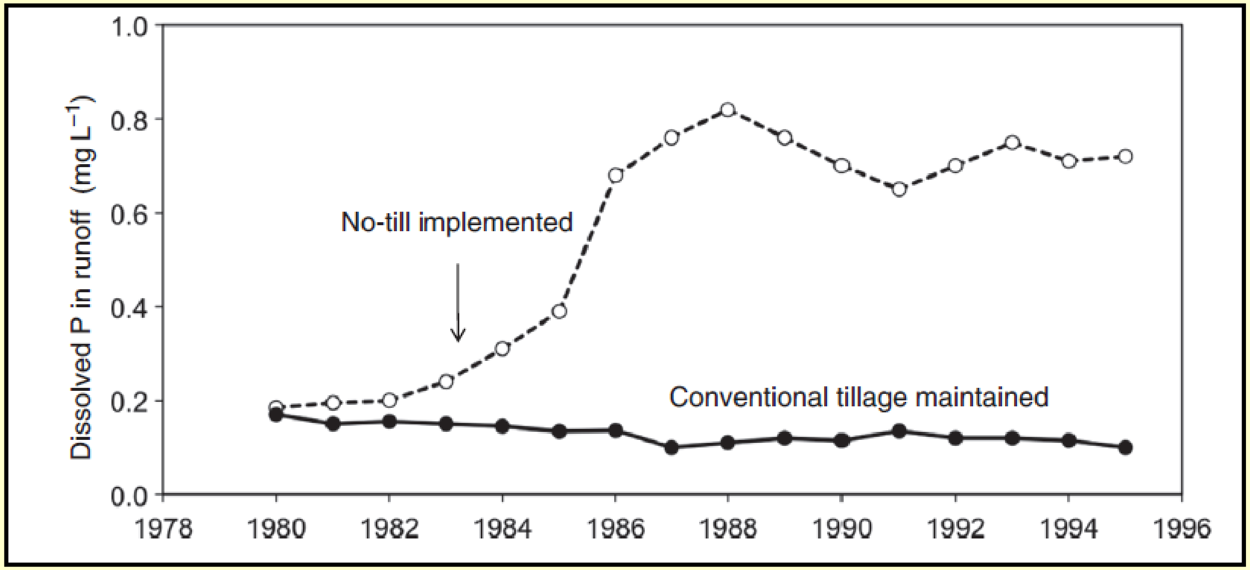


Adoption of conservation tillage in the Sandusky Watershed 1989-2004



Increase in dissolved phosphorus concentrations in the Sandusky River 1989-2016

Concentrations of dissolved phosphorus often increase under no-till management and other erosion control practices.



