BGSU – NSF -- NOAA

Global Solutions to Regional Problems: Collecting Global Expertise to Address the Problem of Harmful Algal Blooms

Bowling Green State University
April 13, 2015

Nutrient Sources and Land-Lake Management in the Lake Erie Basin

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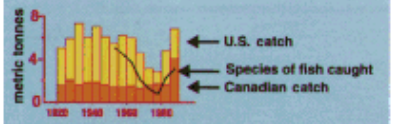
U.S. EPA

LAND USE, FISHERIES & EROSION

Land Use

- Intensive General Farming
- Low-Intensity Farming/Pasture
- Coniferous Forest
- Mixed-wood Forest
- Deciduous Forest
- Urban Areas

Commercial Fisheries



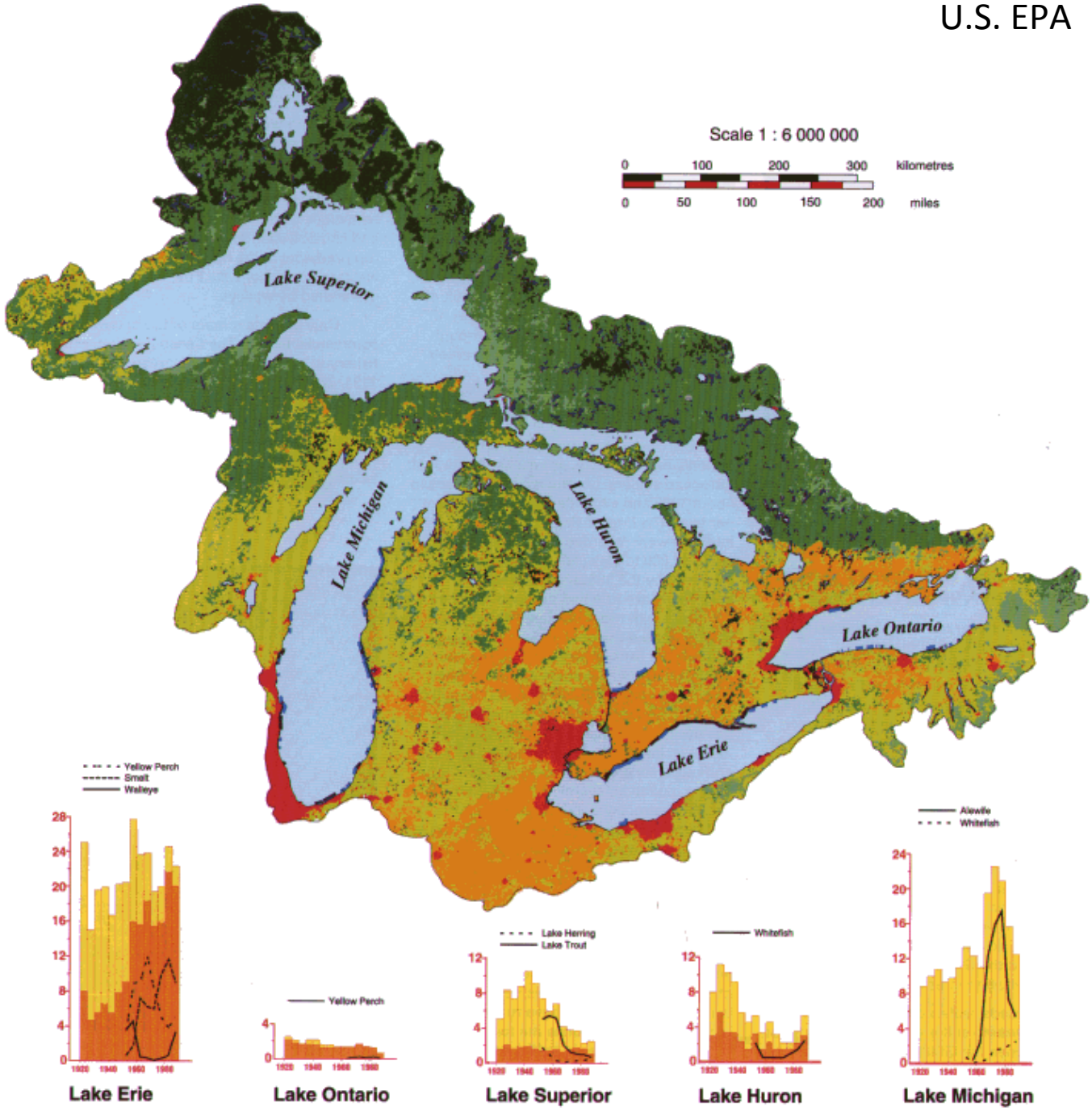
NOTE:

1. Each bar represents the average catch over a five-year period.
2. The species shown for each lake are those which have been consistently important since 1950. They are not necessarily those which yielded the largest catch in any five-year period.

Tonnes	Tons
4 000	4 400
8 000	8 825
12 000	13 225
16 000	17 625
20 000	22 050
24 000	26 450
28 000	30 875

Shoreline Erosion

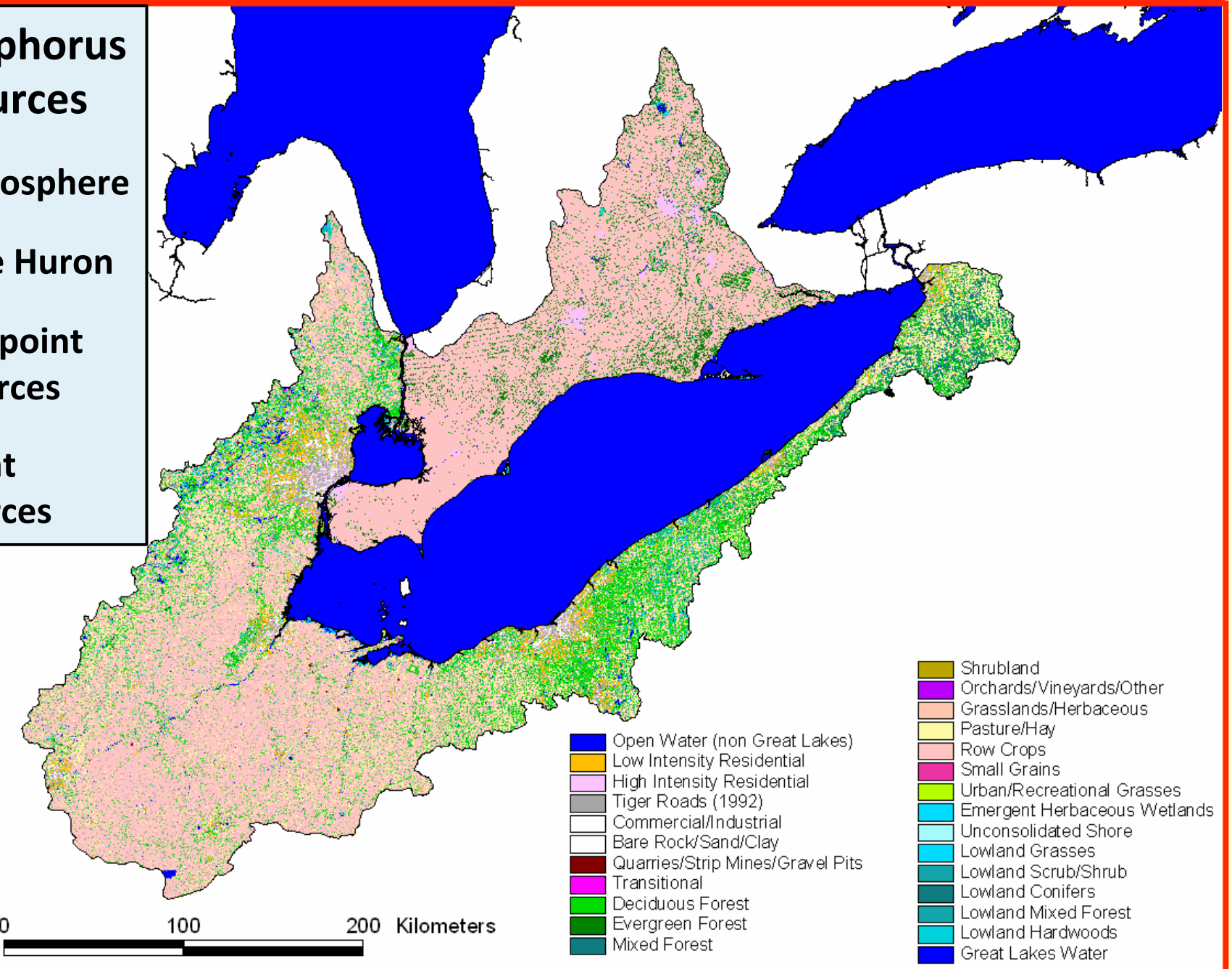
- Minimal
- Moderate
- Severe



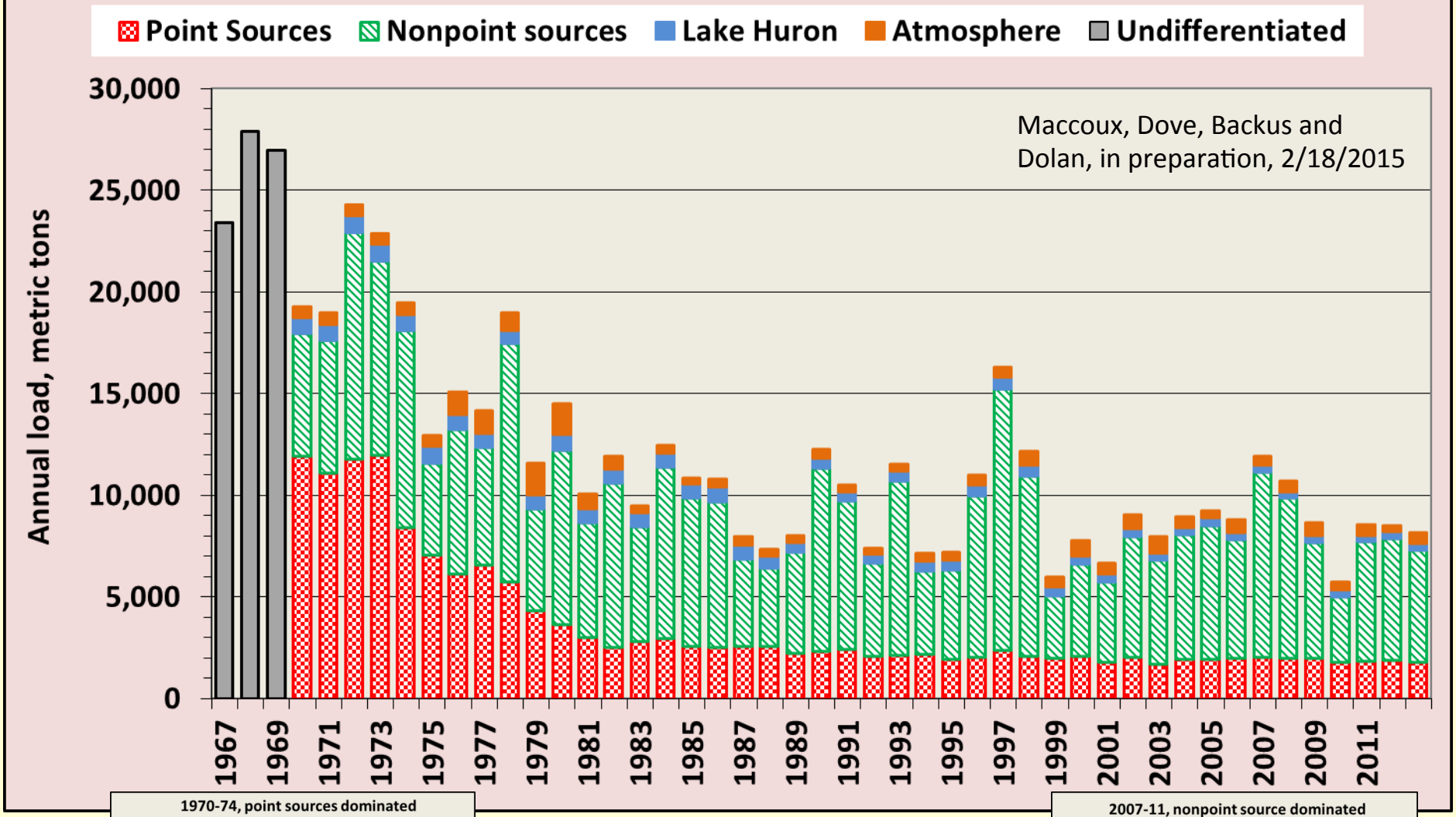
The Lake Erie Watershed: Sources of Phosphorus Loading

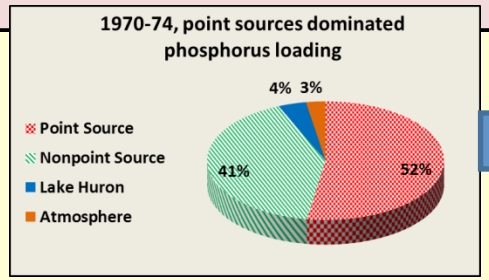
Phosphorus Sources

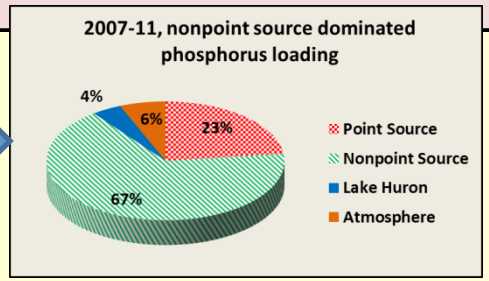
1. Atmosphere
2. Lake Huron
3. Nonpoint Sources
4. Point Sources



Lake Erie Total Phosphorus Loads from External Sources

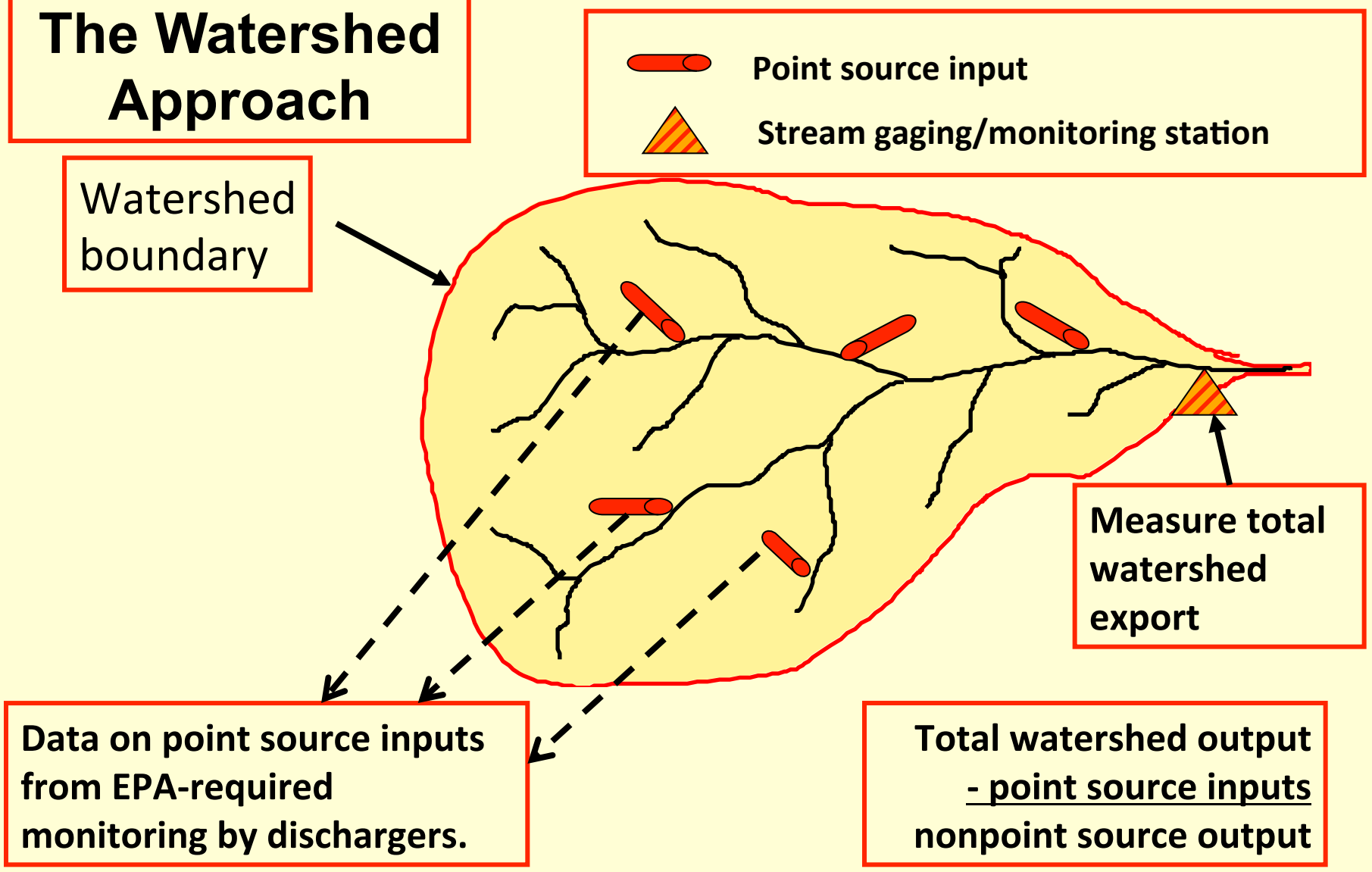






How do we measure nonpoint phosphorus loads?

The Watershed Approach

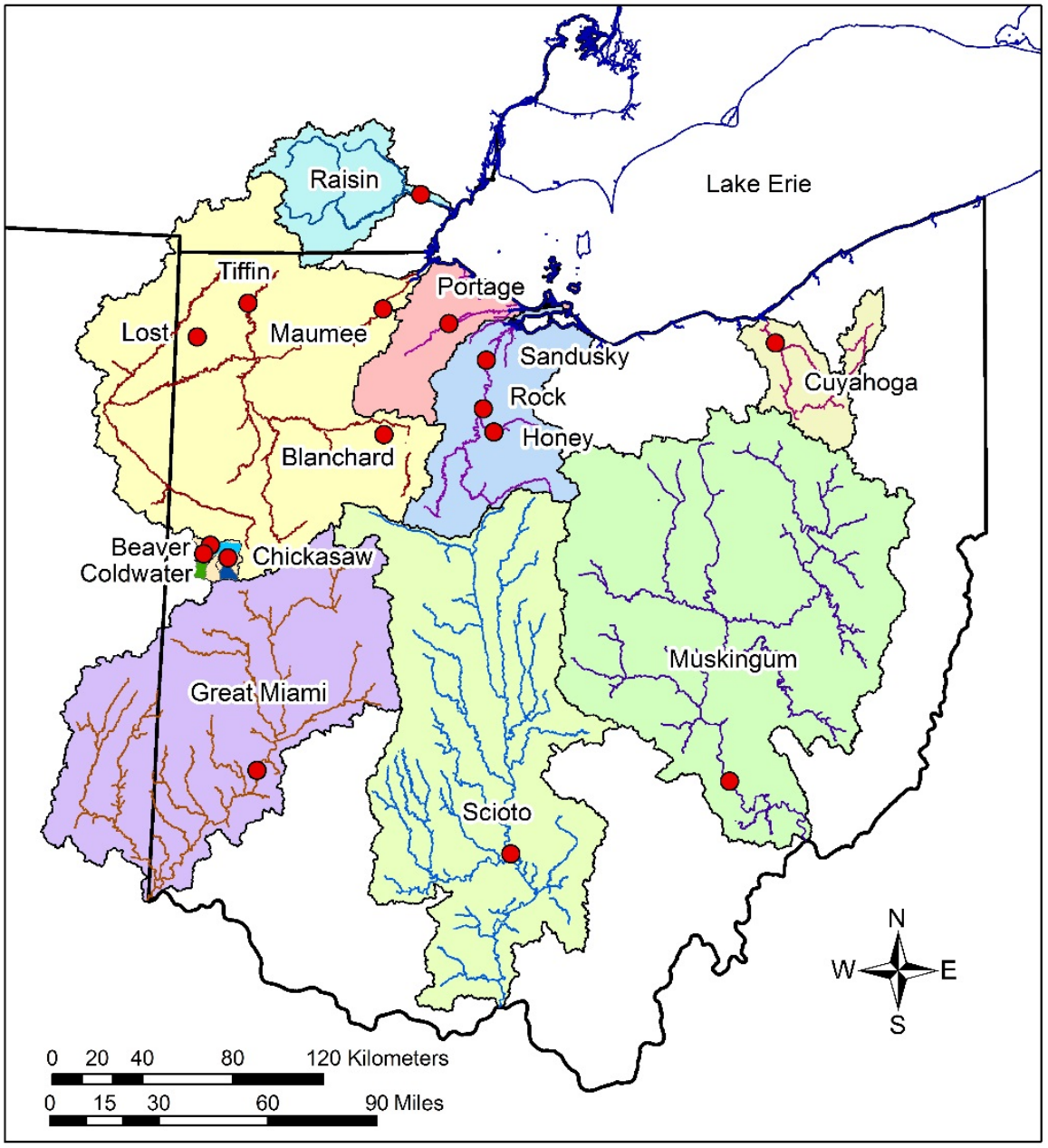


The Heidelberg University Tributary Loading Program

16 stations

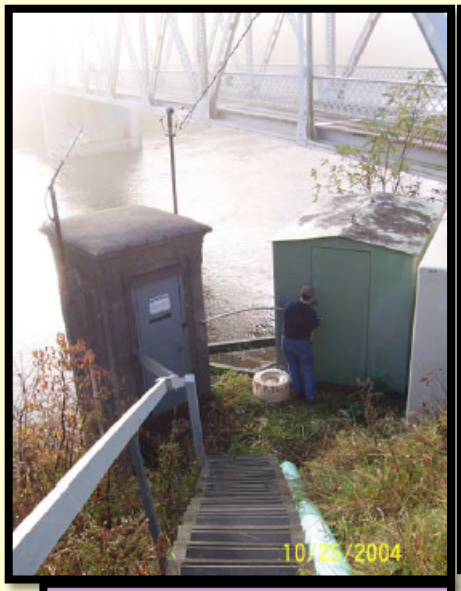
14 with automatic samplers

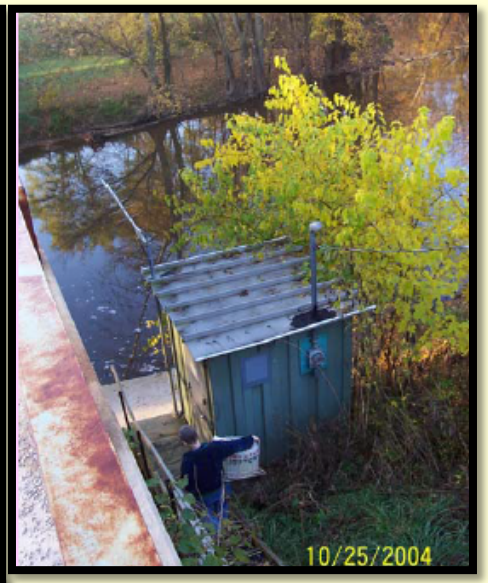
Network supports comparative watershed analyses relative to land use, size, soils etc.