Mostly rotational no-till

Rotational no till →59%

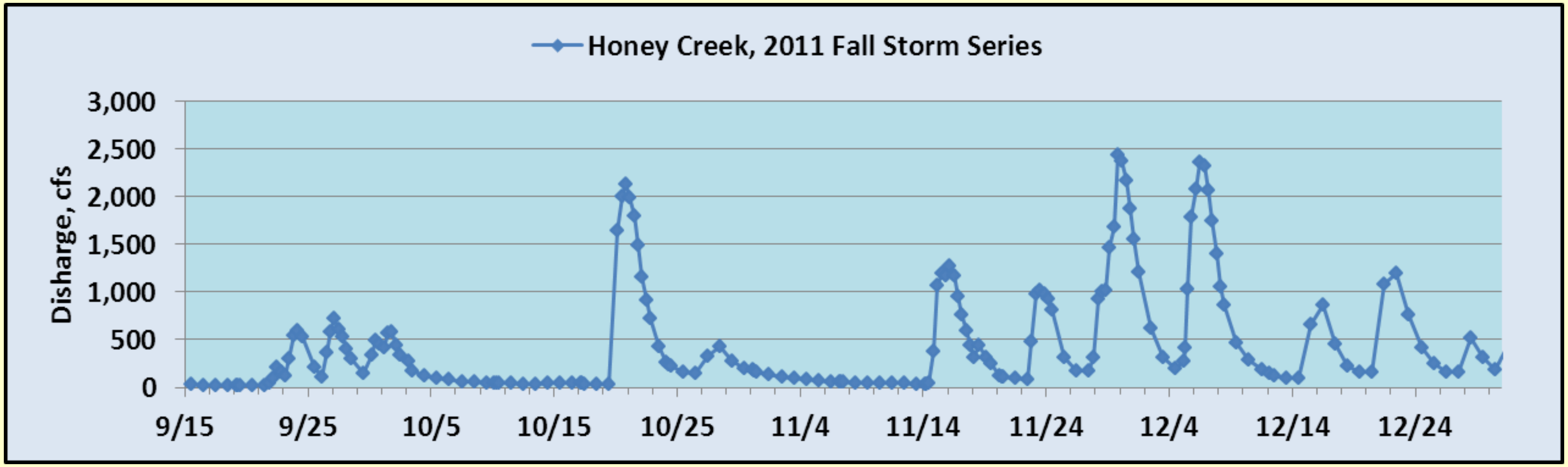
Continuous no till → 8%

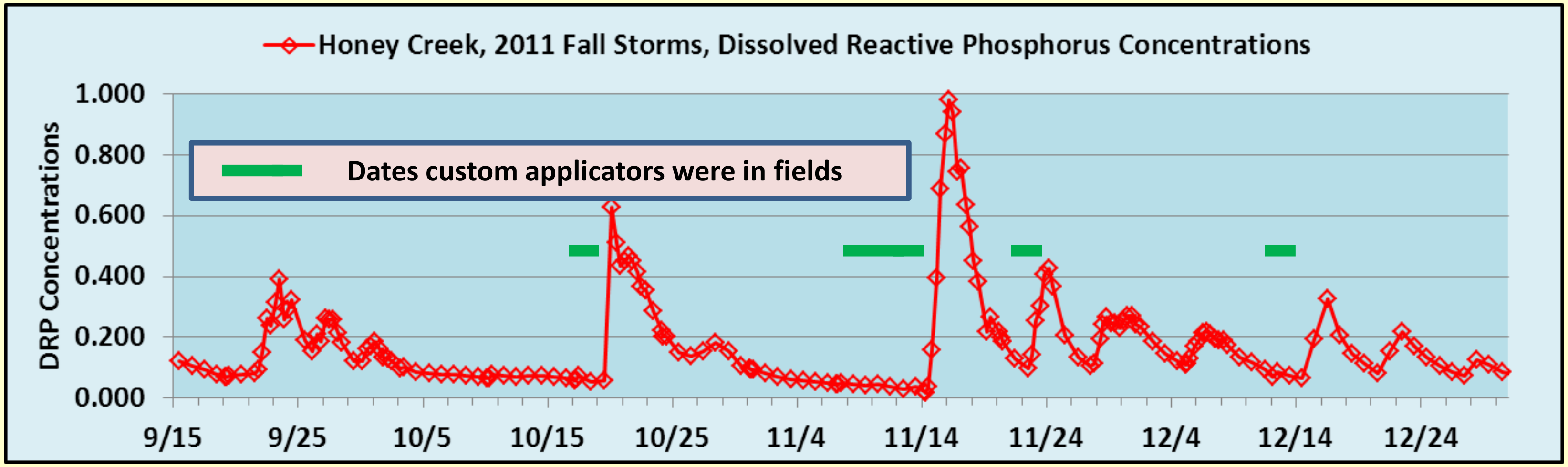
Why does dissolved phosphorus loading increase with no-till?

- **Increases phosphorus stratification in the soil**
- **More broadcasting of fertilizer… Broadcasting contributes to stratification and is subject to acute runoff.**
- **Breakdown of crop residues adds phosphorus at soil surface**
- **More macropore formation leads to higher delivery of DRP to streams through tile lines.**

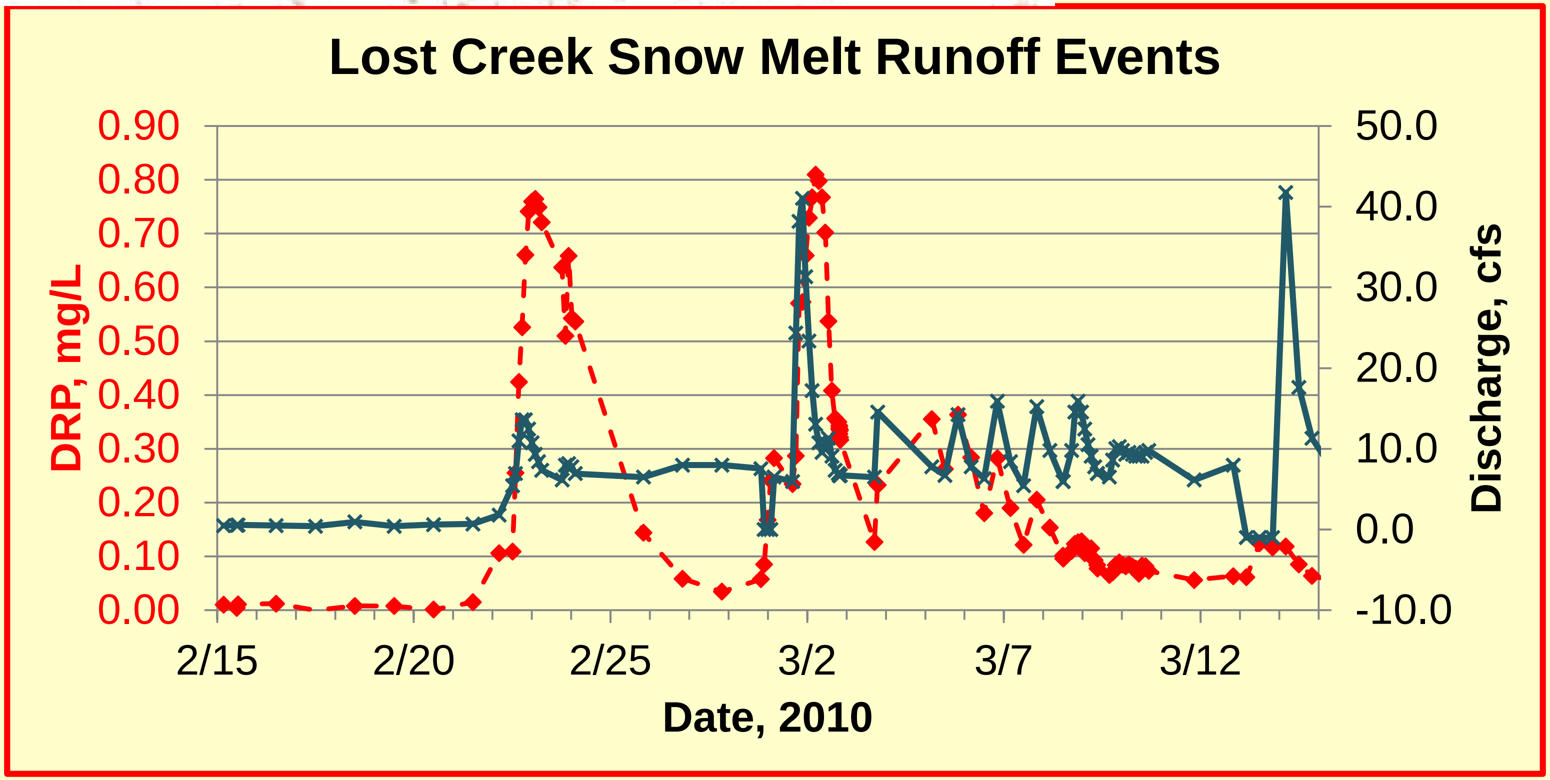
Tributary monitoring does reveal <u>acute losses</u> at the watershed scale