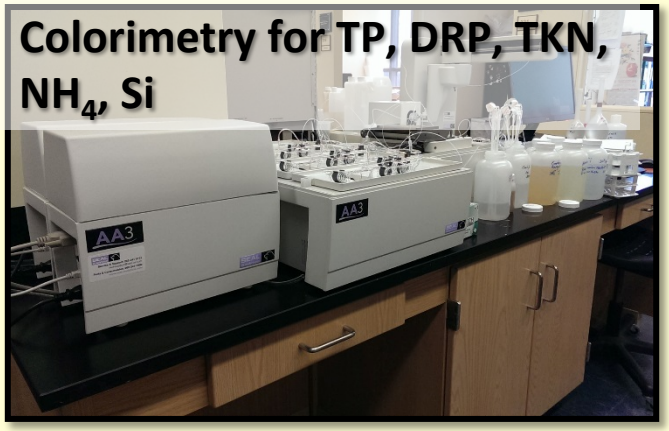


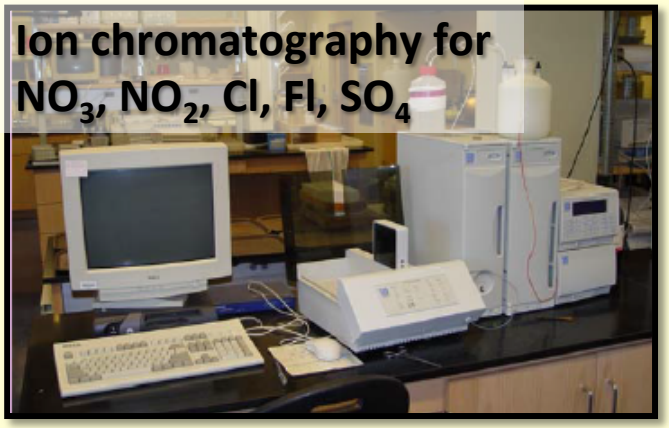
We watch the water go by!

… along with the USGS.

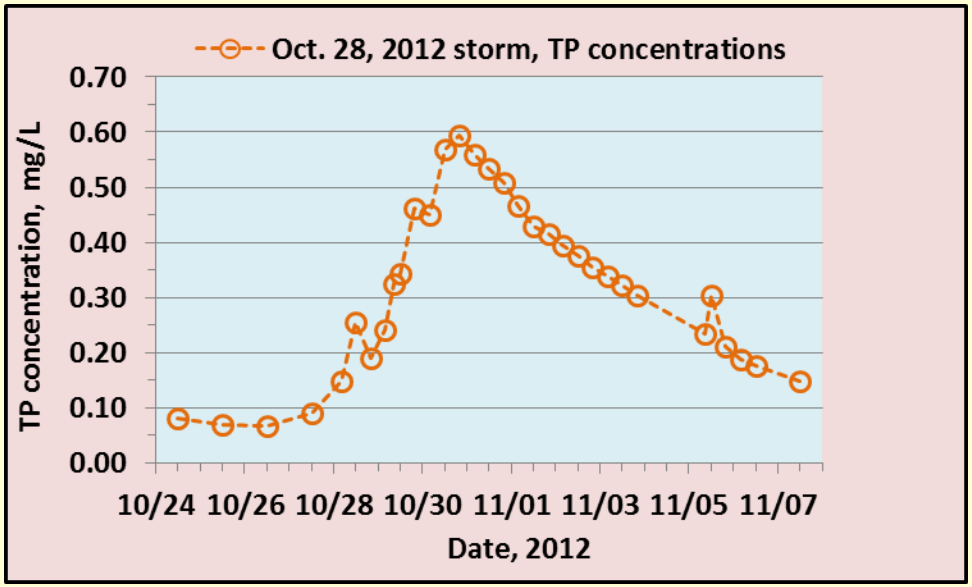








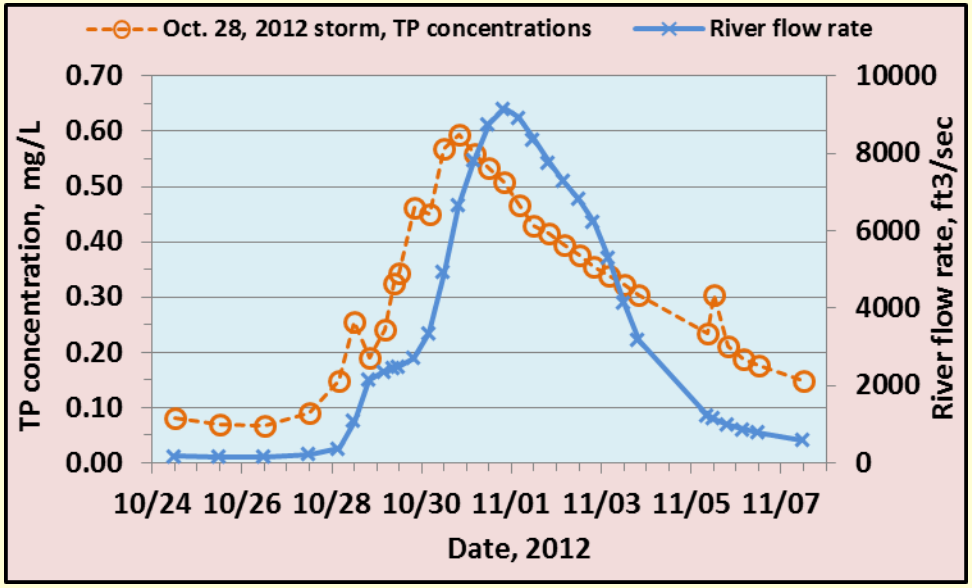
- Samples collected 3x a day
- Analyzed for all major nutrients and suspended sediments



Sandusky River

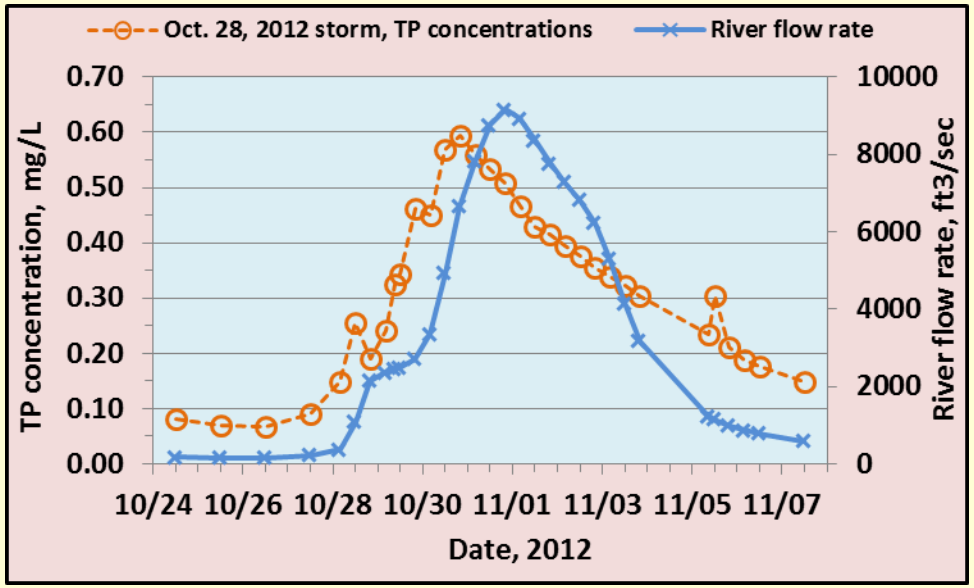
Start out with concentration data…

mg/L



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

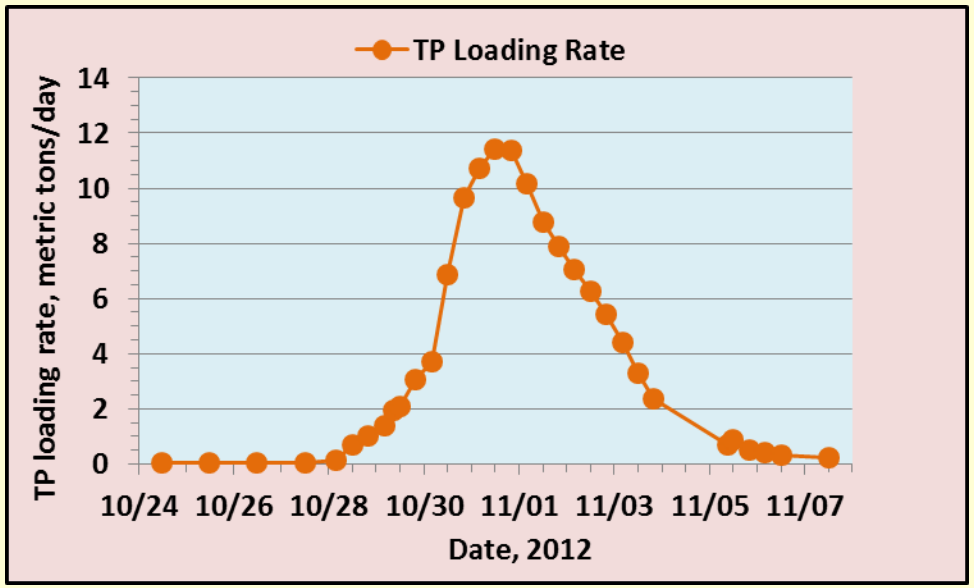
cubic feet/second



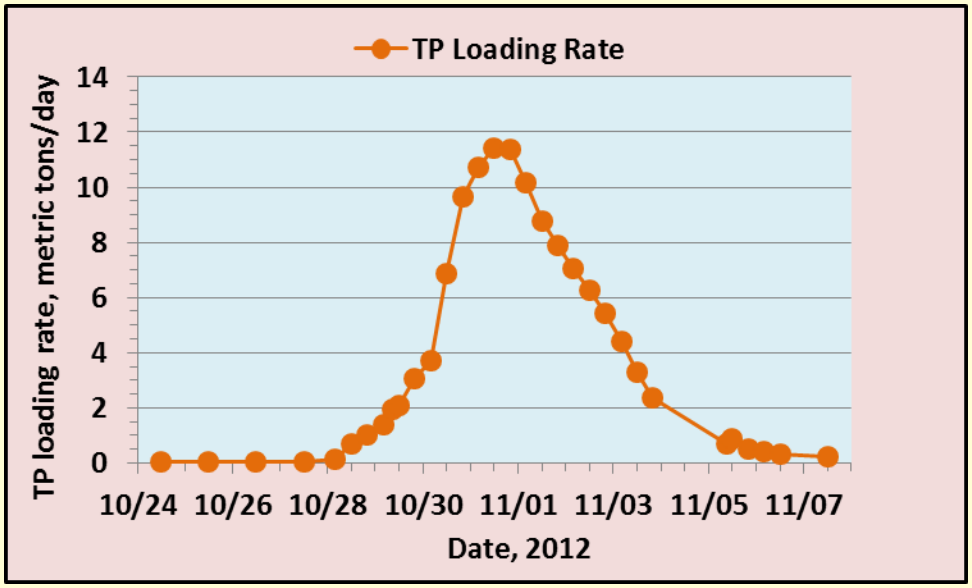
Calculate the loading rate… Amount/time

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

(loading rate) **(concentration)** **(flow rate)**

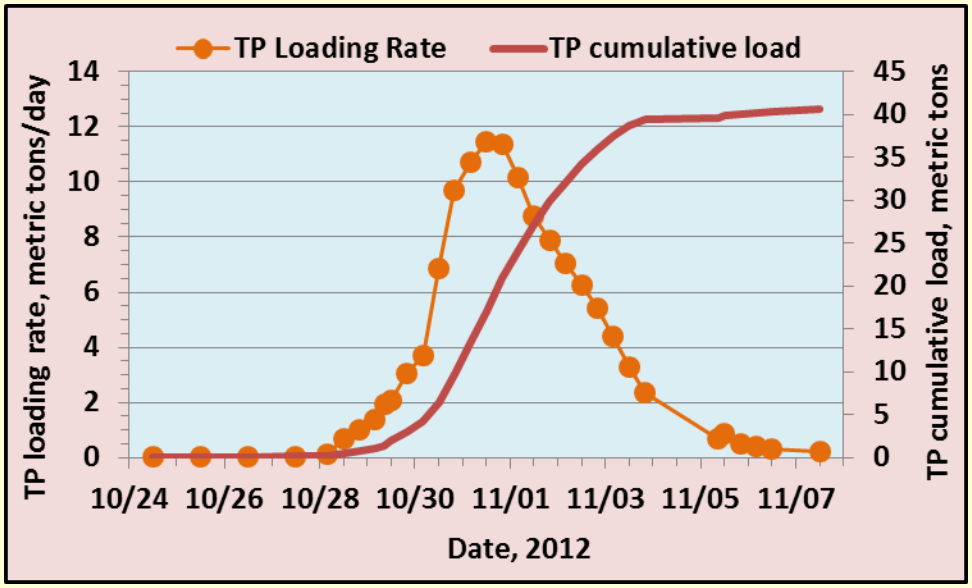


Here is the TP loading rate in units of metric tons per day



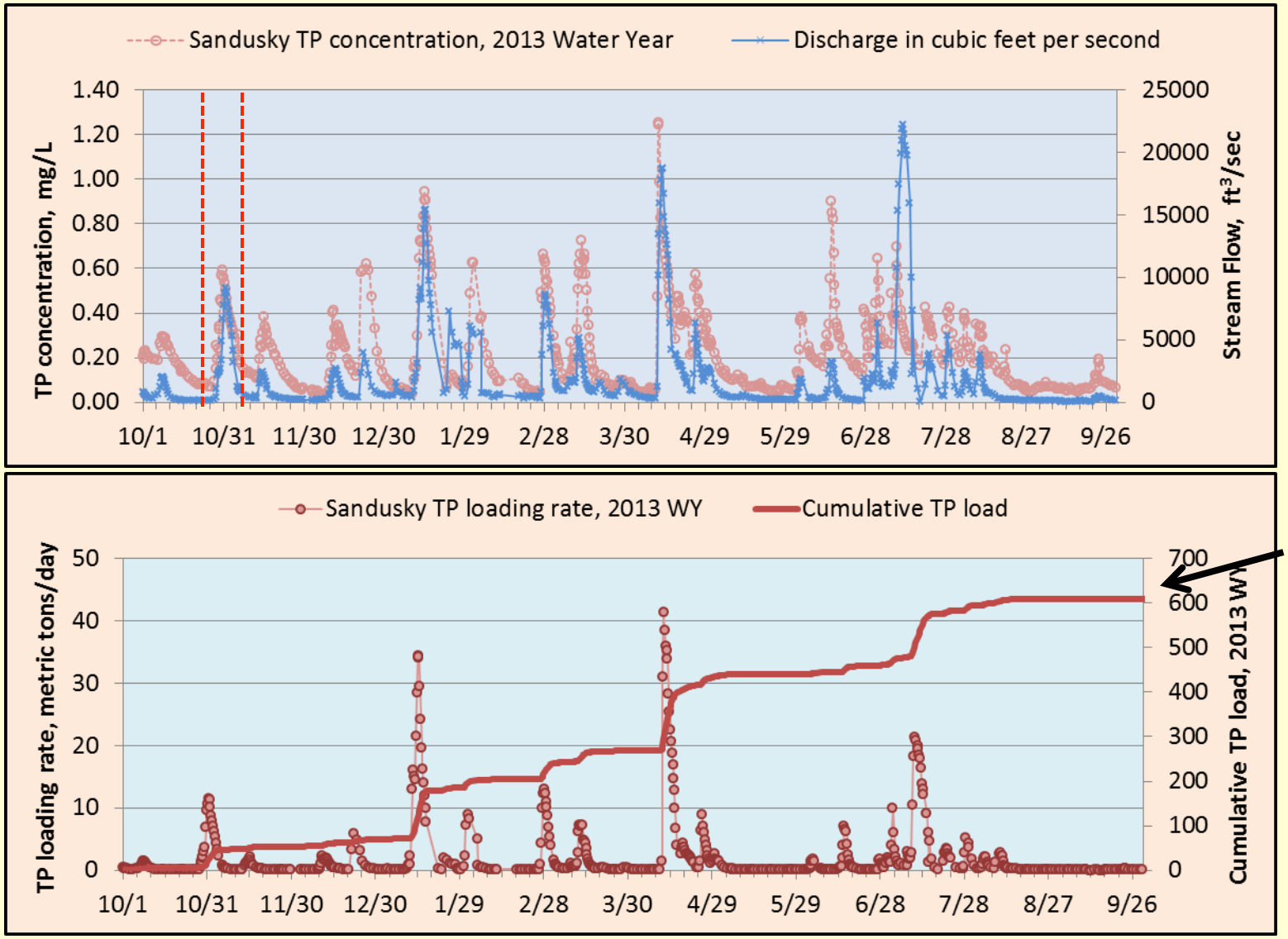
Calculate TP load over a particular time period

Metric tons/day x days = metric tons

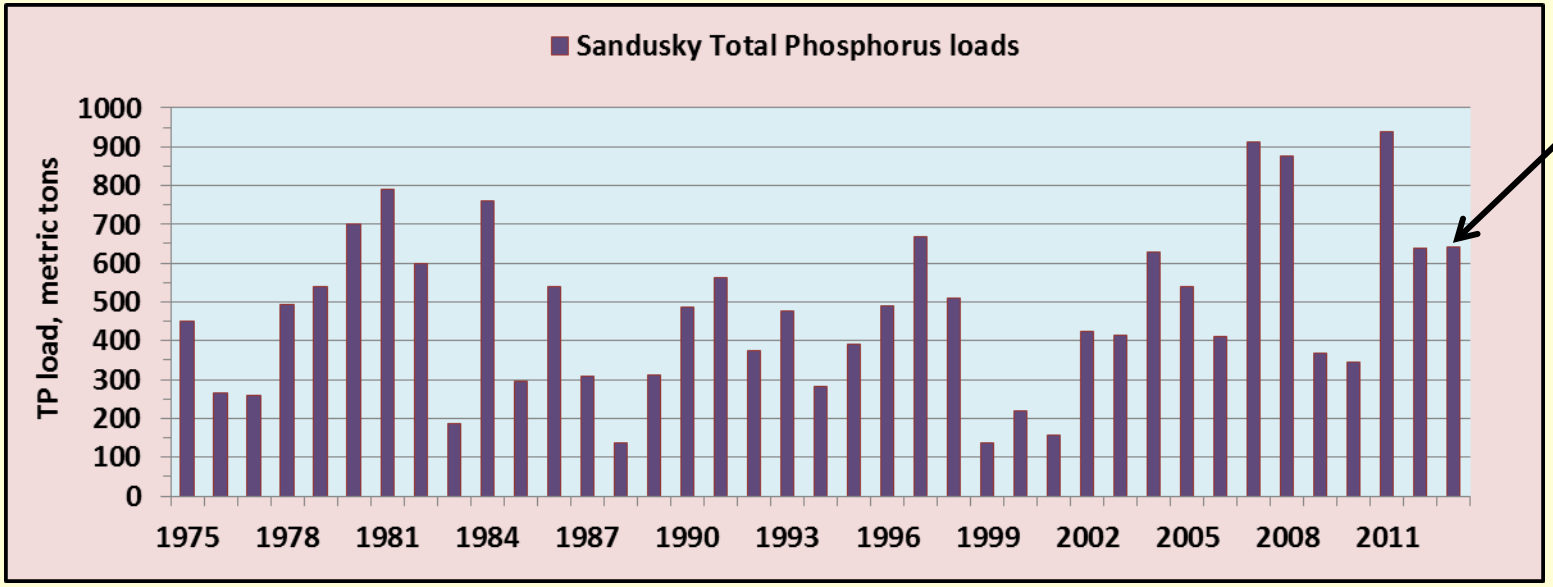


Add load for each successive sample to obtain cumulative loads for time period

Apply the above procedures to data for an entire year (Here the 2013 Water Year)



610 metric tons of Total Phosphorus



610 metric tons of Total Phosphorus for 2013 WY

The Sandusky Fremont data set through the 2014 Water Year

- **40 Water Years (1975-2014)**
- **18,625 samples analyzed**

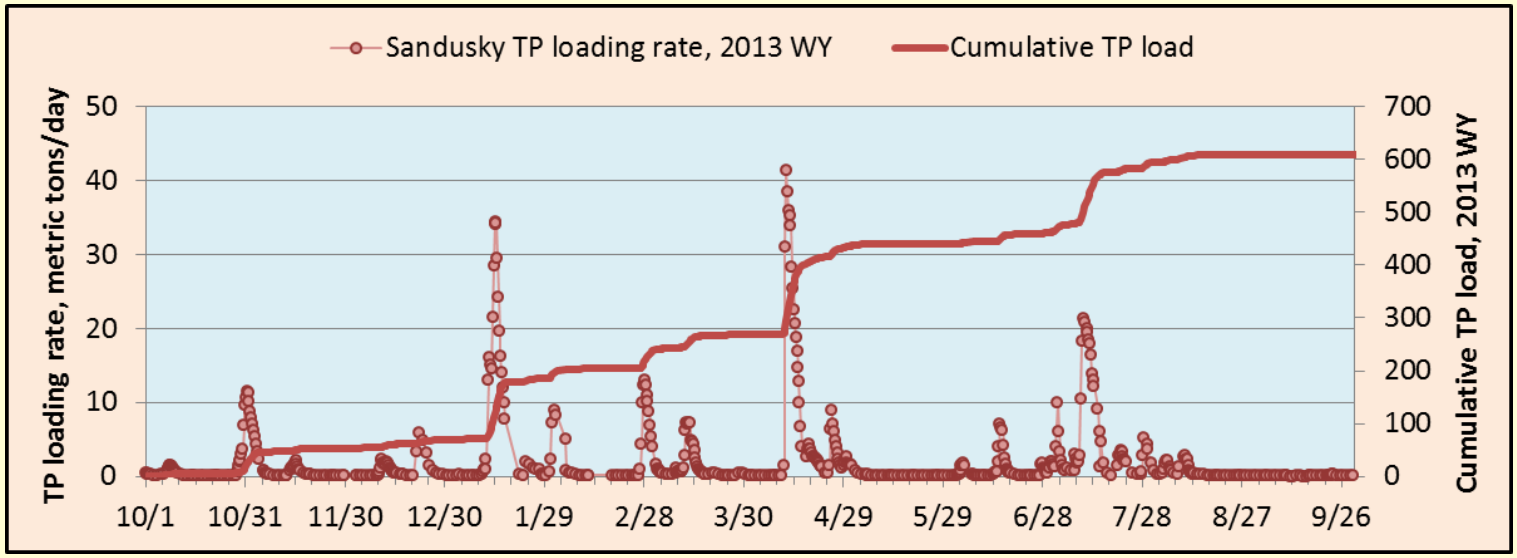
Calculation of nonpoint source TP loads from Sandusky River, 2013 Water Year