Fertilizer application just before precipitation





Fertilizer application on frozen ground



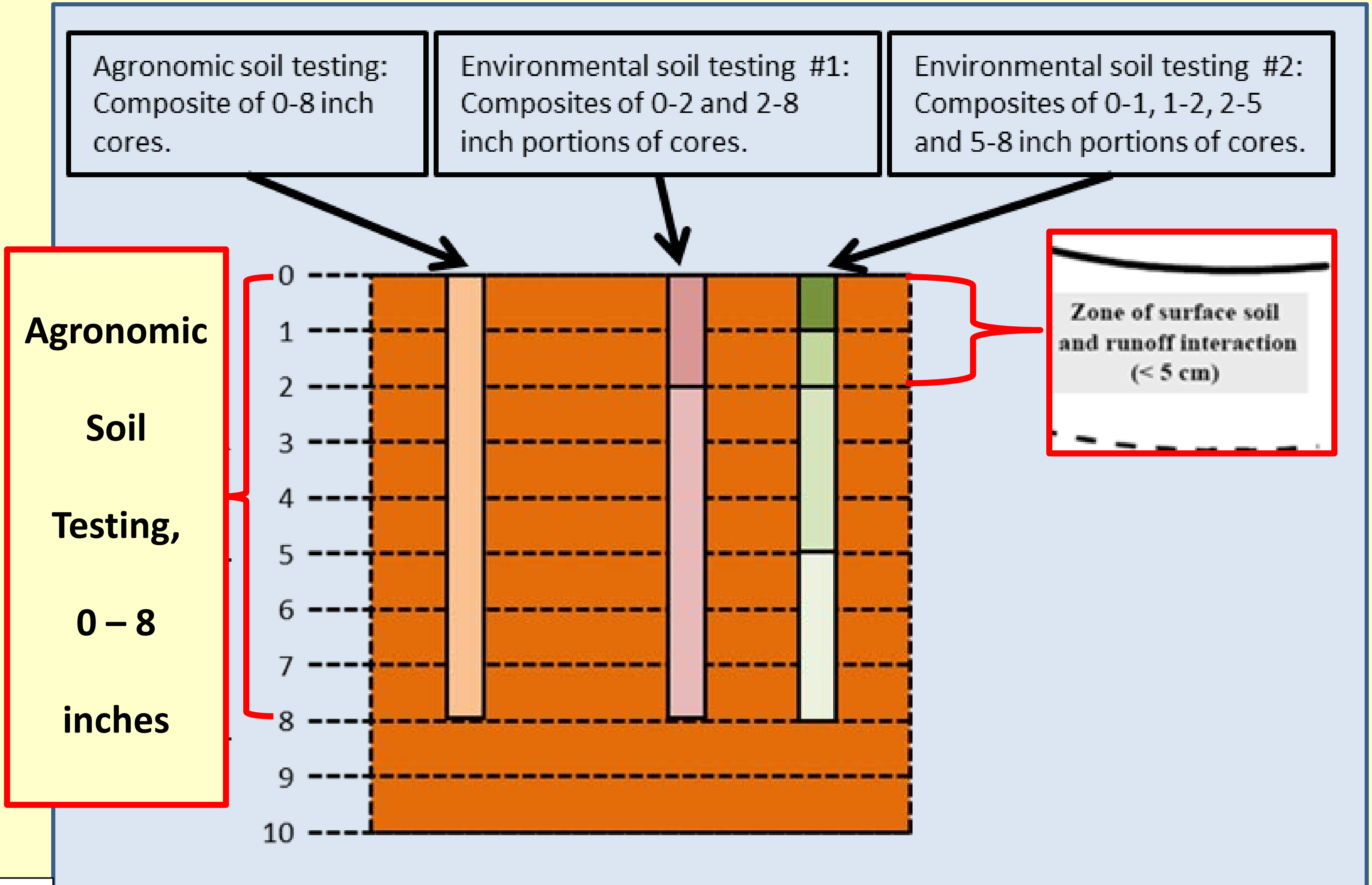
We think chronic losses of dissolved phosphorus are more important than acute losses, in terms of recent increases in dissolved P export.

- Applications of fertilizer or manure on frozen ground or before predicted heavy rainfalls have been banned in Ohio.

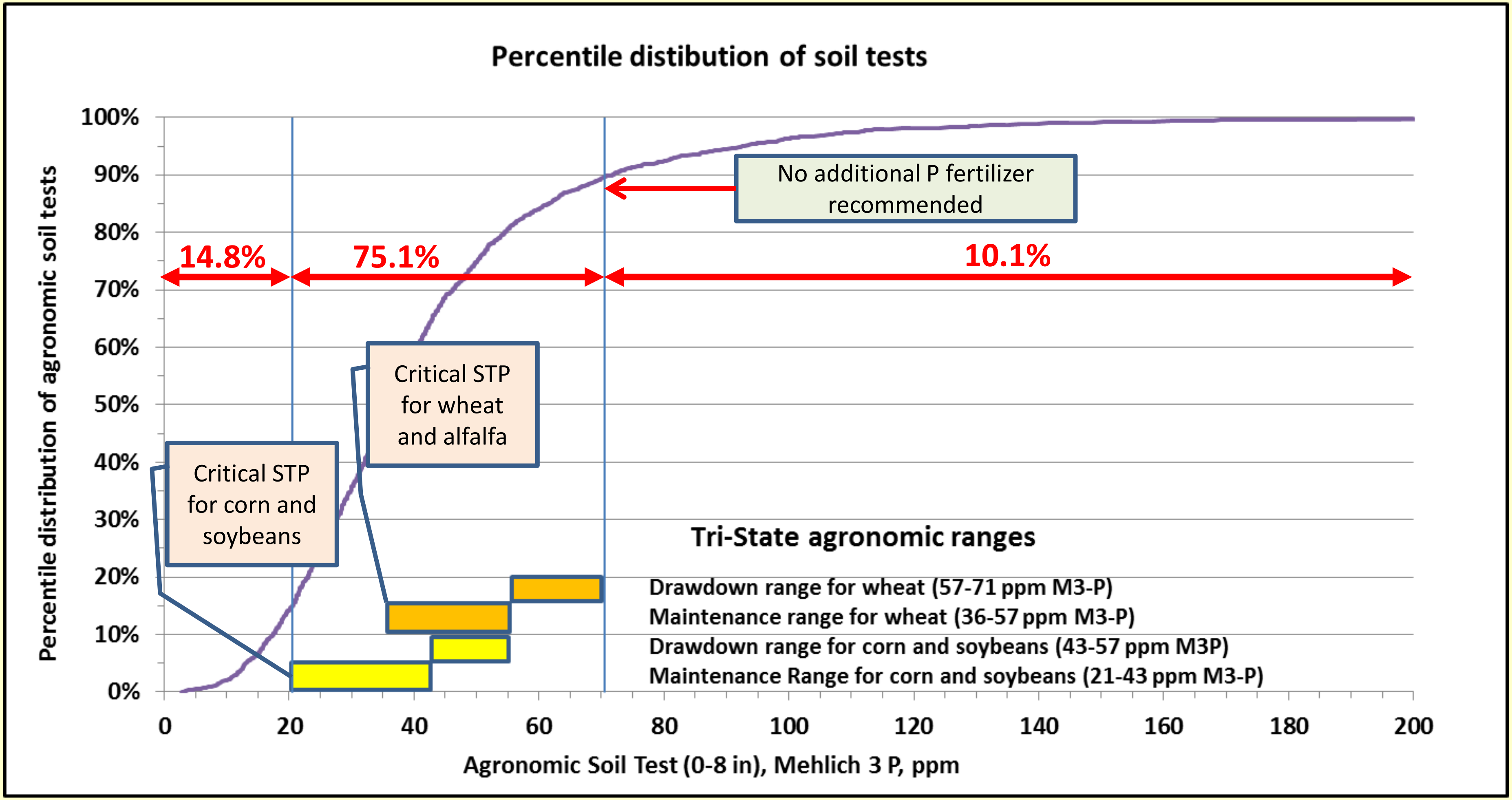
What management practices can reduce chronic DP losses?