Total watershed output----------610 metric tons
- point source inputs----------15 metric tons
Nonpoint source output----------595 metric tons

2.5% point sources
97.5% nonpoint sources

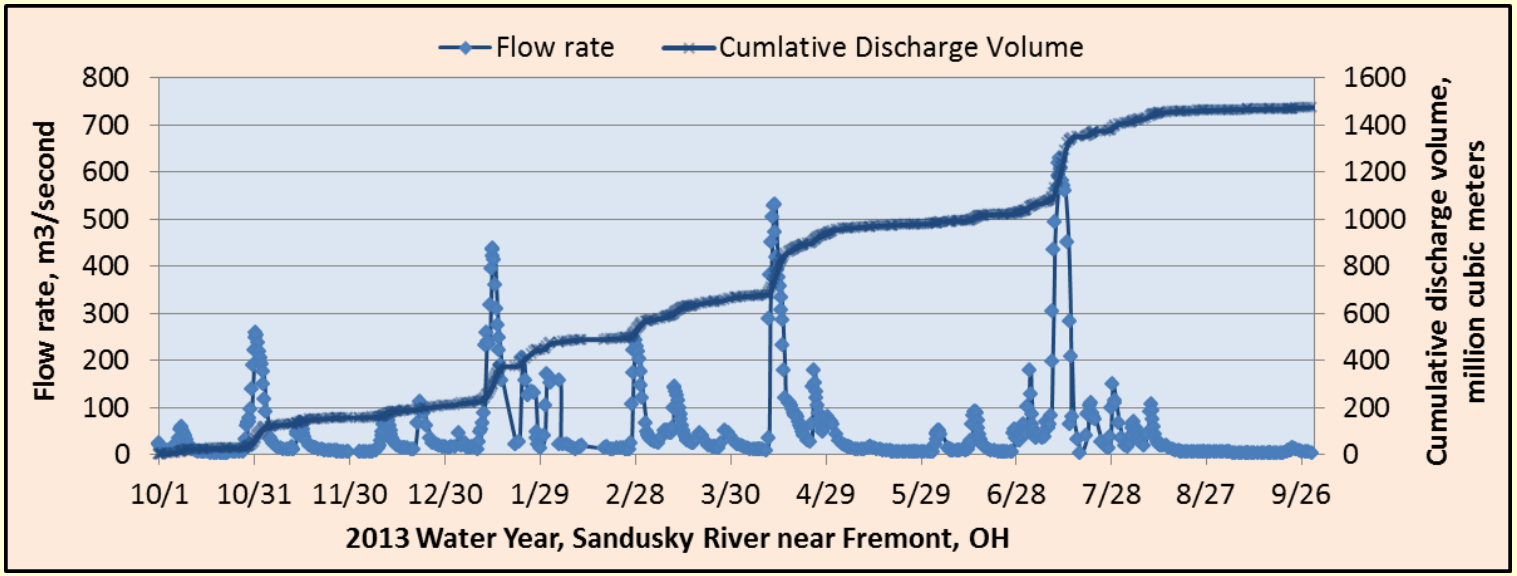
For the Maumee River at Waterville, 1995-2005 average -- 6.7% point sources.

A word on Flow Weighted Mean Concentrations (FWMCs)…



TP load-

610.1 metric tons (Amount)



Volume discharged

1,473.9 million cubic meters (Volume)

Annual Flow Weighted Mean Concentration (FWMC) of Total Phosphorus

610.1 metric tons/1,473.9 million cubic meters = 0.414 mg/L

FWMCs can be calculated for any time periods and any parameters ….

Annual …
Seasonal …
Monthly …
Storm events (Storm event mean concentration) …
etc. …

In all cases the calculation is the same ….

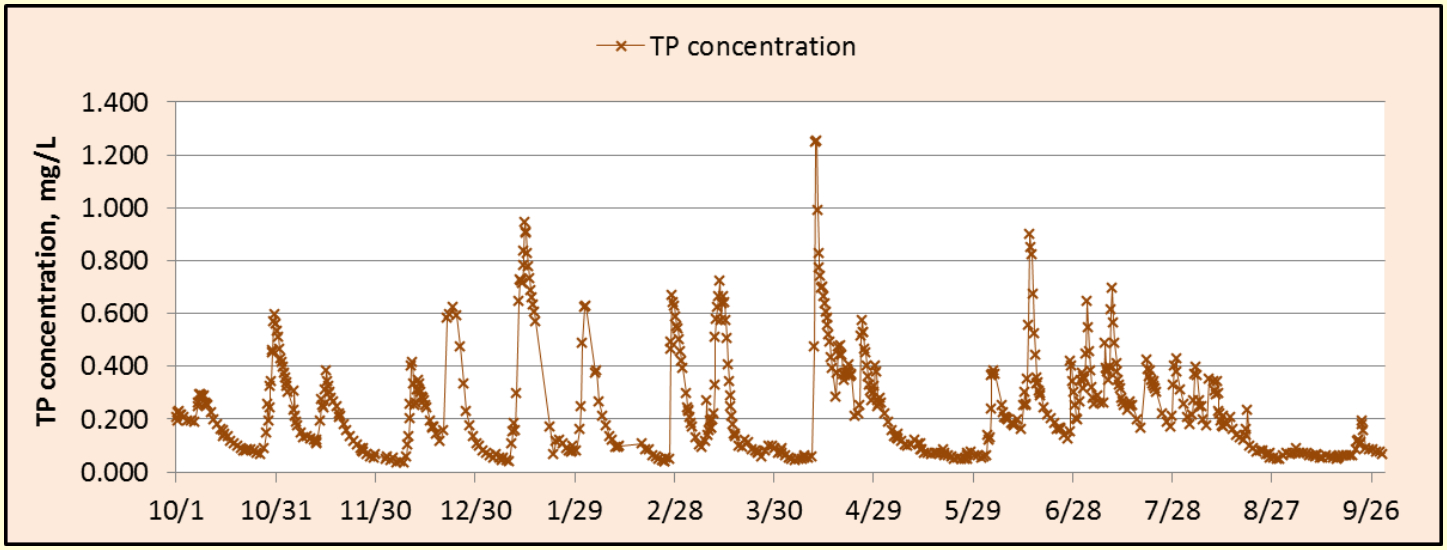
$$\text{FWMCs}_{(\text{period})} = \text{load}_{(\text{period})} \div \text{volume}_{(\text{period})}$$

Typical units

mg/L = metric tons ÷ million cubic meters

Flow Weighted versus Time Weighted Concentrations

A look at TP concentrations at the TP loading station on the Sandusky River



What is the average concentration of TP at the monitoring station?

1. **Add up all the samples and divide by the number of samples?**
   155.75/604 = <u>0.258 mg/L</u>

But not all of the samples represent the same amount of time!

2. **Time weighted mean concentration (TWMC)**
   Sum(t_i*c_i) / Sum (t_i) = <u>0.203 mg/L</u> **(t = sample time window)**

3. **Flow weighted mean concentration = <u>0.414 mg/L</u>**

From here in the 1960s & 1970s…

With some very good years in between!

Re-eutrophication of Lake Erie

… to here in the 2000s

October
2011

A blue-green algal bloom in the vicinity of the Toledo public water supply intake in 2014 resulted in a 2-day closure of the drinking water supply.

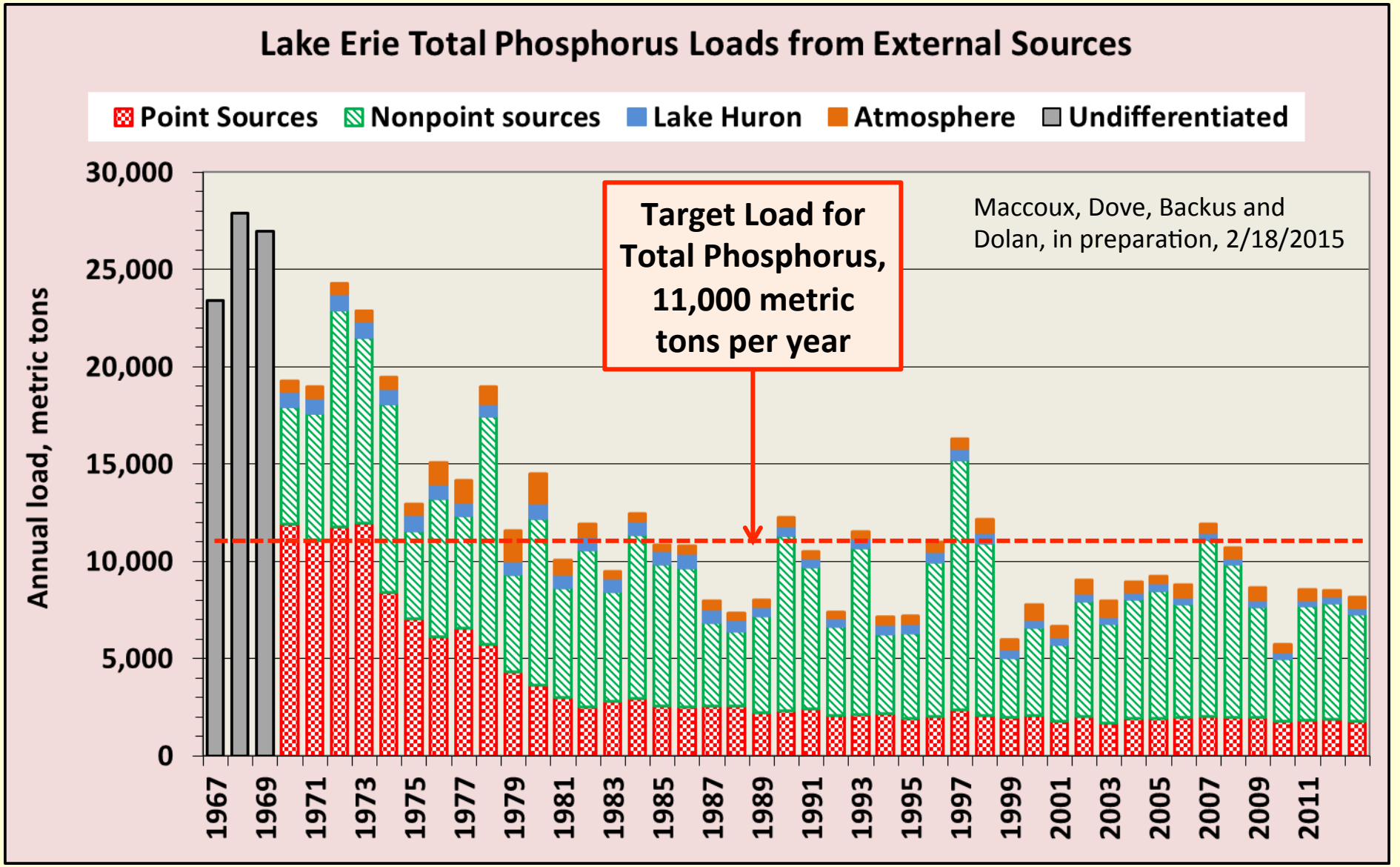
This has triggered a legislative response --- Ohio Senate Bill 1

From here in the 1960s & 1970s…

With some very good years in between!

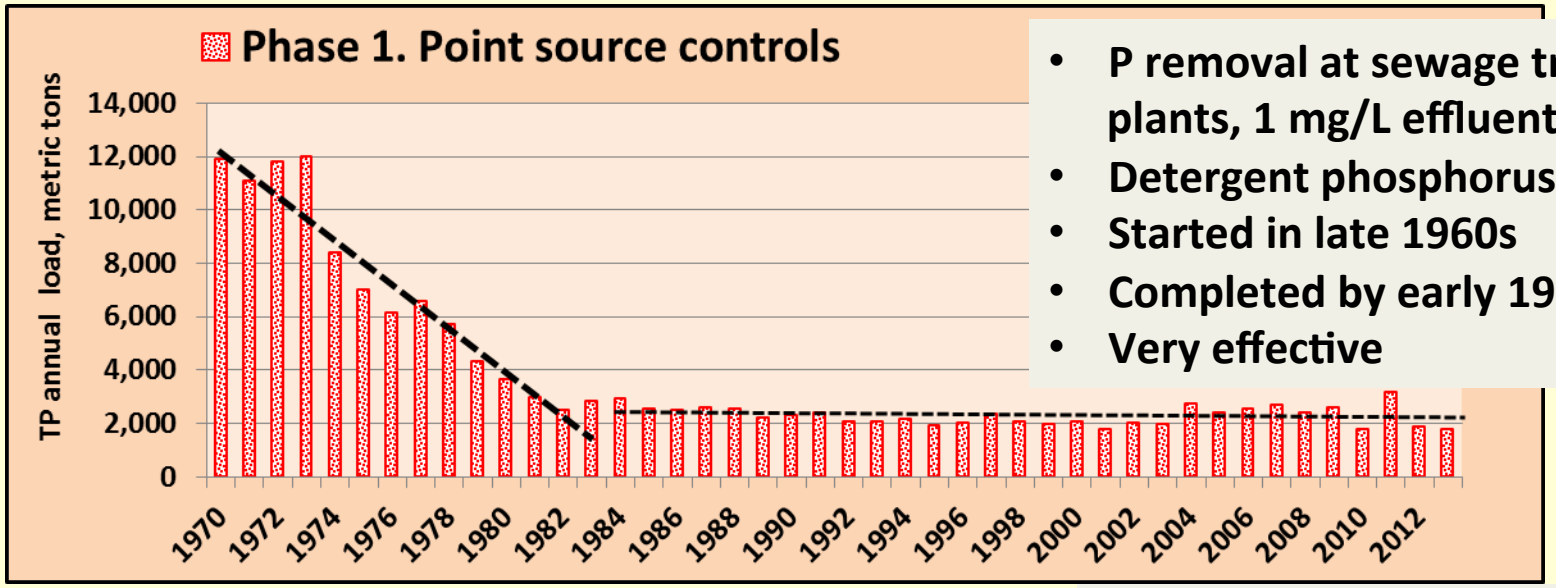
Why?

… to here in the 2000s

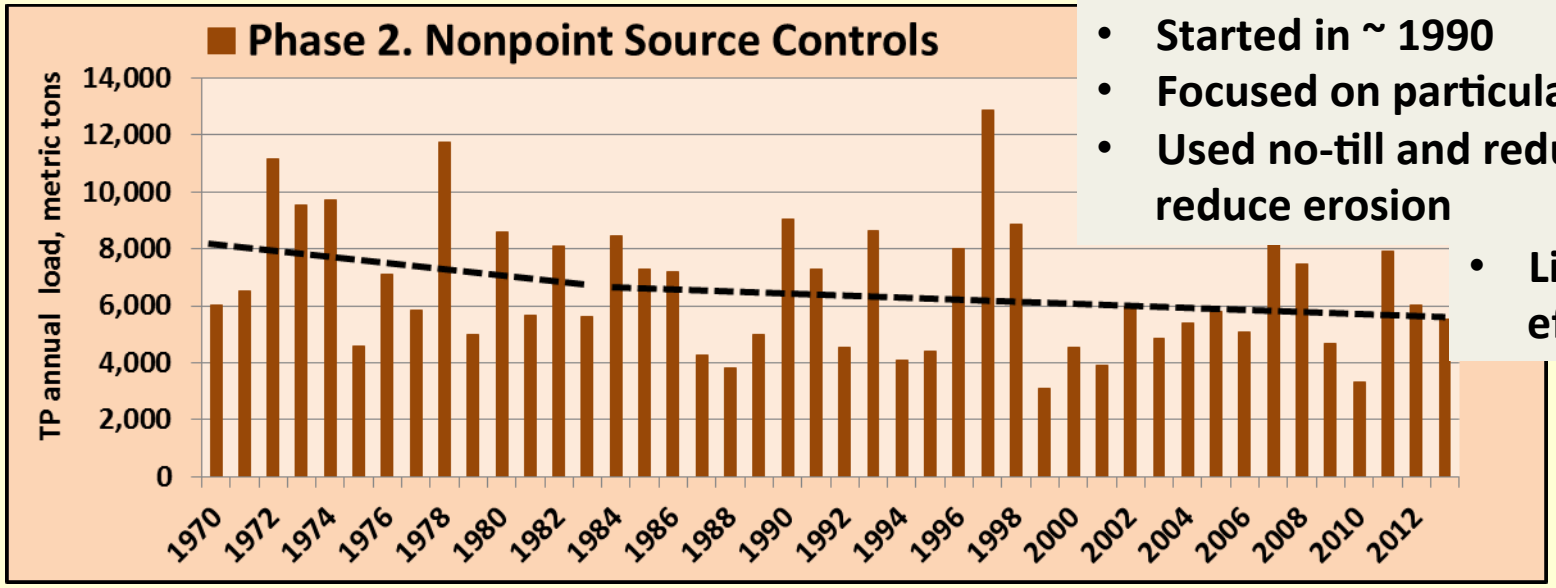


1. Target load first met in 1981 – a year with low nonpoint source loads.
2. A 1983 supplement of Annex 3 of the 1978 Great Lakes Water Quality Agreement called for an additional 2,000 metric ton reduction in TP loads.
3. This led to the onset of agricultural nonpoint control programs.

Lake Erie Phosphorus Control Programs, Phases 1 & 2



- P removal at sewage treatment plants, 1 mg/L effluent limit
- Detergent phosphorus bans
- Started in late 1960s
- Completed by early 1980s
- Very effective

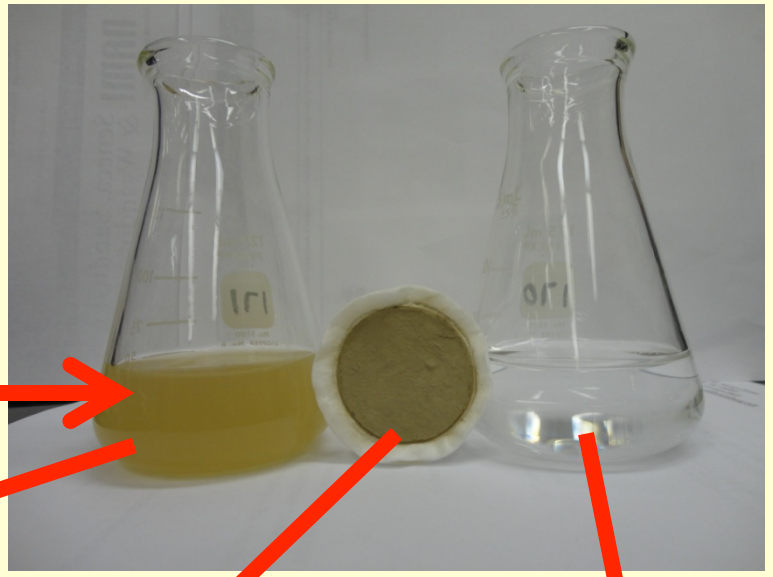


- Started in ~ 1990
- Focused on particulate P
- Used no-till and reduced till to reduce erosion
- Limited effectiveness

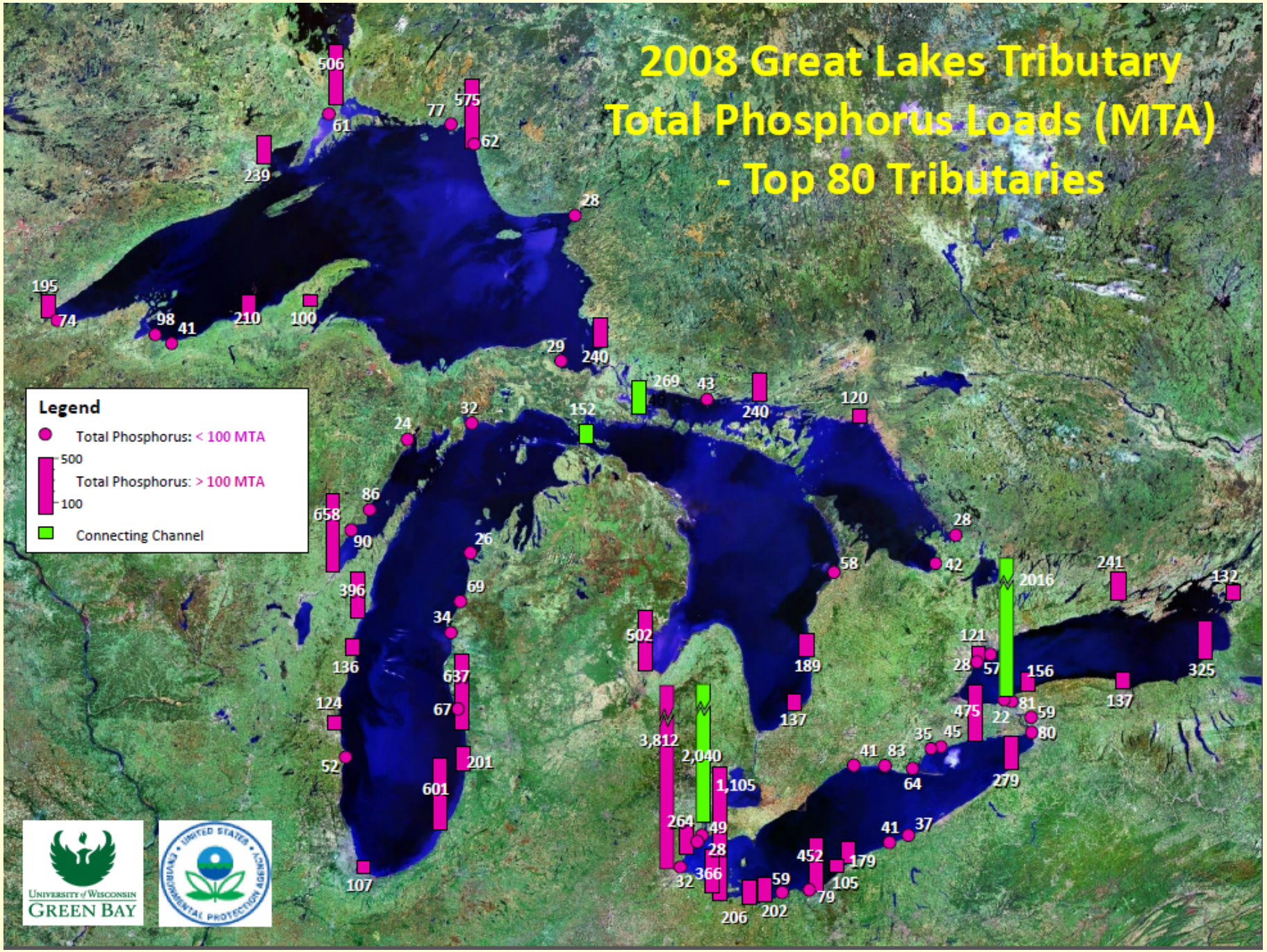
Re-eutrophication cannot be attributed to increased TP loading to Lake Erie

Zebra Mussels
Climate Change
Detroit
What happened?
Lawn Chemicals
Dissolved P loads
Combined Sewers
Dish Washer Detergents

What is “dissolved phosphorus”?



Total Phosphorus	=	Particulate Phosphorus	+	Dissolved Phosphorus
Measure		Calculate		Measure
Availability to algae		25% Bioavailable		100% Bioavailable


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
32
24
86
658
90
26
28
58
42
2016
241
132
396
69
34
502
189
121
28
57
156
325
136
637
67
137
475
22
81
59
80
124
35
45
137
3,812
2,040
41
83
64
279
52
201
1,105
601
264
49
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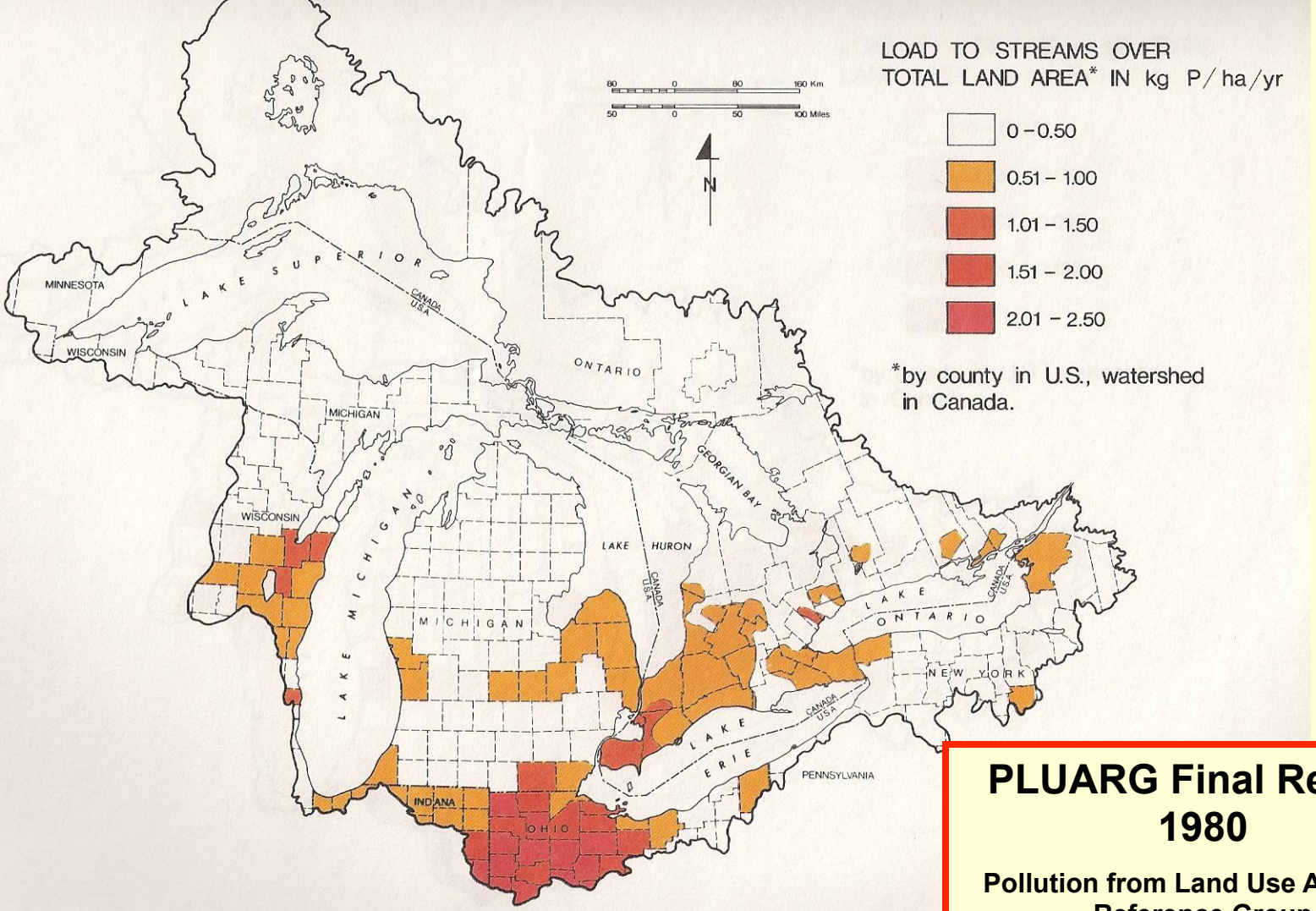
79
107
206
202
University of Wisconsin
GREEN BAY
United States Environmental Protection Agency

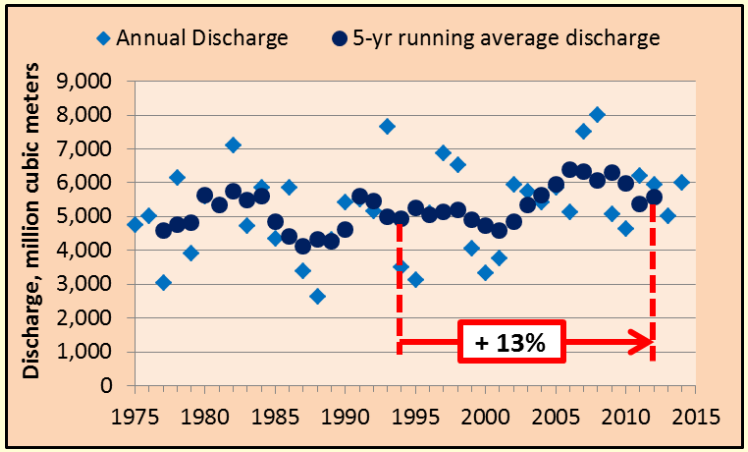


PLUARG Final Report, 1980

Pollution from Land Use Activities Reference Group

FIGURE 1. LOCATIONS OF ESTIMATED AGRICULTURAL CONTRIBUTIONS OF TOTAL PHOSPHORUS TO STREAM LOADINGS (by extrapolation, 1976 data).

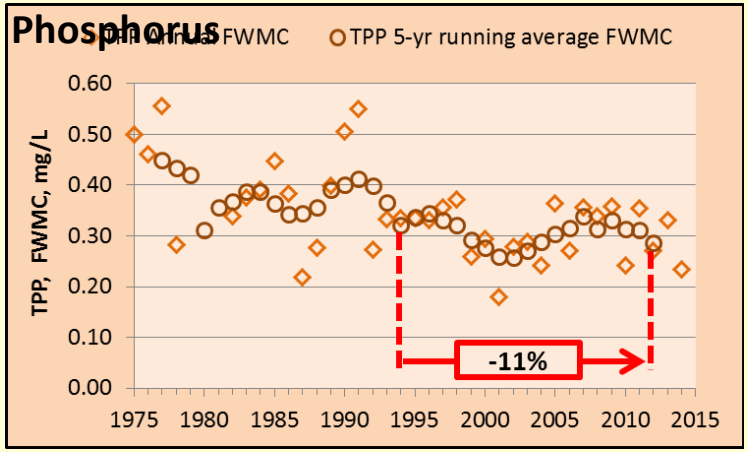
Maumee River at Waterville Particulate and Dissolved Phosphorus, Annual FWMCs and Loads, 1975 -2014



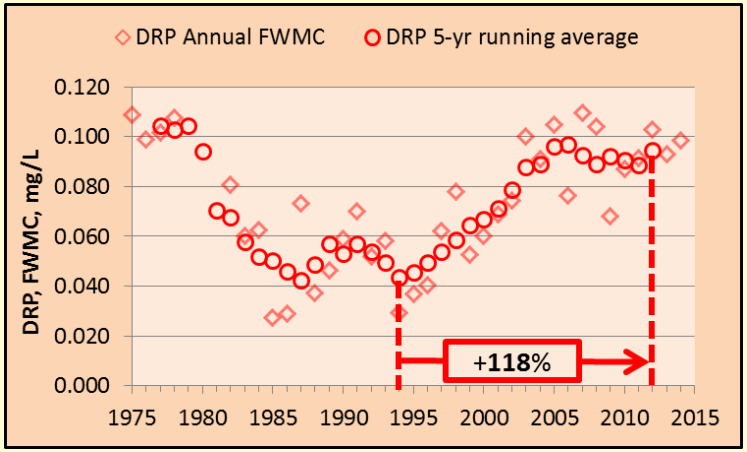
Annual and 5-year running average of annual discharges

% change between the 1992-1996 average and the 2010-2014 average

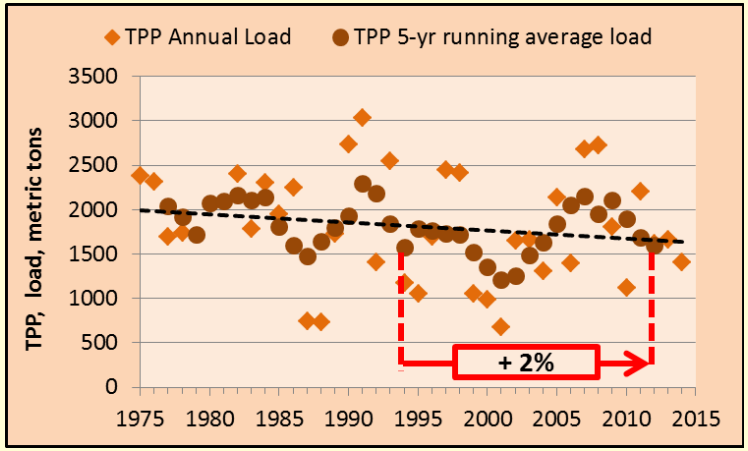
Total Particulate Phosphorus



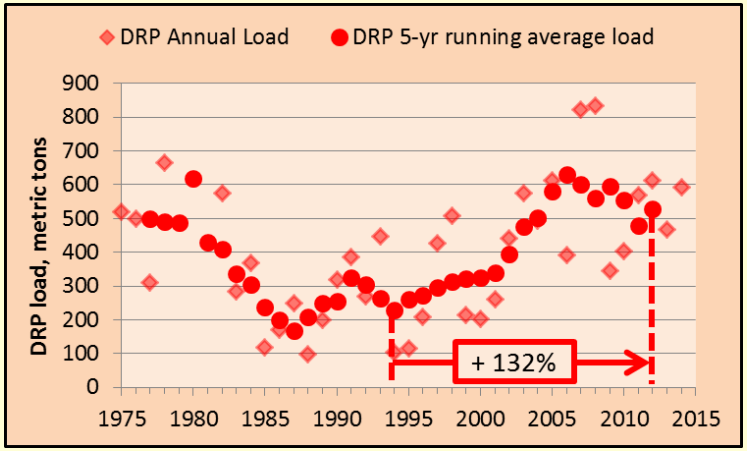
Dissolved Reactive Phosphorus



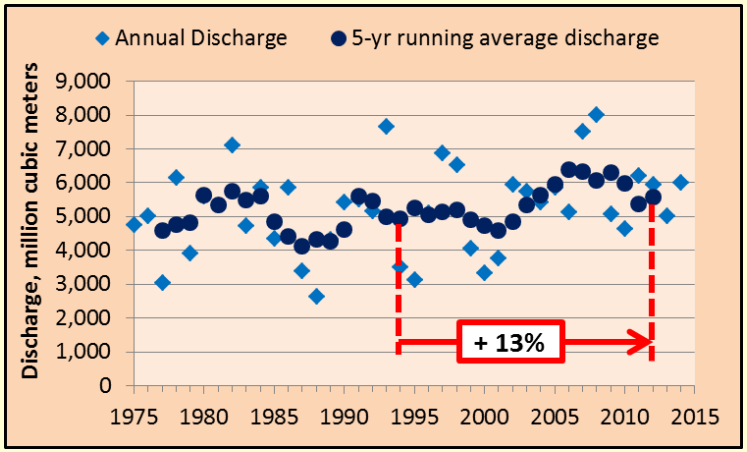
Annual FWMCs



Annual Loads



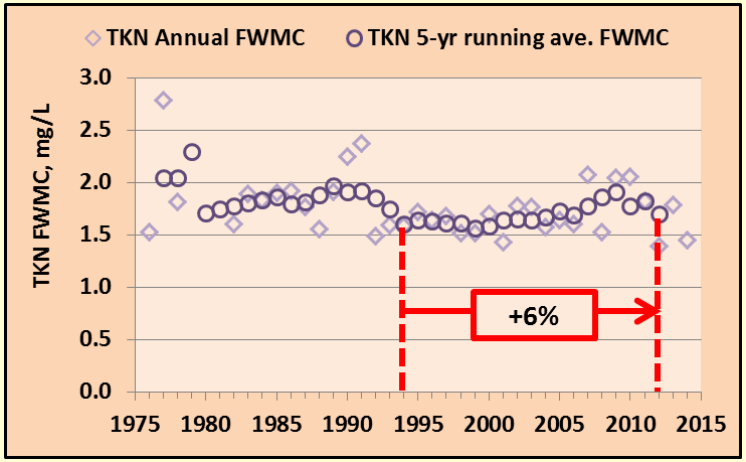
Maumee River at Waterville, Total Kjeldahl Nitrogen and Nitrate-N FWMCs and Loads, 1975 -2014



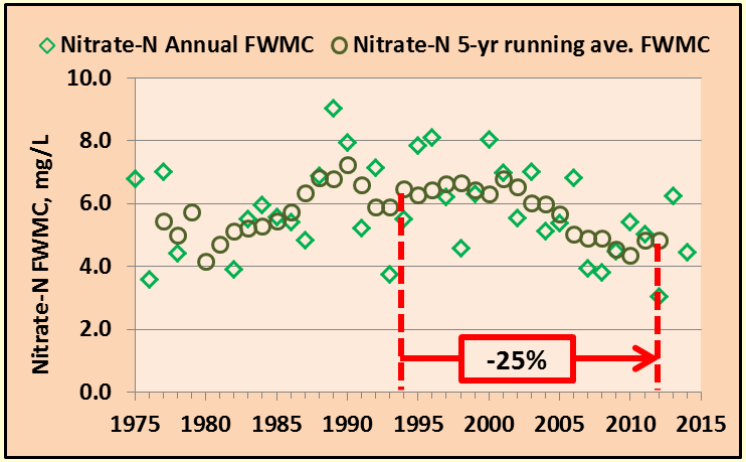
Annual and 5-year running average of annual discharges

% change between the 1992-1996 average and the 2010-2014 average

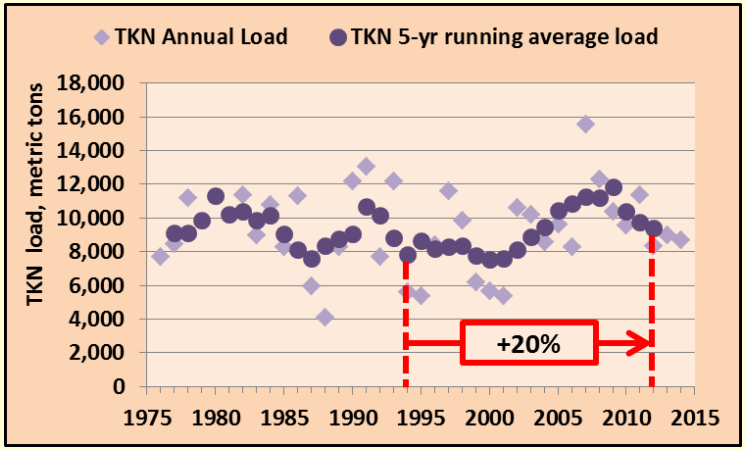
Total Kjeldahl Nitrogen (TKN)



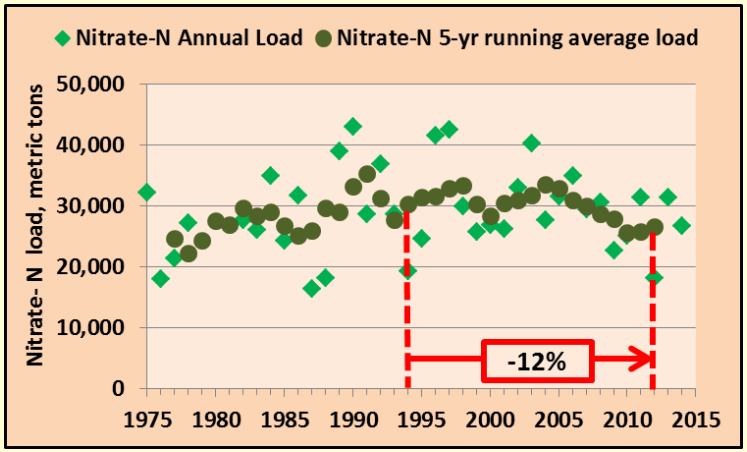
Nitrate-Nitrogen



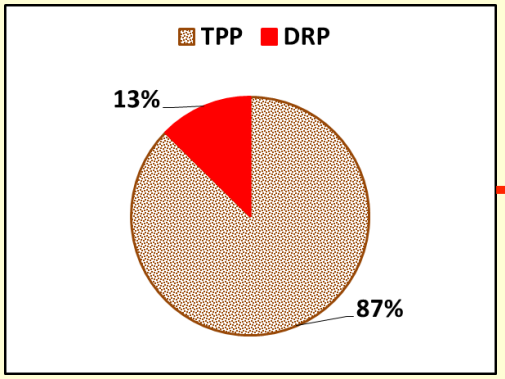
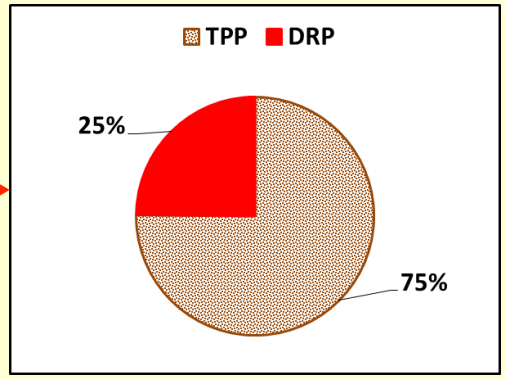
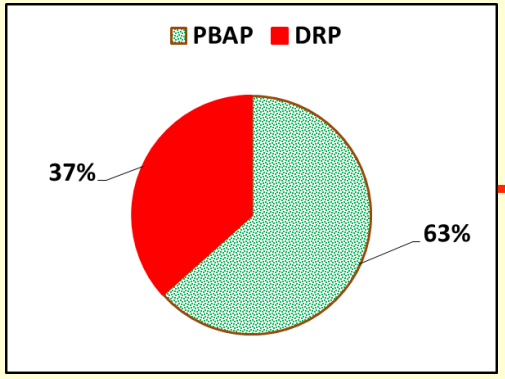
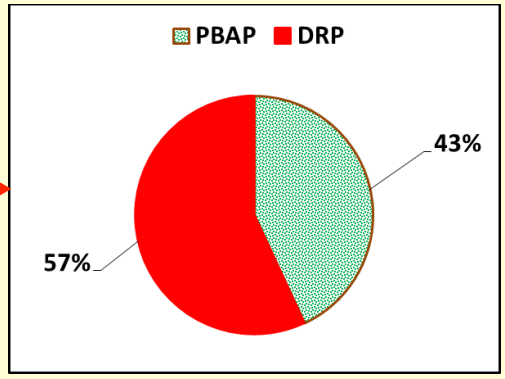
Annual FWMCs



Annual Loads



How important is DRP loading relative to total phosphorus and total bioavailable phosphorus loading?

	1992-96 Average		2010-14 Average
Total Phosphorus Loading		+ 18%	
Bioavailable Phosphorus Loading **PBAP = 25% TPP**		+ 50%	

DRP can be even more important, depending on another aspect of bioavailability.

Two Aspects of Bioavailability

	Chemical Bioavailability	Positional Bioavailability
Total Particulate Phosphorus (TPP)	25-30%	???
Dissolved Reactive Phosphorus (DRP)	100%	100%

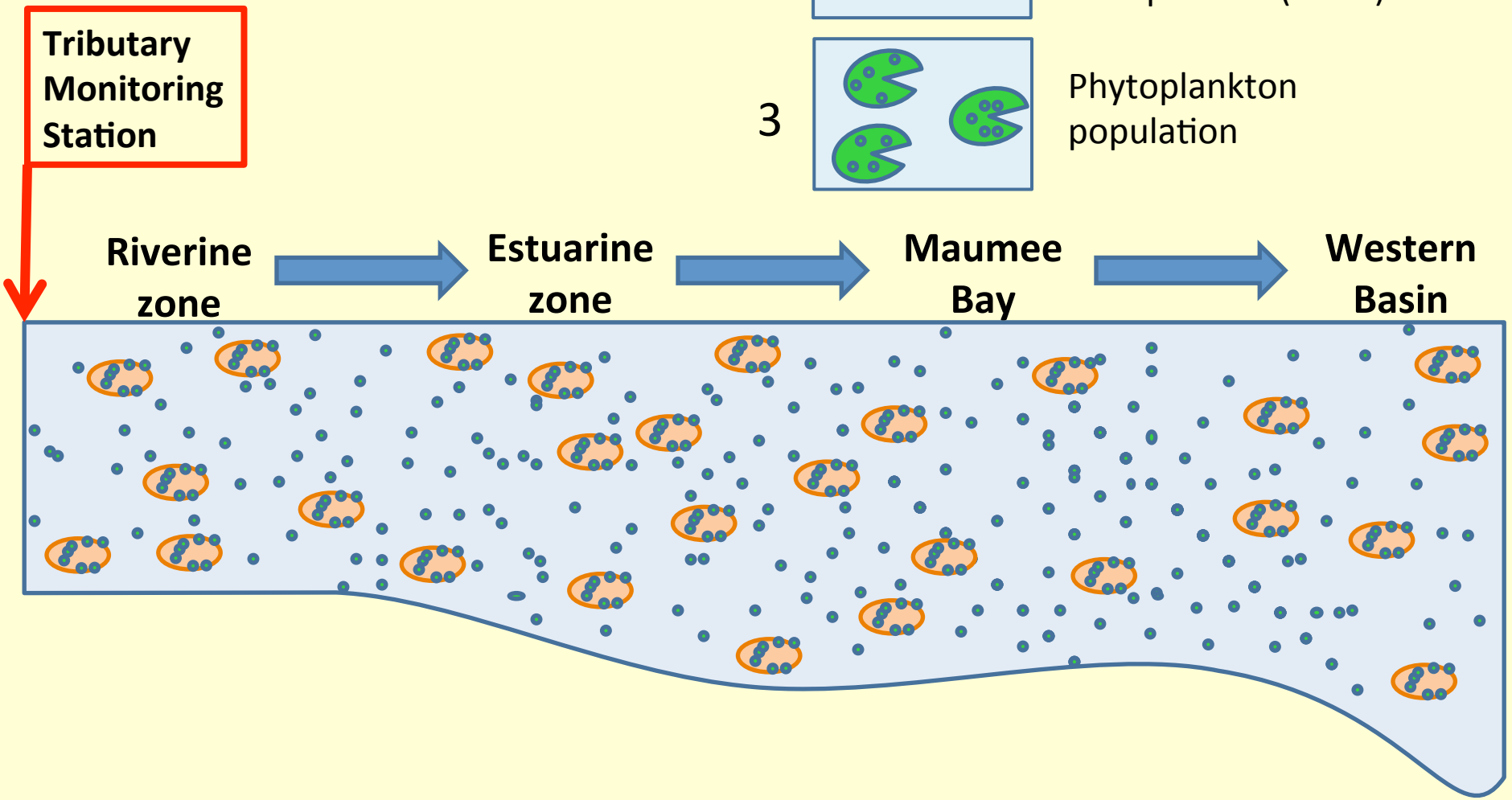
On average, 85% of the external phosphorus loading to Lake Erie moves into sediment sinks in the lake. Only 15% moves on into Lake Ontario via the Niagara River.