- A closer look at stratification …

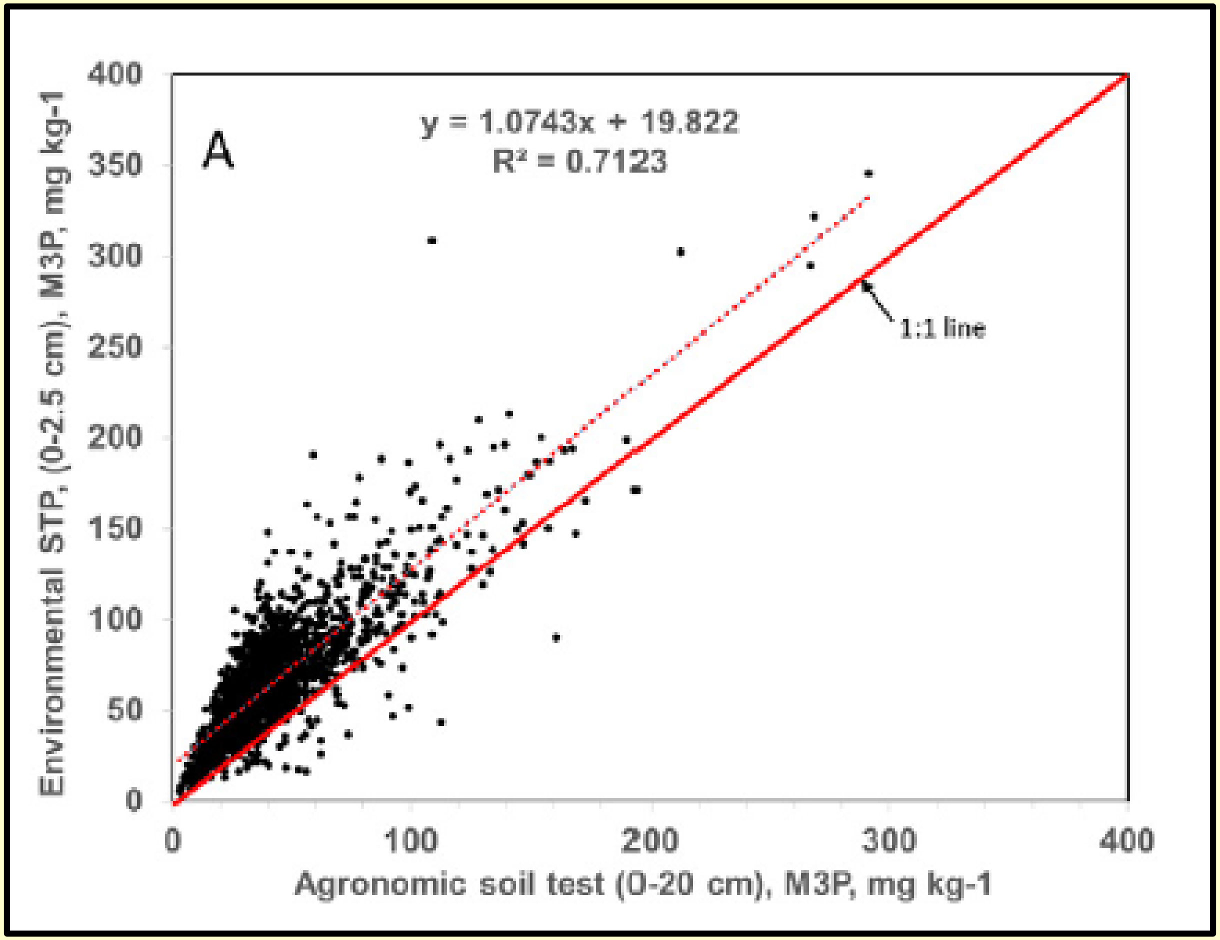
Sandusky Watershed Stratified Soil Testing Program: A cooperative program with area CCAs



Distribution of agronomic soil test levels in relation to Tri-State recommendations



Some results from the stratified soil testing program --



On average, the environmental (surficial) soil test levels were 55% higher than the agronomic soil test levels.

Do increases of Mehlich 3 P soil test levels of these amounts result in significant increases in DRP concentrations in runoff water?

How do we manage <u>environmental soil test levels</u>, to reduce chronic dissolved phosphorus export?

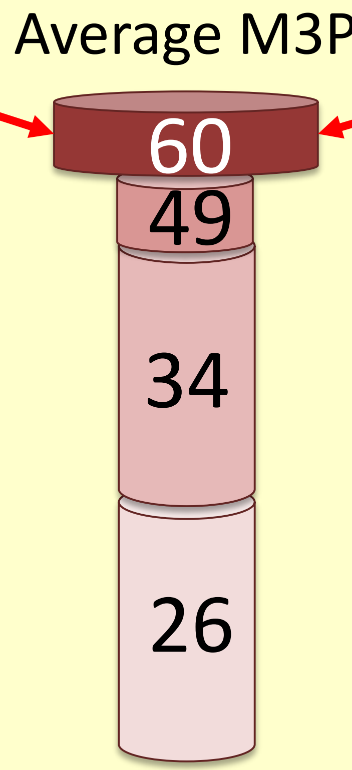
#1 Measure surficial soil test level! We can't fly blind!

Zone of interaction, sources of surficial P

- Broadcast fertilizers and manures (un-incorporated)
- Breakdown of crop residues
- Breakdown of cover crops

Source Management Practices (see 4Rs)

- Incorporate fertilizers or manures having broadcast application
- Band or inject fertilizers or manures
- Remove crop or winter cover residues
- Drawdown of agronomic P