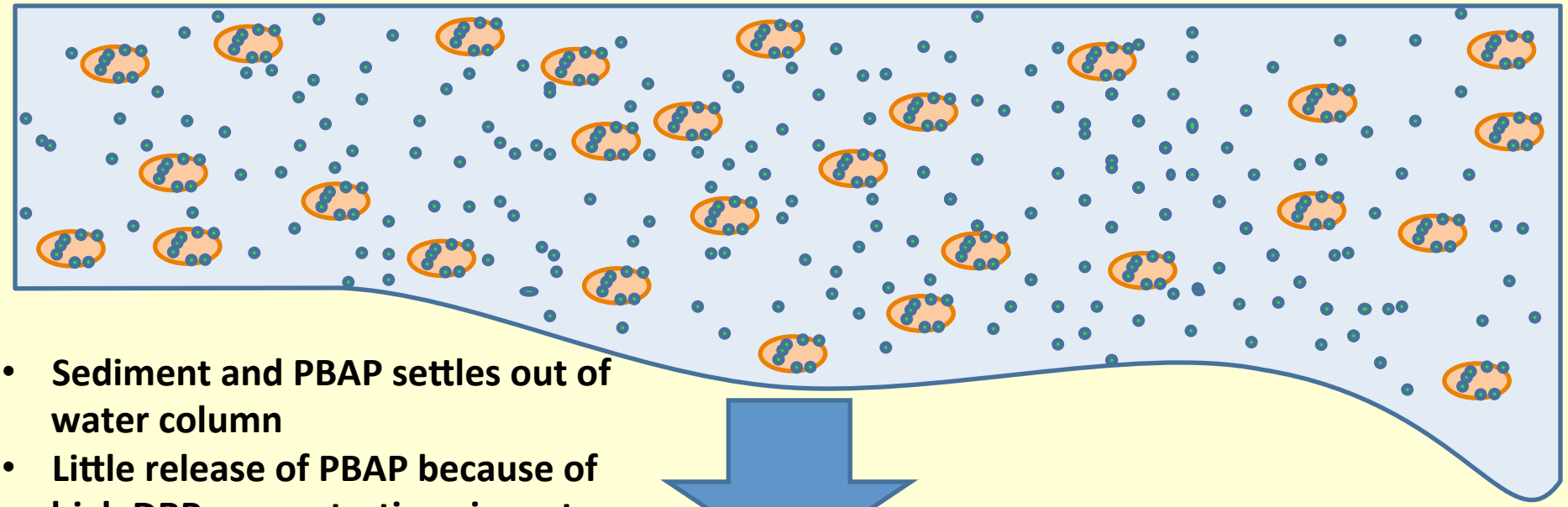
During large storms, Maumee River storm water displaces pre-existing river and bay water and moves into the nearshore zones of the Western Basin.

1 DRP - ortho-phosphate ions in solution

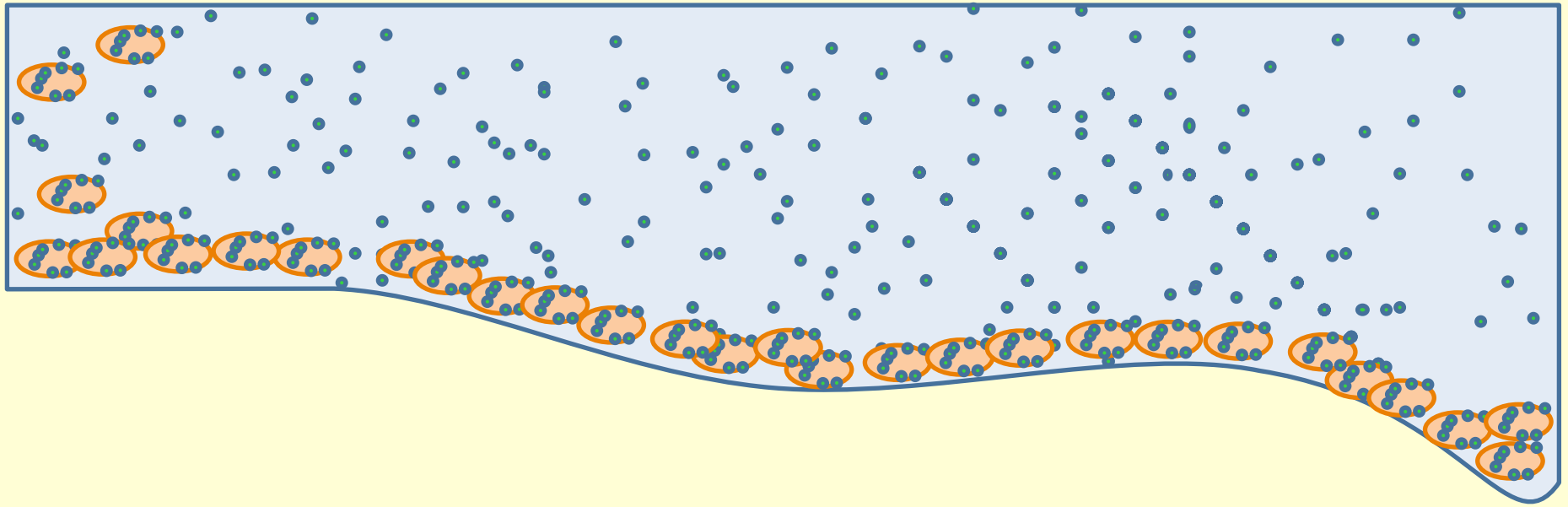
2 Clay particles with attached bioavailable phosphate ions in suspension (PBAP)

3 Phytoplankton population

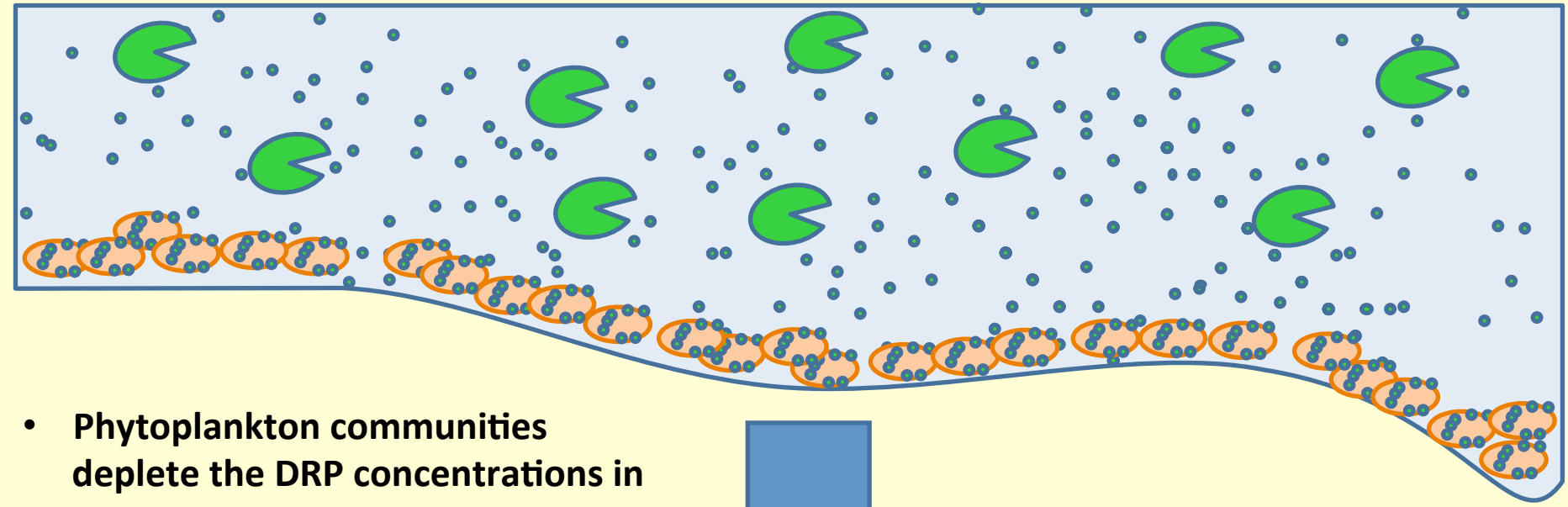


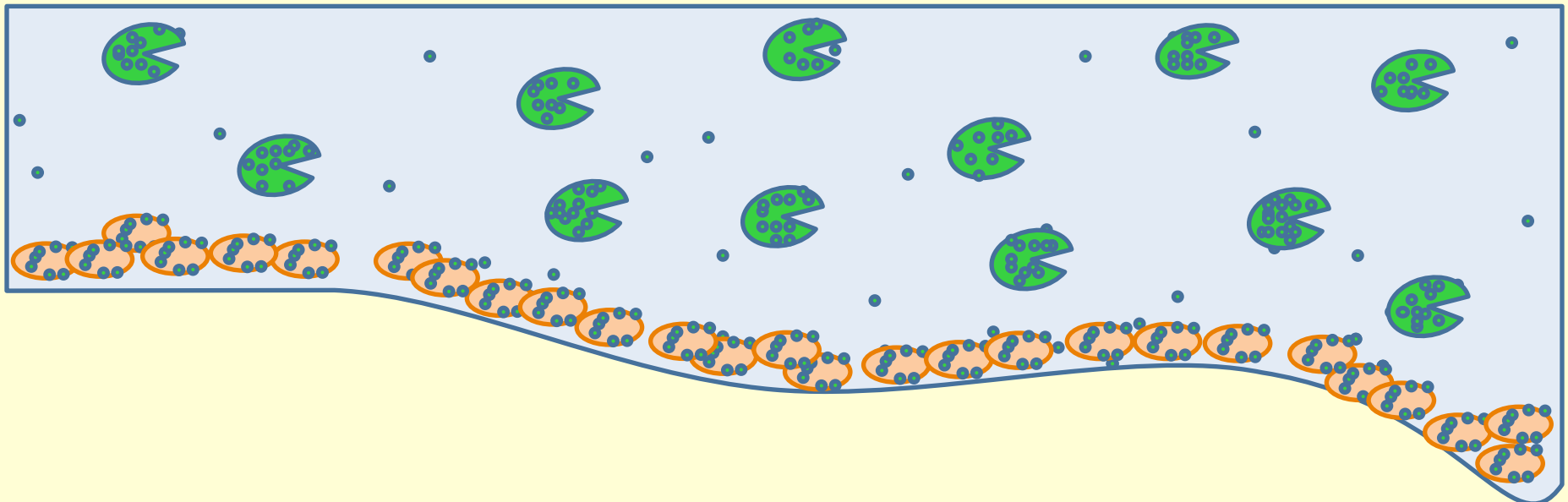


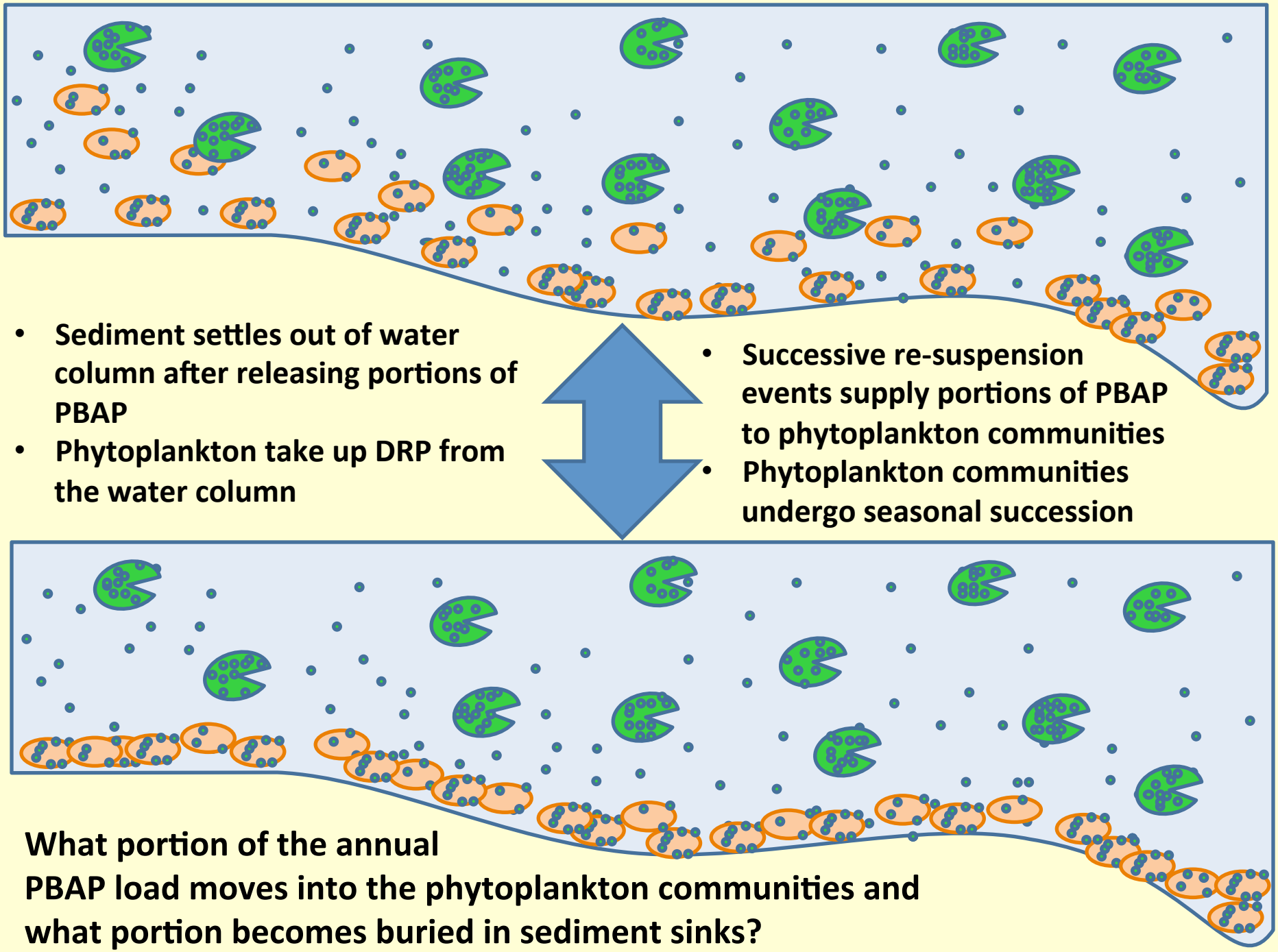
- **Sediment and PBAP settles out of water column**
- **Little release of PBAP because of high DRP concentrations in water column.**



- **Phytoplankton communities deplete the DRP concentrations in the water column.**



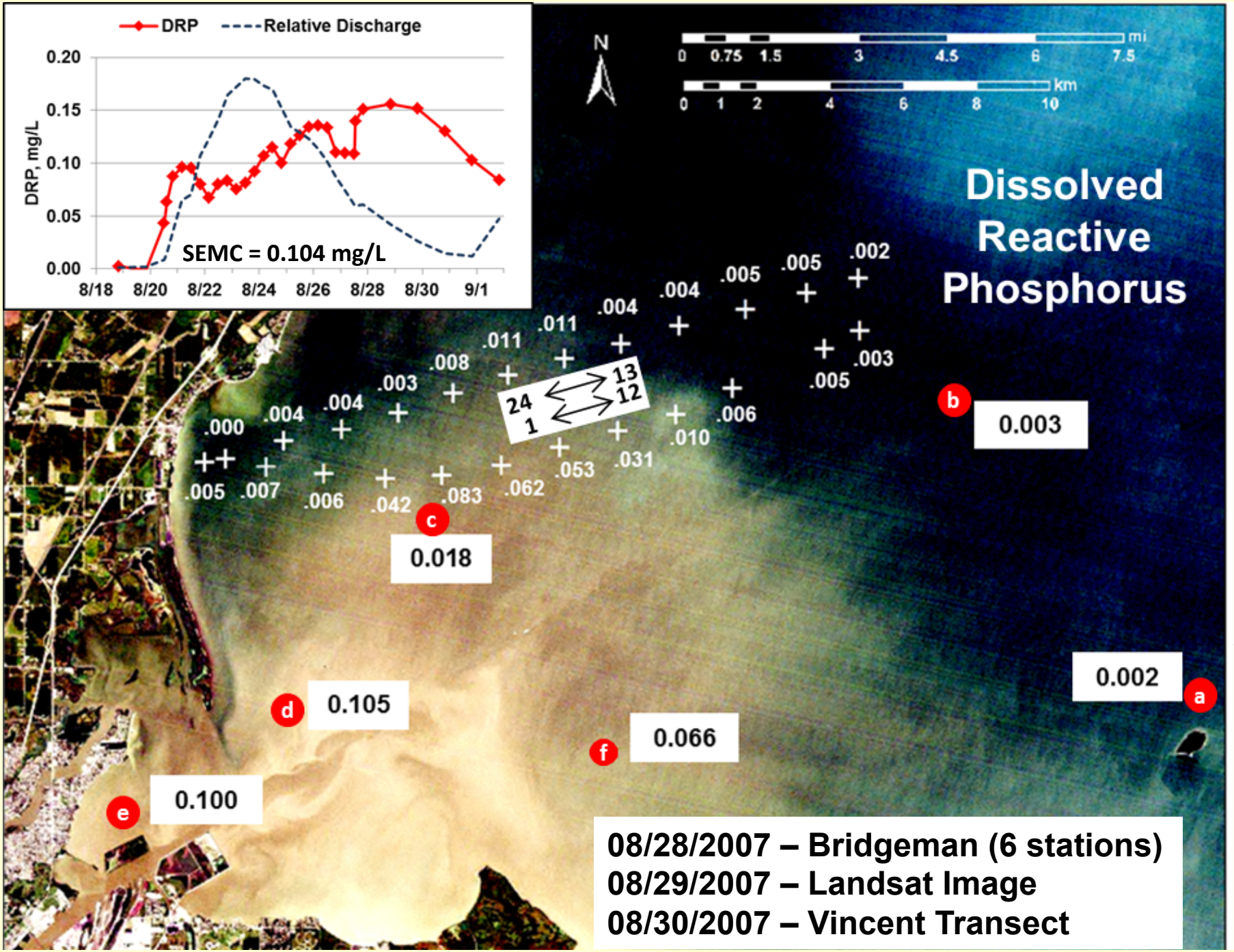


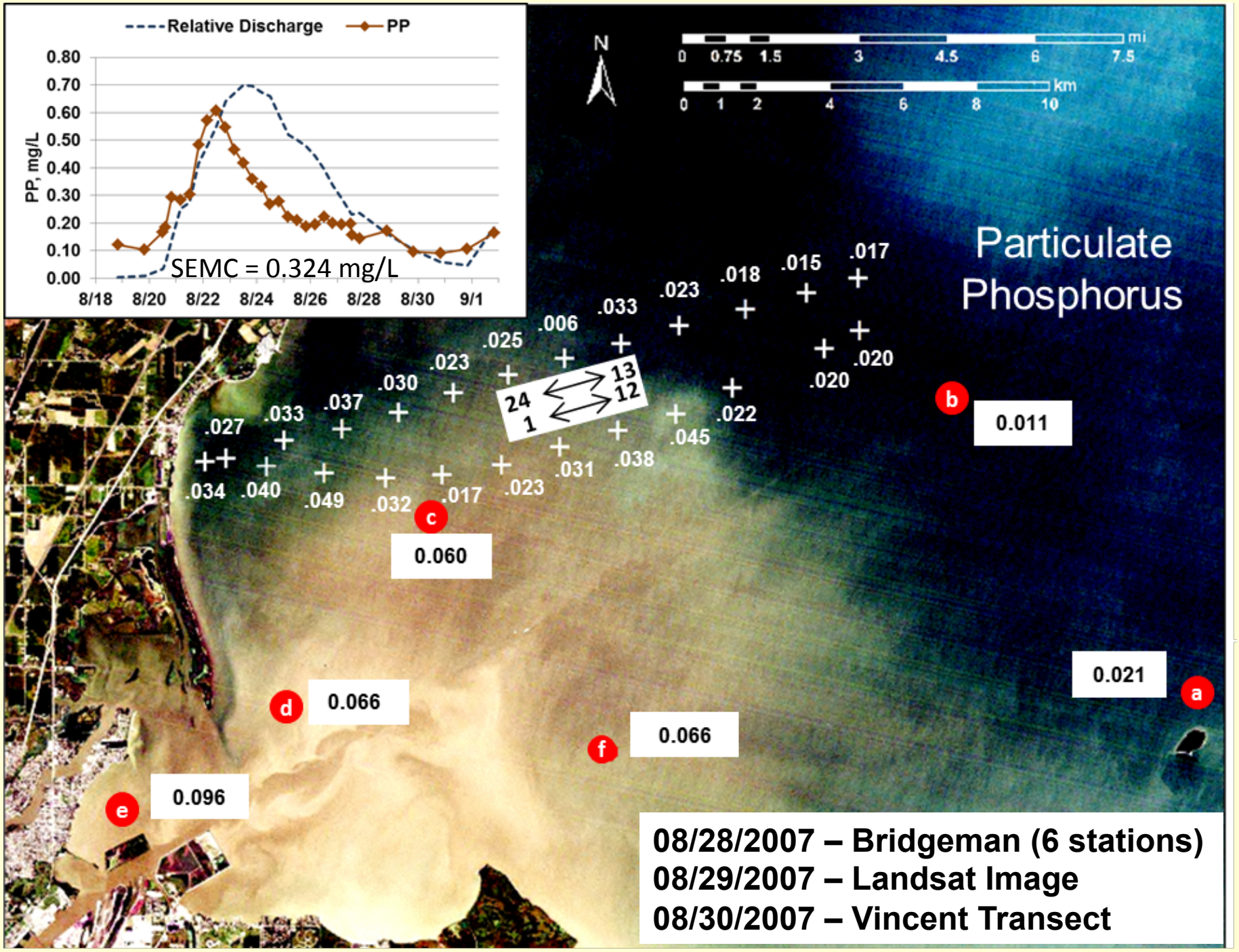


- Sediment settles out of water column after releasing portions of PBAP
- Phytoplankton take up DRP from the water column

- Successive re-suspension events supply portions of PBAP to phytoplankton communities
- Phytoplankton communities undergo seasonal succession

What portion of the annual PBAP load moves into the phytoplankton communities and what portion becomes buried in sediment sinks?