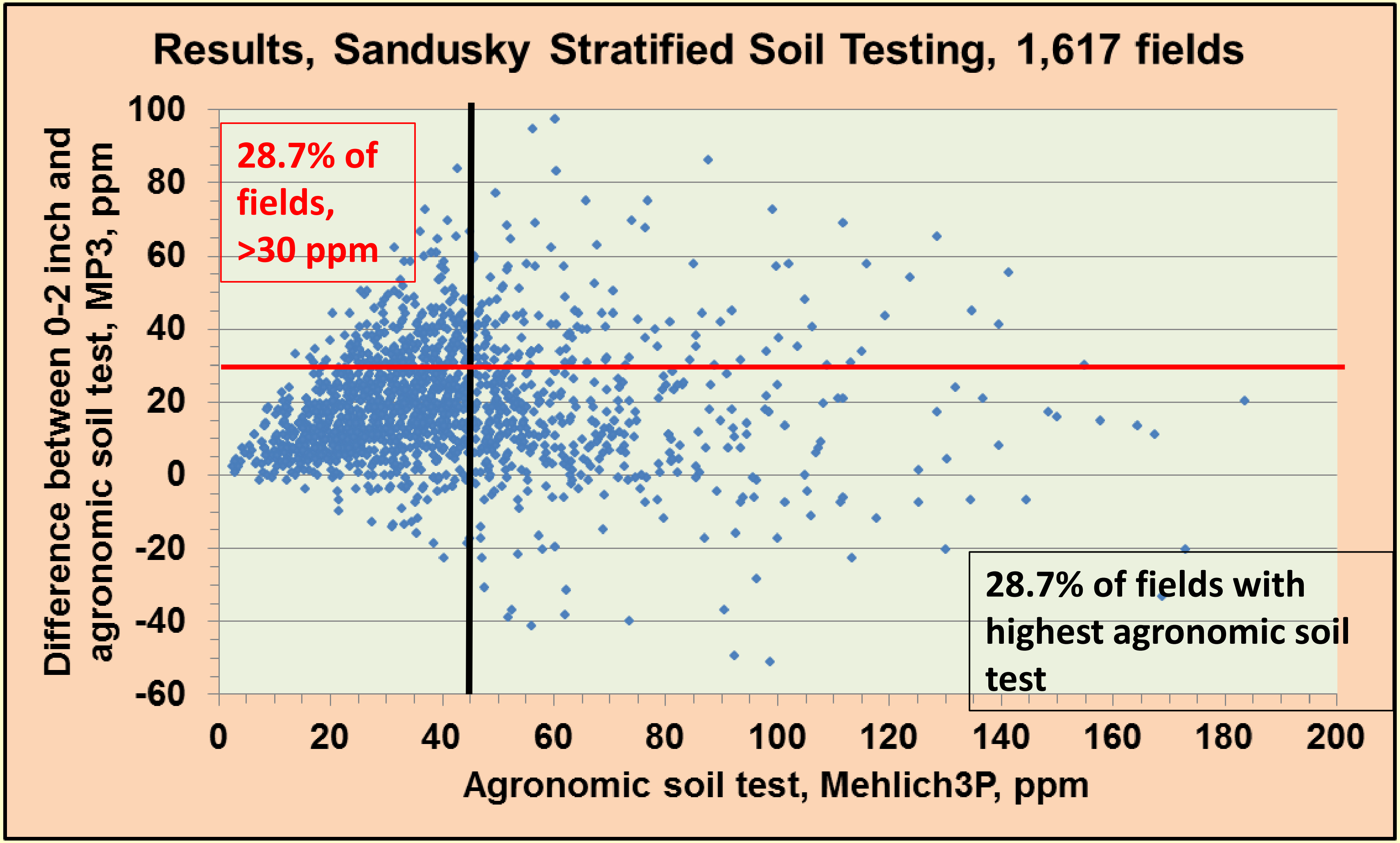


Zone of interaction, P transport

- Reduce surface runoff and macropore flow
- Increase water infiltration into soil matrix and associated P leaching
- Use soil amendments to reduce P solubility
- Selective drawdown of surficial P?

Targeted one-time inversion tillage (moldboard plowing), followed by practices that minimize subsequent development of stratification and reduce erosion.

Using inversion tillage to reduce risks of DRP runoff



Effects of inversion tillage of risks of DRP runoff (no effect on agronomic soil tests)

Targeted to fields with stratification increments >30 ppm – 19.8% risk reduction

Targeted to same # of fields with highest agronomic STP – 10.8% risk reduction

Soluble nutrient runoff for WY 2000-2016 in relation to average annual maintenance application rates in the Sandusky Watershed

Nutrient	Maintenance Application rate (as P) lbs/acre	Average Annual Export rate lbs/acre	Export Rate as a percent of maintenance rate
Phosphorus (DRP)	20.8	0.330	1.6%
Nitrogen, nitrate	67.2	16.9	25%

A very small percentage of phosphorus fertilization rates are exported as dissolved phosphorus each year.

Reducing that export by 40% (or more) does represent a challenge.

Conclusions/Recommendations

1. Action plans for reduction of algal blooms in Lake Erie should place much more emphasis on reducing dissolved phosphorus loading to Lake Erie than on particulate phosphorus reductions.

2. Management practices need to be selected or developed that reduce P-soil test levels in the zone of interaction (upper inch of soil).

3. Managing environmental soil test levels will require measuring environmental soil test levels, i.e. stratified soil testing.

4. As nutrient management advisors, CCAs have a major role in addressing bioavailable nutrient losses from cropland.

Heidelberg Tributary Loading Program – Current Sponsors

Muskingum Watershed Conservancy District

MCD Miami Conservancy District

The City of Columbus – Michael B. Coleman, Mayor

Ohio Department of Natural Resources

Northeast Ohio Regional Sewer District – Protecting Your Health and Environment

Ohio Water Development Authority

United States Environmental Protection Agency

NOAA – National Oceanic and Atmospheric Administration – U.S. Department of Commerce

NSF

The Andersons

The Fertilizer Institute – Nourish, Replenish, Grow

DEQ – Department of Environmental Quality

Sponsors of Current Research Projects

The Ohio State University – College of Food, Agricultural, and Environmental Sciences

4R Research Fund

United States Environmental Protection Agency

Great Lakes Restoration

OhioHigherEd – Department of Higher Education

NOAA – National Oceanic and Atmospheric Administration – U.S. Department of Commerce

great lakes observing system

Ohio Lake Erie Commission

NOAA – National Oceanic and Atmospheric Administration – U.S. Department of Commerce

Sea Grant – Ohio Sea Grant College Program

Ohio Environmental Protection Agency

USDA

NRCS – Natural Resources Conservation Service

NSF

http://www.ncwqr.org

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