DRP
Relative Discharge
DRP, mg/L
0.20
0.15
0.10
0.05
0.00
8/18
8/20
8/22
8/24
8/26
8/28
8/30
9/1
SEMC = 0.104 mg/L
N
0 0.75 1.5 3 4.5 6 7.5 mi
0 1 2 4 6 8 10 km
Dissolved Reactive Phosphorus
.000
.004
.004
.003
.008
.011
.011
.004
.004
.005
.005
.002
.005
.007
.006
.042
.083
.062
.053
.031
.010
.006
.005
.003
24
1
13
12
b
0.003
c
0.018
0.002
a
d
0.105
f
0.066
e
0.100
08/28/2007 – Bridgeman (6 stations)
08/29/2007 – Landsat Image
08/30/2007 – Vincent Transect


Relative Discharge
PP
PP, mg/L
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
8/18
8/20
8/22
8/24
8/26
8/28
8/30
9/1
SEMC = 0.324 mg/L
N
0 0.75 1.5 3 4.5 6 7.5 mi
0 1 2 4 6 8 10 km
Particulate Phosphorus
.017
.015
.018
.023
.033
.006
.025
.023
.030
.037
.033
.027
.034
.040
.049
.032
.017
.023
.031
.038
.045
.022
.020
.020
24
1
13
12
b
0.011
c
0.060
0.021
a
d
0.066
f
0.066
e
0.096
08/28/2007 – Bridgeman (6 stations)
08/29/2007 – Landsat Image
08/30/2007 – Vincent Transect

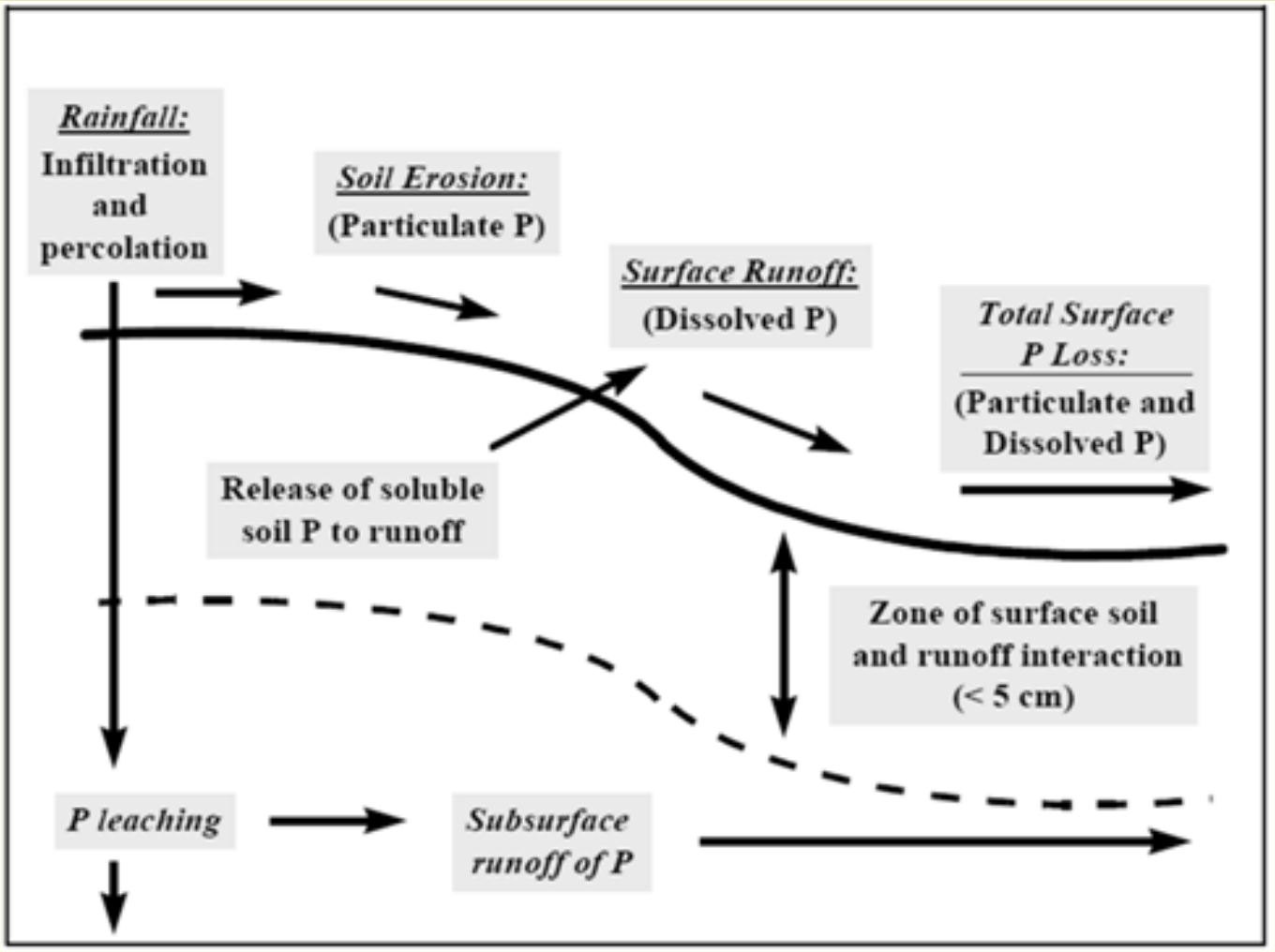
Two Aspects of Bioavailability

	Chemical Bioavailability	Positional Bioavailability
Total Particulate Phosphorus (TPP)	25-30%	A research need linked to issues of internal loading
Dissolved Reactive Phosphorus (DRP)	100%	100%

A management question -- How do we lower the loading of DRP from cropland into Lake Erie?

How does phosphorus move from cropland to streams?

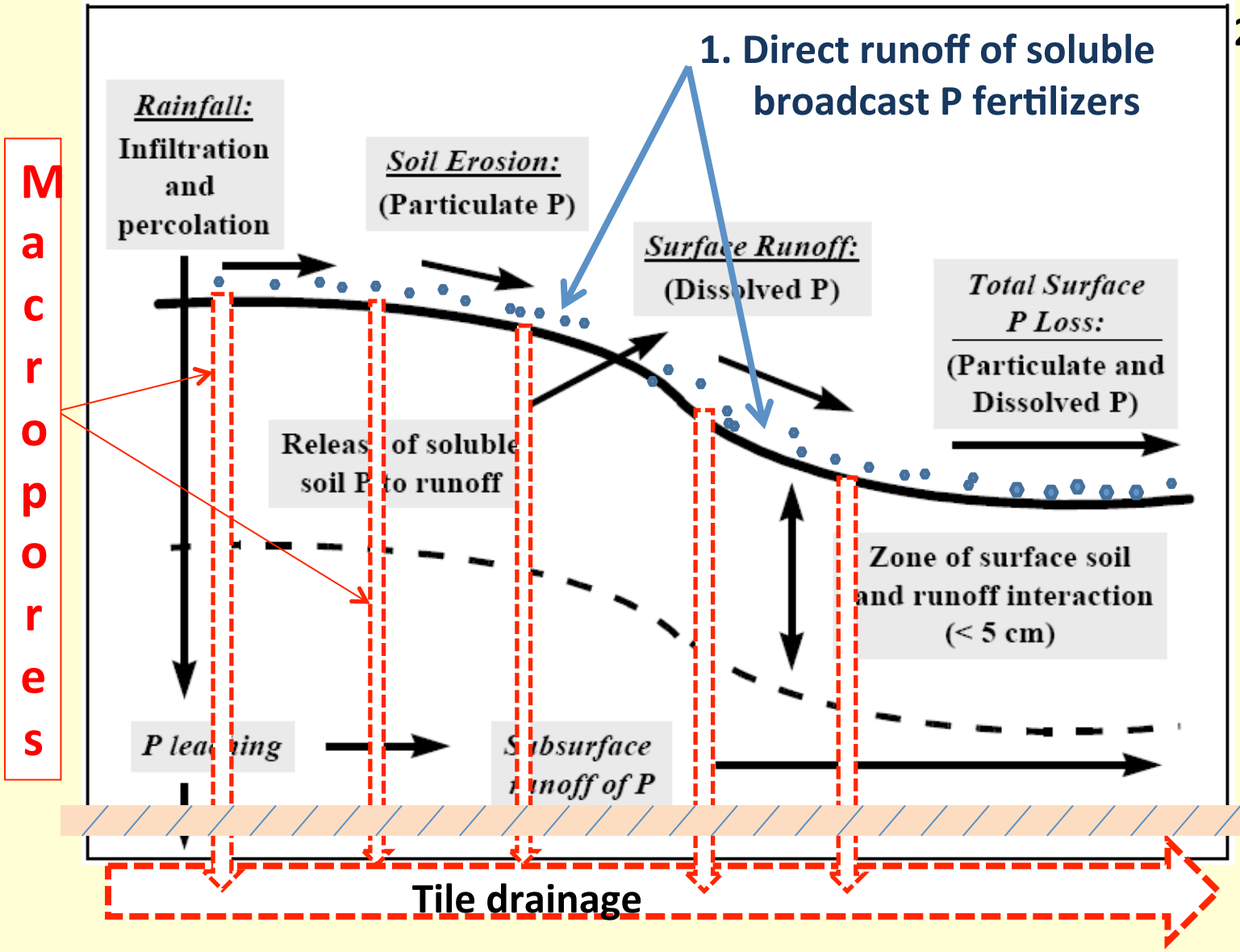
A diagram from the 1970s …



1. Phosphorus movement dominated by surface runoff of particulate and dissolved phosphorus.

2. Minimal subsurface movement of phosphorus.

Current view of P movement from cropland to streams



2. Macropores convey surface runoff to tile systems, bypassing soil matrix.

Tile systems now known to convey large loads of DRP to streams.

Formerly thought to only convey nitrates.

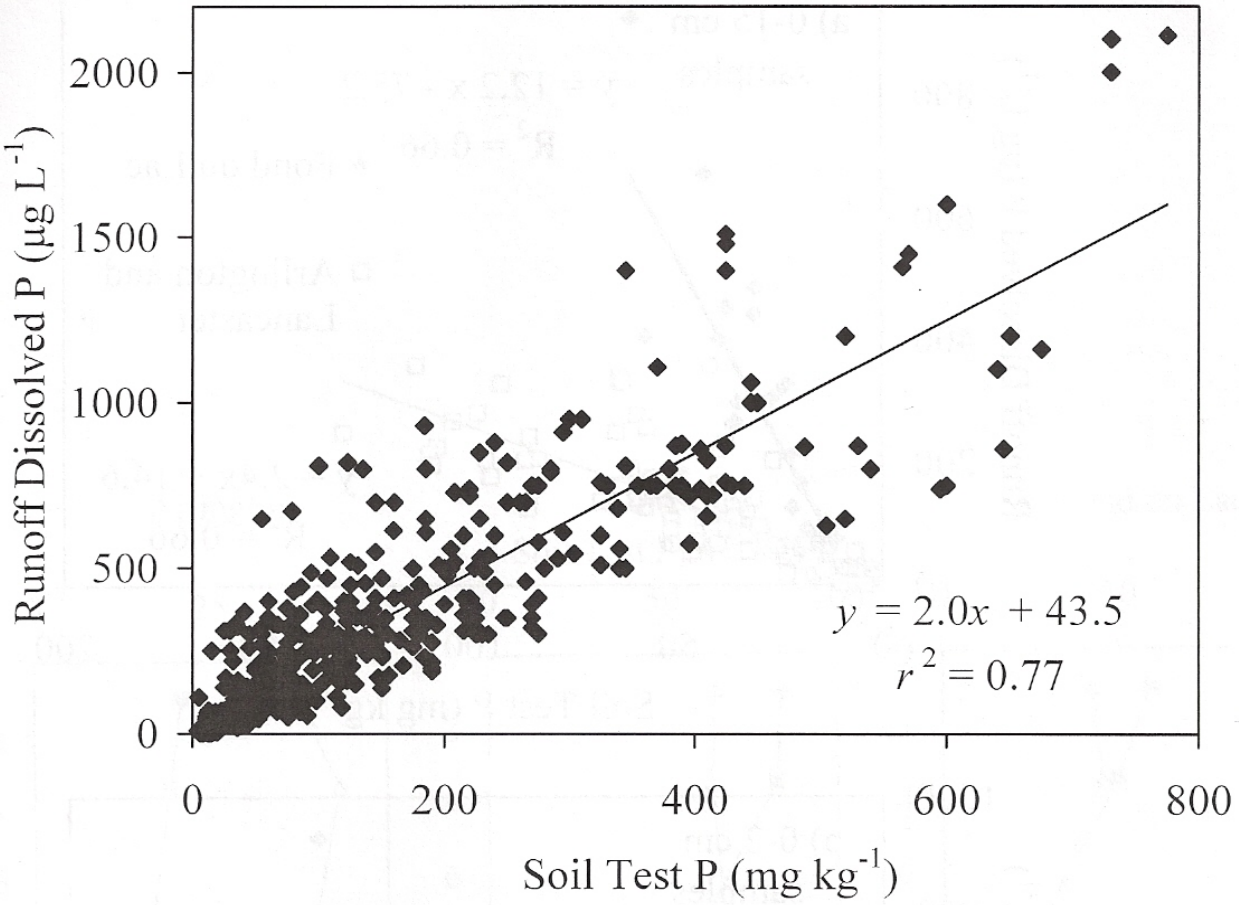
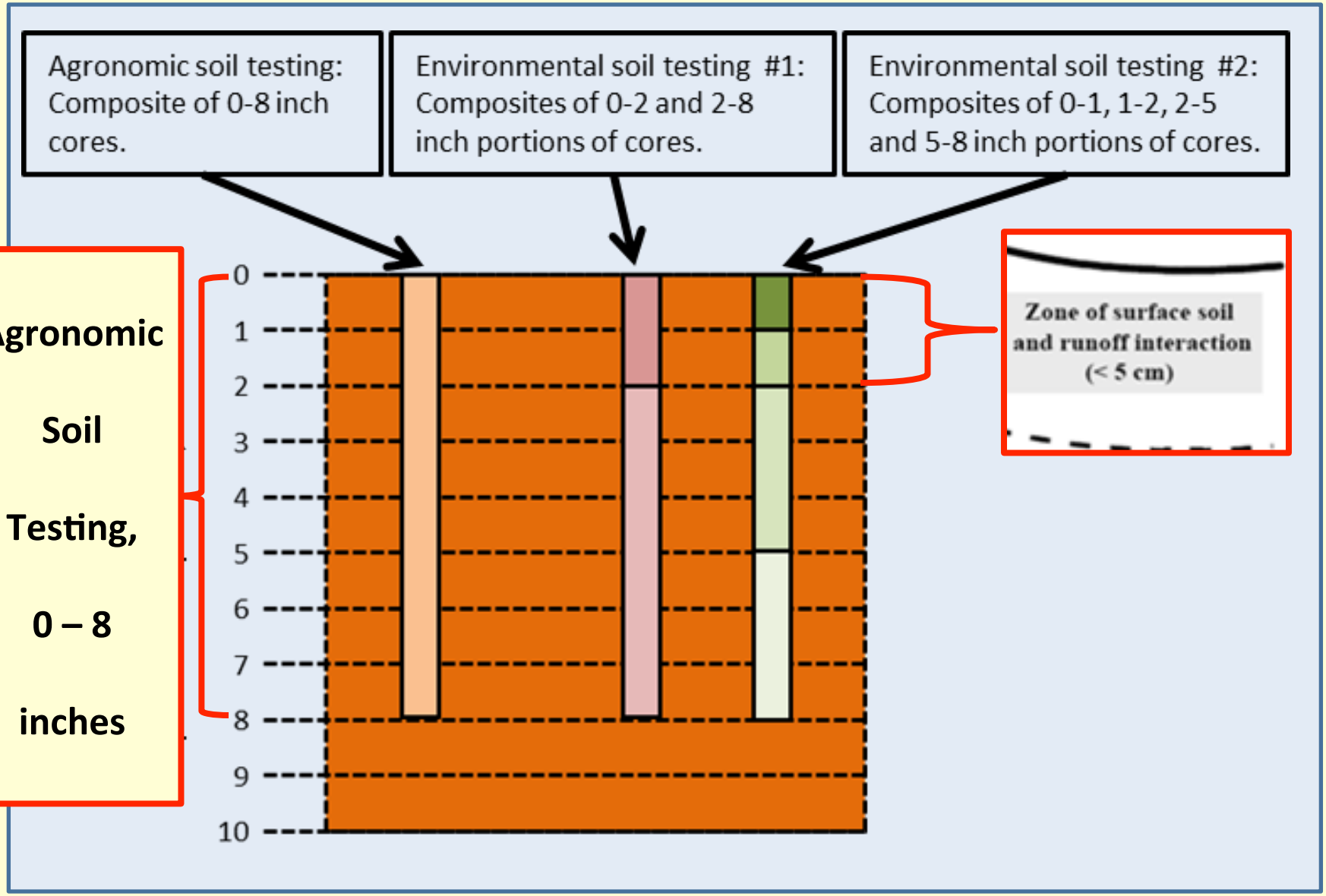
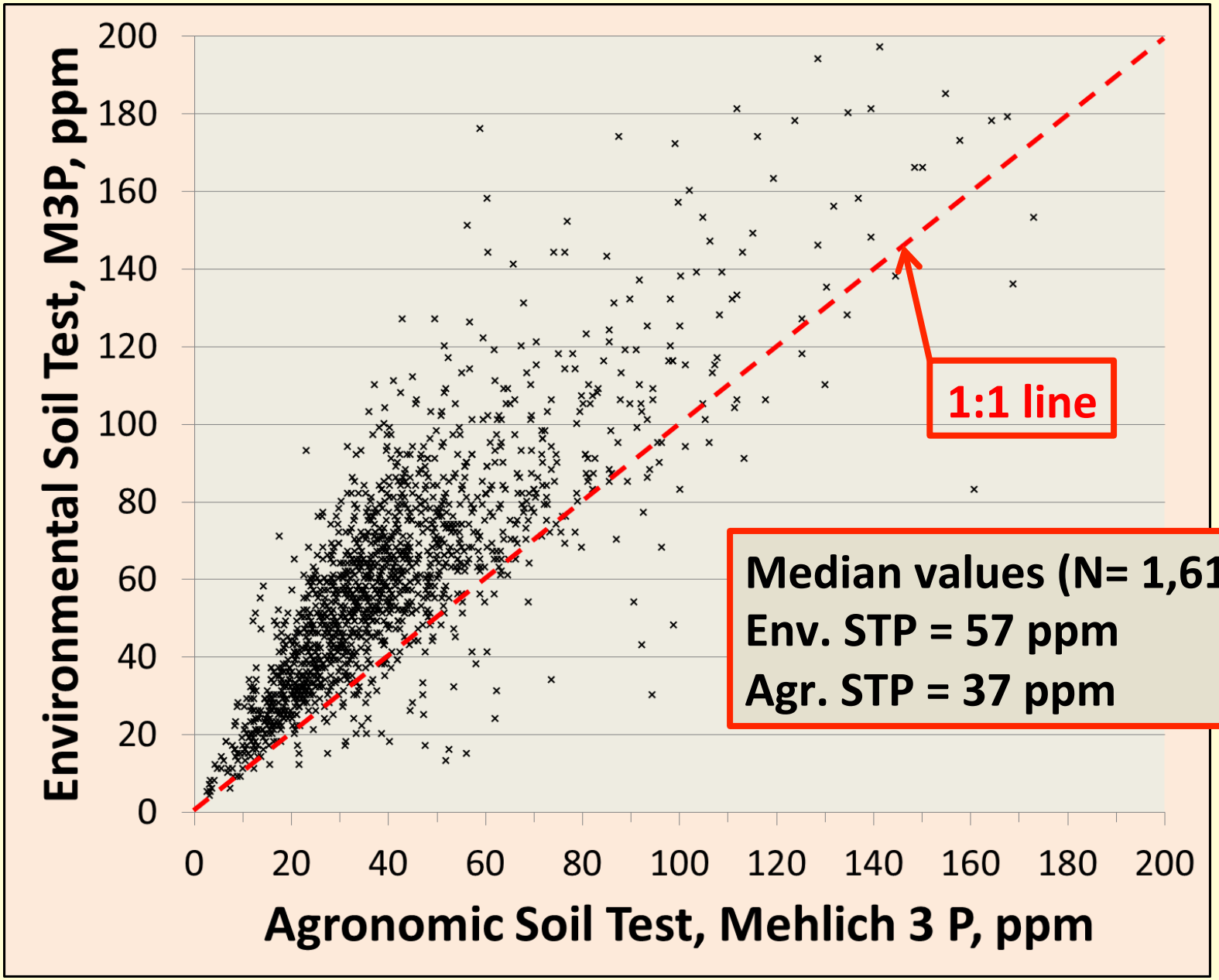


Fig. 6. The commonly observed linear relationship between soil-test P (Bray-1 and Mehlich-3) and dissolved P in runoff. Data are from a survey by Vadas et al. (2005) and represent 14 independent studies and 24 soil types. Data are a combination of samples taken from 0-15 or 0-20 cm in well-tilled soils and from 0-5 cm or less in P stratified soils, showing a consistent relationship between the two sampling depths.

Sandusky Watershed Stratified Soil Testing Program, supported by the Great Lakes Protection Fund

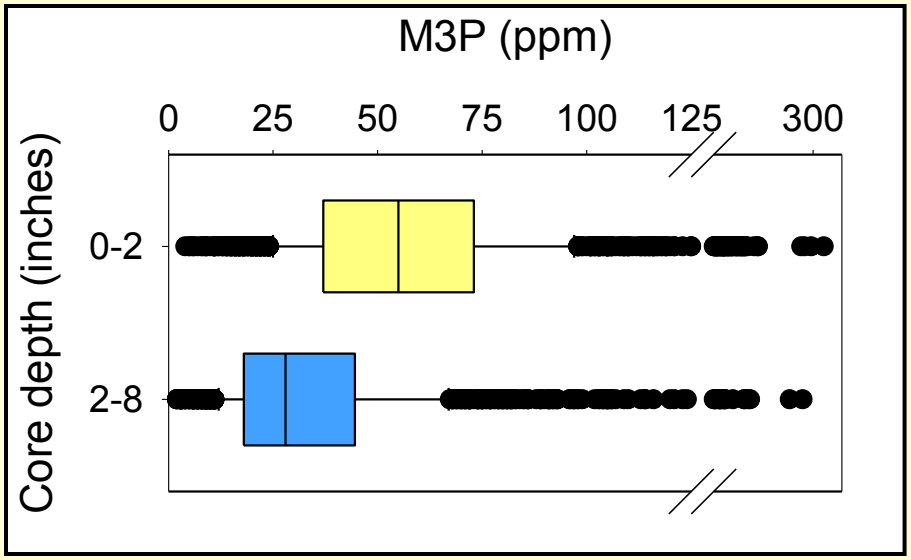


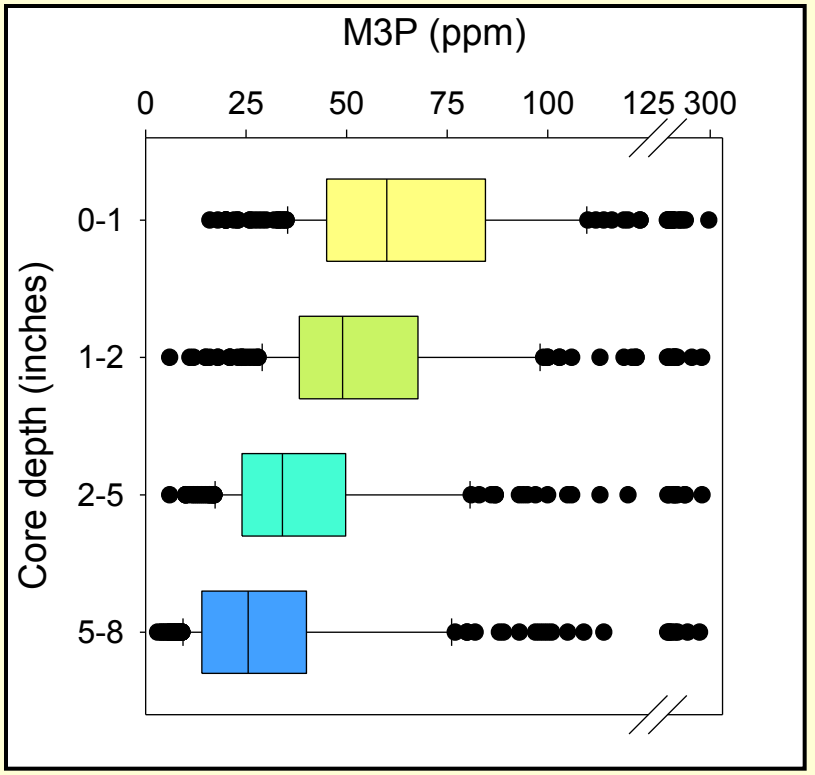
0-2 inch STP



Environmental Soil Test ≠ Agronomic Soil Test

The extent of P stratification





What factors affect the P Soil Test levels in the surficial soils of cropland?

Factors contributing to phosphorus stratification

Tillage Management

- Inversion tillage (moldboard plow)
- Non-inversion tillage (no-till) (vertical tillage)

Nutrient Management, 4-Rs

- Right amount of P fertilizer
- Right place
  - broadcast
  - banded
  - injected
- Right form
  - soluble granular
  - less soluble granular
  - liquid (smaller amounts)
- Right time of application

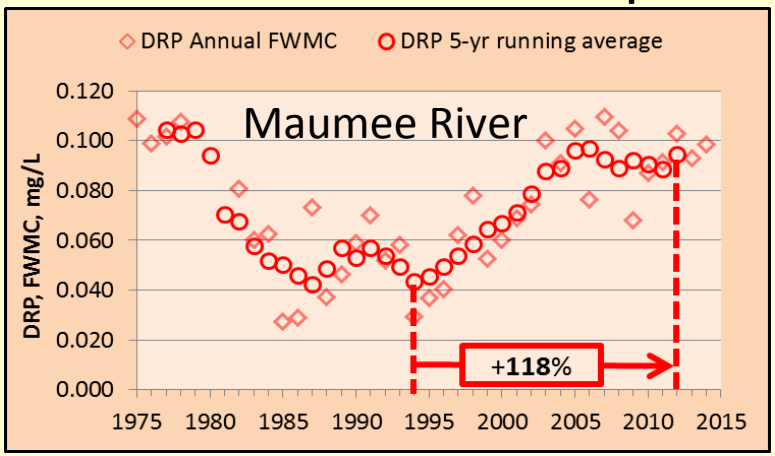
Crop Rotations/Winter Cover

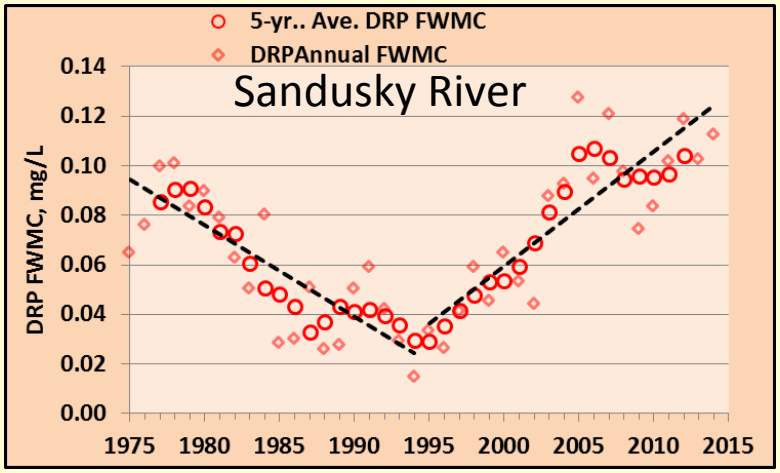
- Crops (including winter cover) move P from root zone to stems and leaves
- Breakdown of stems and leaves releases P at soil surface.

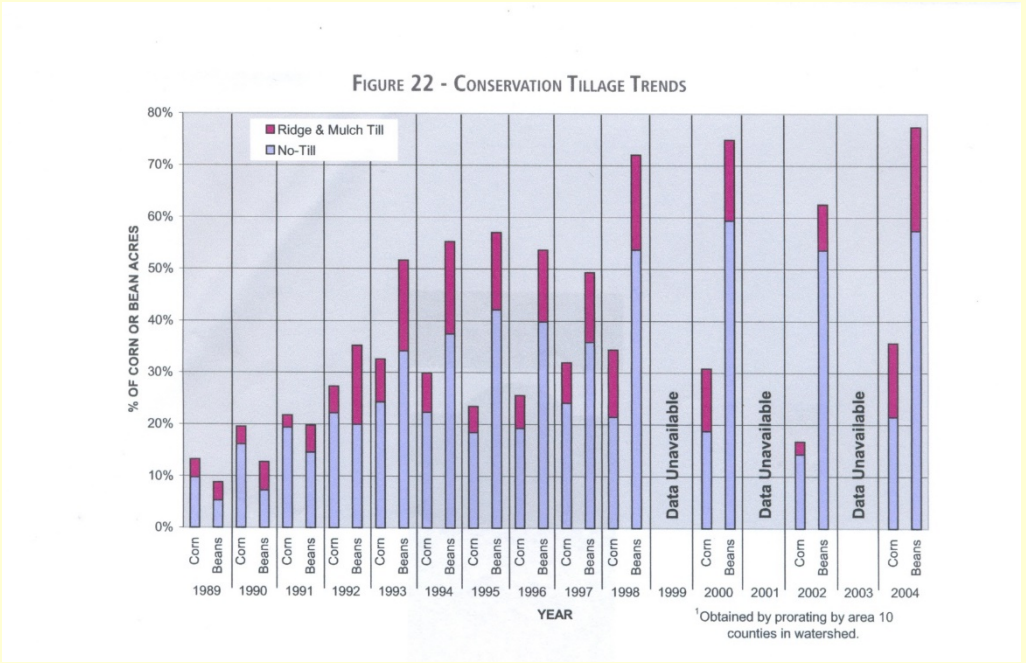
Soil Type

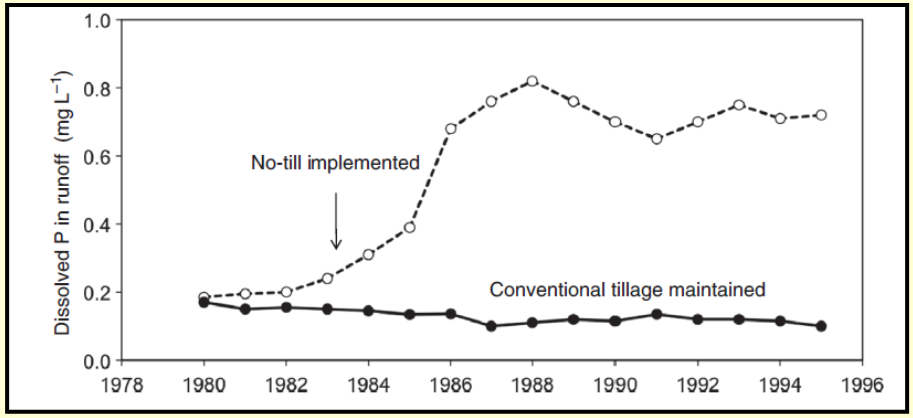
- High clay soils
- Sandier soils

Dissolved Reactive Phosphorus









From Kleinman et al. 2011

Hypothesis: The build-up of P soil test levels in the upper soil strata with the onset of non-inversion tillage in the Lake Erie Basin offer the best explanation for the increasing DRP FWMCs beginning in the mid-1990s and the related increases in DRP loading. We need to consider the related DRP management implications.

Lake Erie Phosphorus Control Programs – now planning for Phase 3 – includes reduction of DRP loading.

1. **Reduce P stratification and environmental soil test levels**

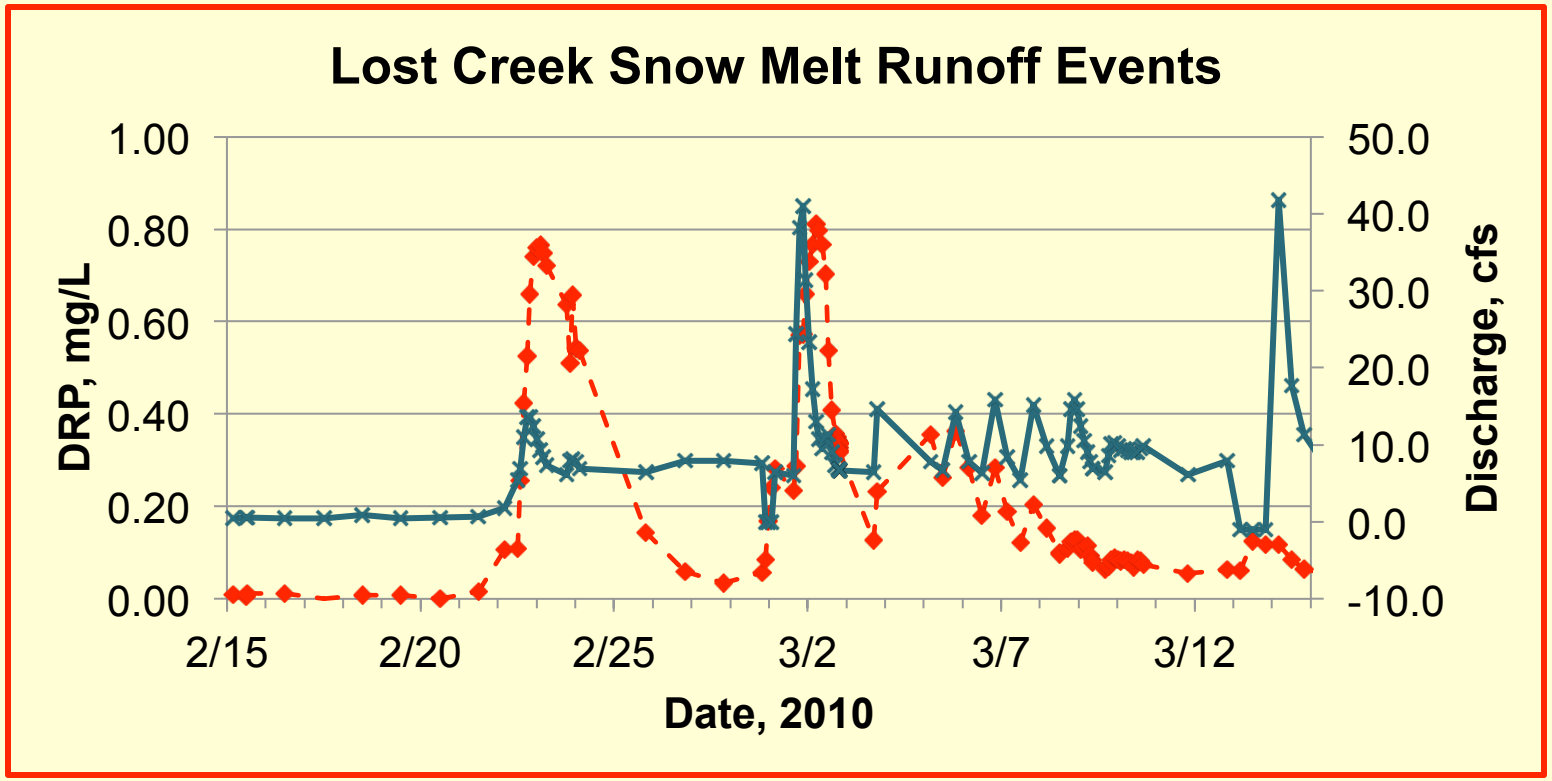
2. **Soil tilth management via no-till and use of cover crops**
   - increase soil matrix flow relative to macropore flow?
   - increase soil water holding capacity via increased organic matter
   - decrease surface runoff with high DRP concentrations
   - Increase nutrient availability

3. **Use of soil amendments**
   - Gypsum treatments

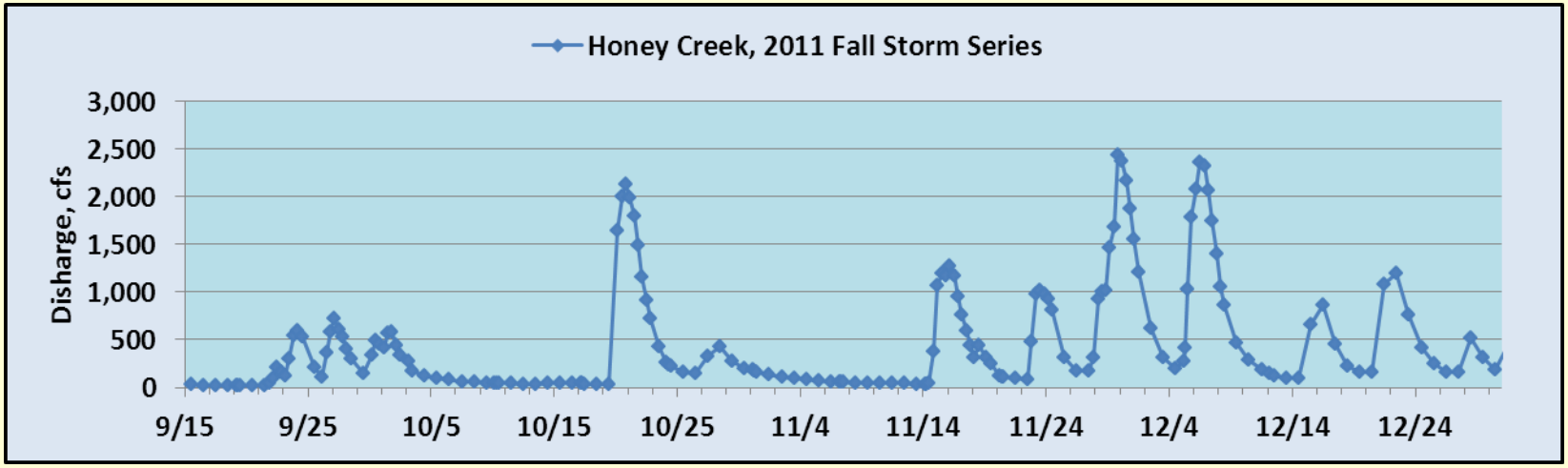
4. **Treatment to remove DRP along flow paths**
   - Blind inlets to tile systems
   - Treatment systems to remove DRP at tile outlets
   - Controlled drainage using tile risers
   - Strategically placed wetlands between cropland and streams or along streams
   - Stream channel modifications to increase instream processing of DRP

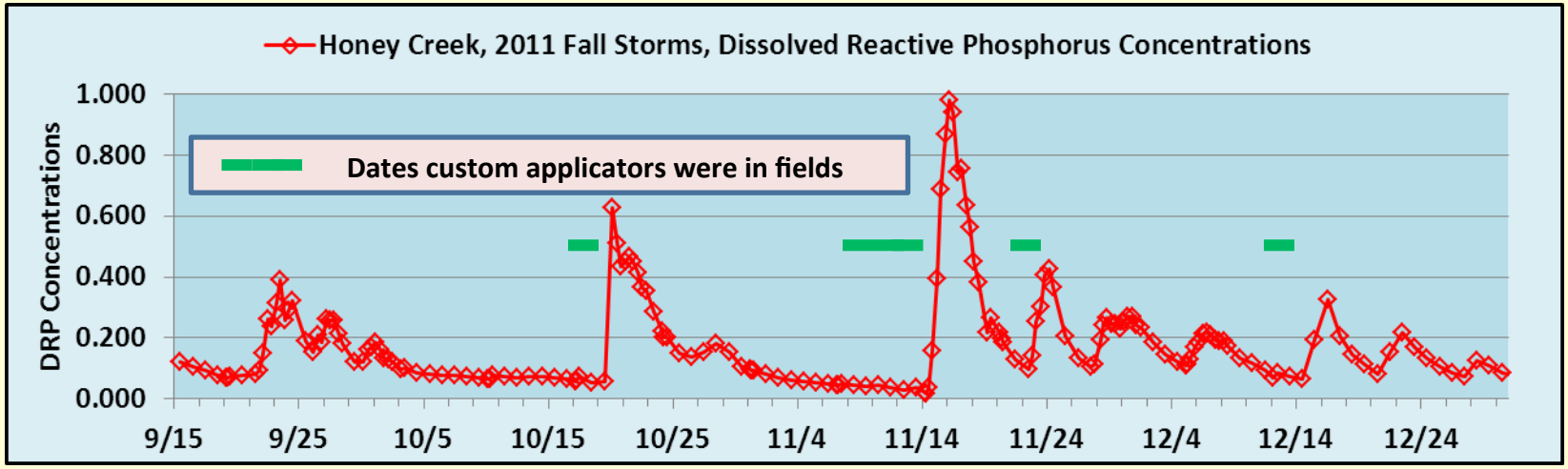
A major research question— What is the most effective and efficient combination of management practices to reduce DRP loading?

Fertilizer application on frozen ground



Fertilizer application just before precipitation





Timing of these kinds of loading events may be irrelevant to CHAB formation.

Fertilizer application rates versus watershed export rates --

Watershed	TP export rate for whole watershed lbs/acre/year	DRP export rate for whole watershed lbs/acre/year	Agricultural land as fraction of watershed area	Non-ag-land as fraction of watershed area	TP export rate from cropland[1]	DRP export Rate from cropland[1]	TP runoff as % of maintenance[2]	DRP runoff as % maintenance[2]
Sandusky	1.53	0.35	0.776	0.224	1.72	0.392	8.3%	1.9%
Honey Cr.	1.47	0.44	0.811	0.189	1.62	0.488	7.8%	2.3%
Rock Cr.	1.63	0.29	0.719	0.281	1.89	0.334	9.1%	1.6%
Maumee	1.24	0.29	0.733	0.267	1.44	0.333	6.9%	1.6%

1. Assumes that the loss rate from non-cropland is 50% of that from cropland.

2. Maintenance rate from NRCS Rapid Assessment of Sandusky Watershed (47.5 lbs P_2O_5 per acre, 20.8 lbs P per acre)

Can we reduce a current loss rate of <2% by 40-80%?

… no small task.

… but, we do see a concerted effort by many groups, including farmers, fertilizer dealers, environmental groups, state and federal agencies, and the research and monitoring communities to advance Phase 3 of nutrient control programs in the Lake Erie Basin.

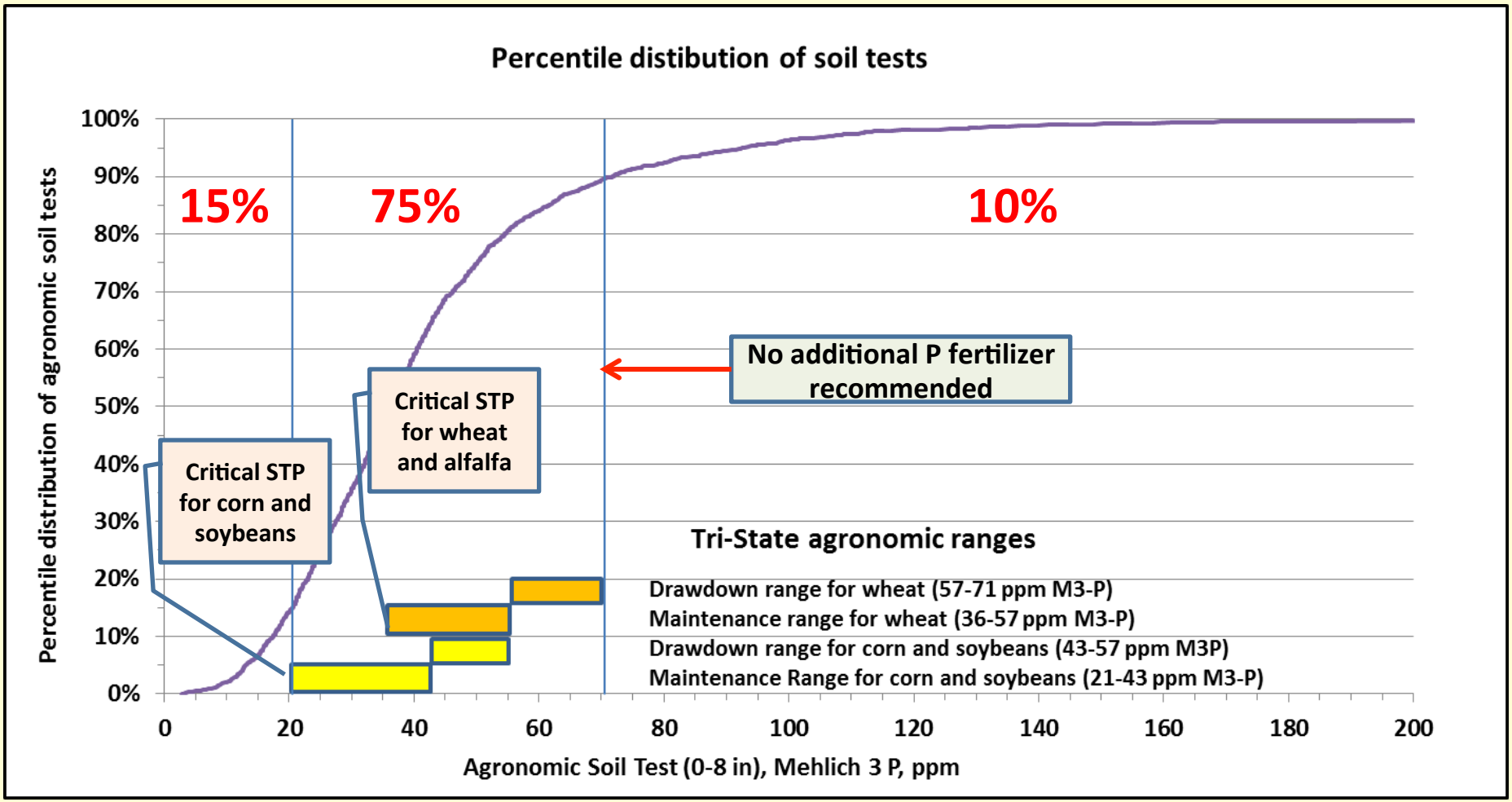
Email – dbaker@heidelberg.edu

Website – http://www.heidelberg.edu/ncwqr

End of Presentation

(followed by some extra slides)

Tri-State Fertilizer Recommendations



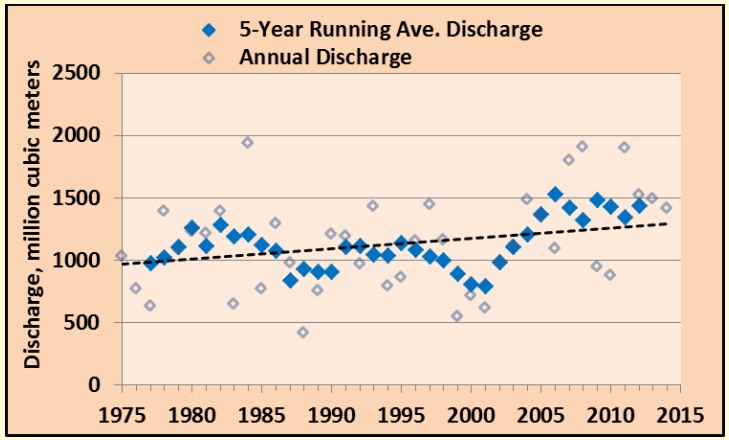
How do soil test values in Ohio compare with these ranges?

Compared to most areas, Ohio's soil test levels are not excessive!

Factors contributing to – and extent of – changes in nutrient and sediment export from the Maumee River between the early 1990s to the early 2010s.

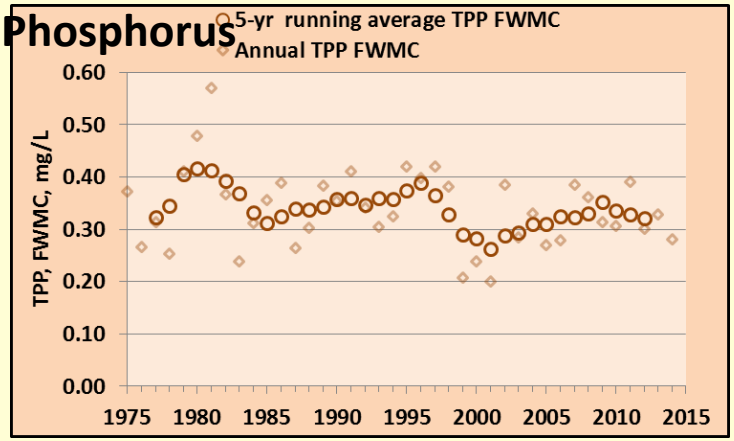
Parameter	1992-96	2010-14	% change
Discharge	4,926	5,578	13%
TPP FWMC, mg/L	0.321	0.286	-11%
TPP load, MTA	1,578	1,604	2%
DRP FWMC, mg/L	0.043	0.095	118%
DRP load, MTA	228	530	132%
TP FWMC, mg/L	0.364	0.381	5%
TP load, MTA	1,806	2,134	18%
TBAP FWMC, mg/L	0.123	0.169	33%
TBAP load, MTA	623	931	50%
Nitrate-N FWMC, mg/L	6.47	4.84	-25%
Nitrate-N load, MTA	30,260	26,600	-12%
SS FWMC, mg/L	164	144	-12%
SS load, MTA	801,600	803,400	0%

Sandusky River near Fremont, Total Particulate and Dissolved Phosphorus, Annual FWMCs and Loads, 1975-2014

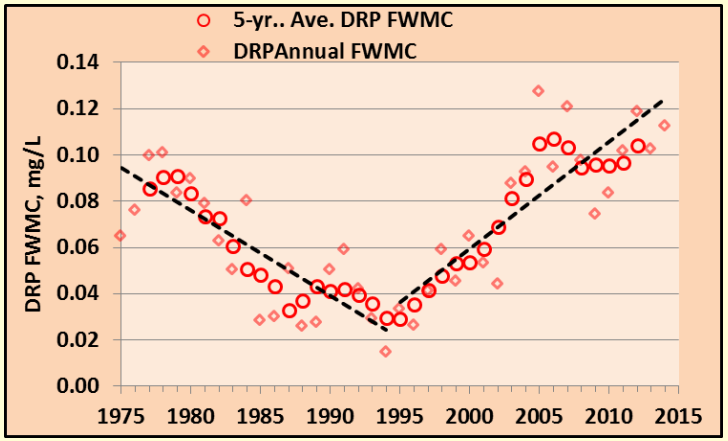


Annual and 5-year running average of annual discharges

Total Particulate Phosphorus

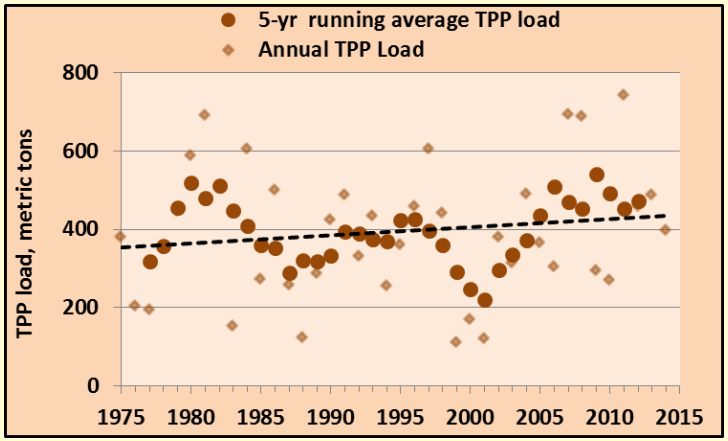


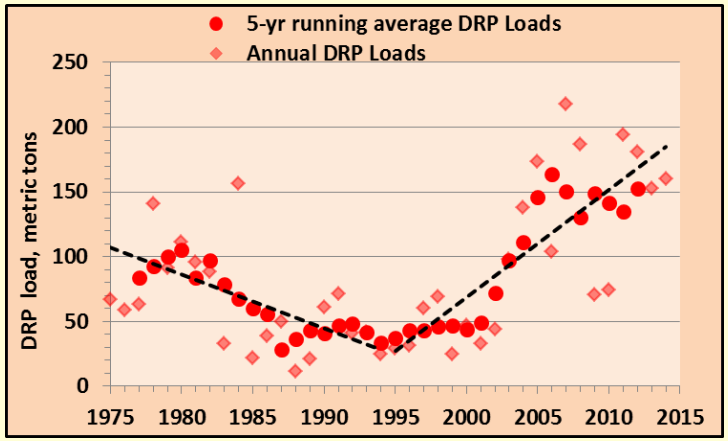
Dissolved Reactive Phosphorus



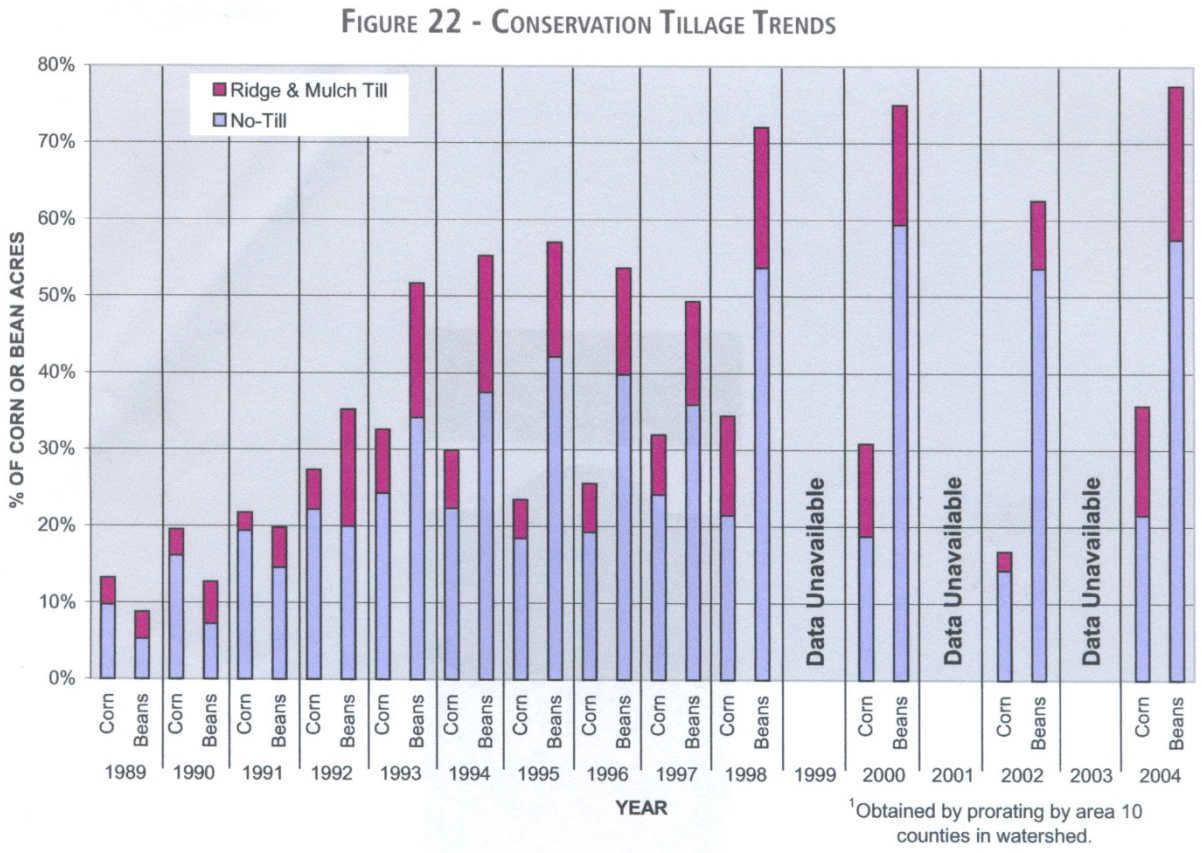
Annual FWMCs

Annual Loads





Tillage BMP adoption in the Sandusky Watershed



Average Gross Erosion Rate 1982 = 3.1 T/Ac/Yr

Average Gross Erosion Rate 1997 = 1.9 T/Ac/Yr

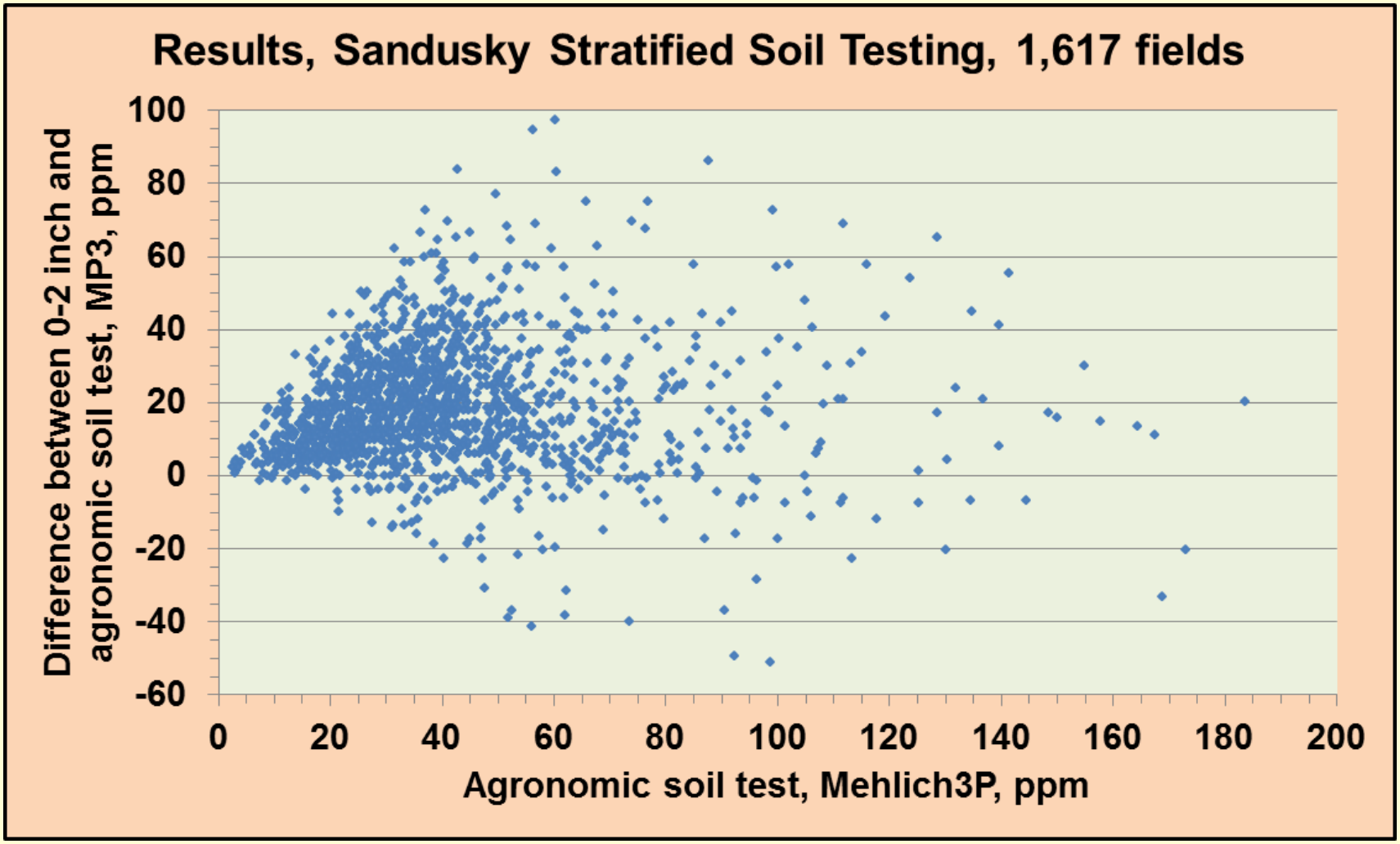
Similar adoption in the Maumee Watershed

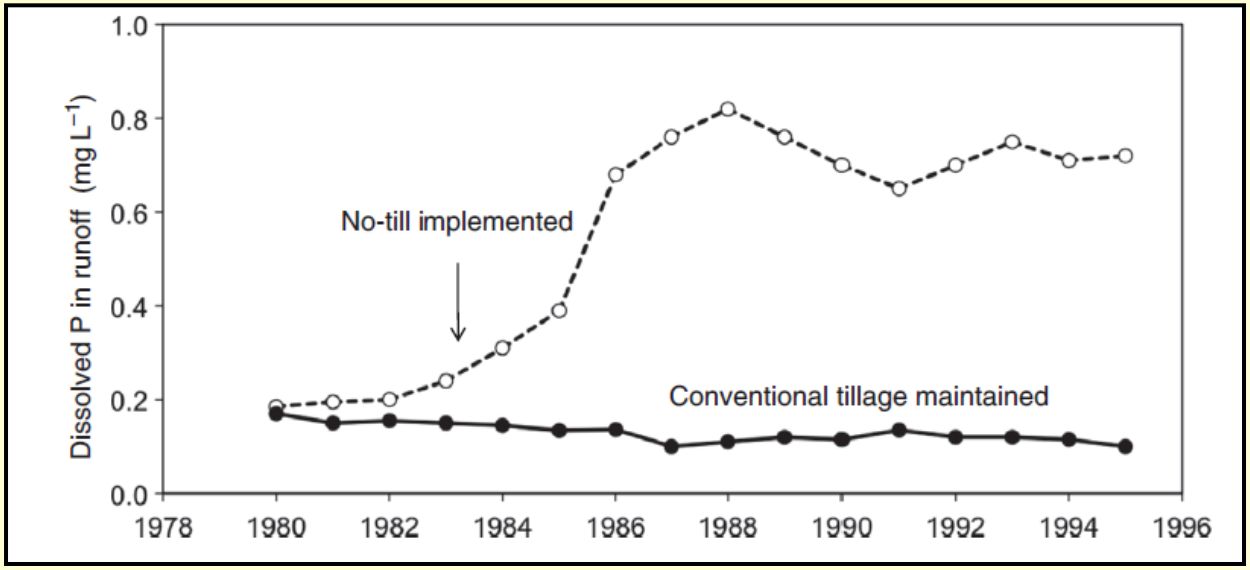
Relationship of FWMCs, discharge volumes, and loads

Annual Flow Weighted Concentration		Annual discharge volume		Annual Load
0.414 mg/L	X	1,473.9 million cubic meters	=	610.1 metric tons

Which variable can farmer's impact the most?

- **FWMCs?**
- **Annual Discharge?**

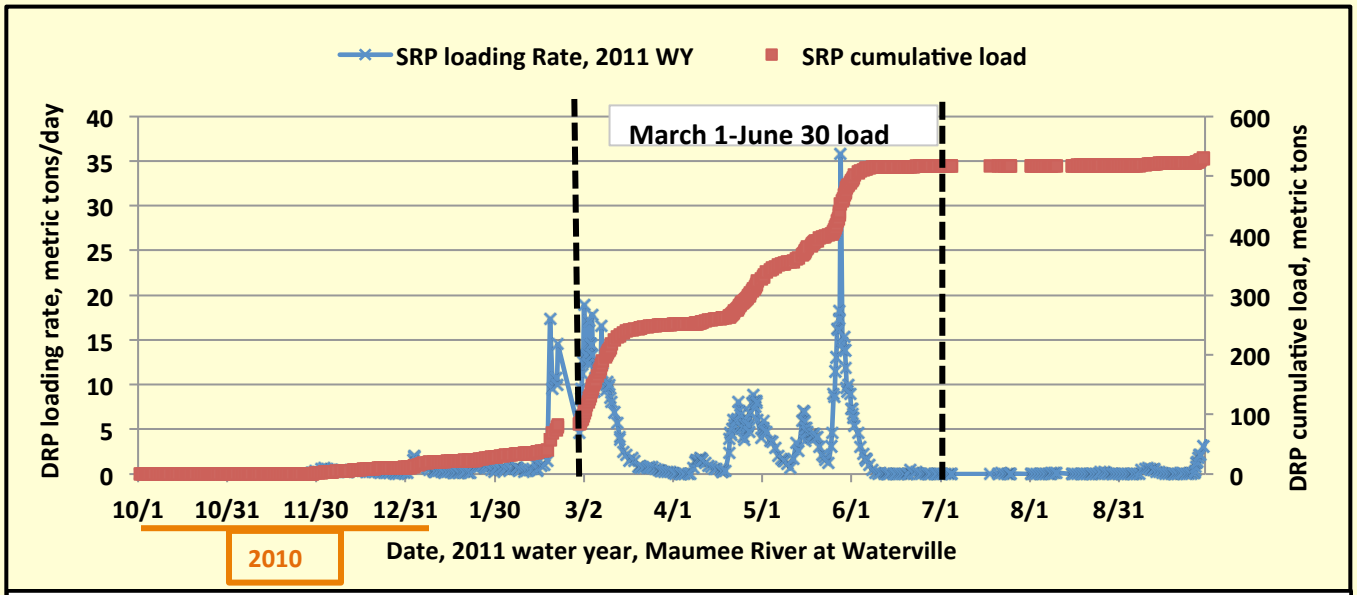

Results, Sandusky Stratified Soil Testing, 1,617 fields
Difference between 0-2 inch and agronomic soil test, MP3, ppm
100
80
60
40
20
0
-20
-40
-60
0
20
40
60
80
100
120
140
160
180
200
Agronomic soil test, Mehlich3P, ppm

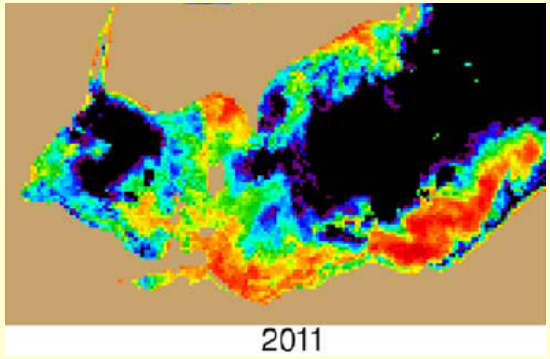


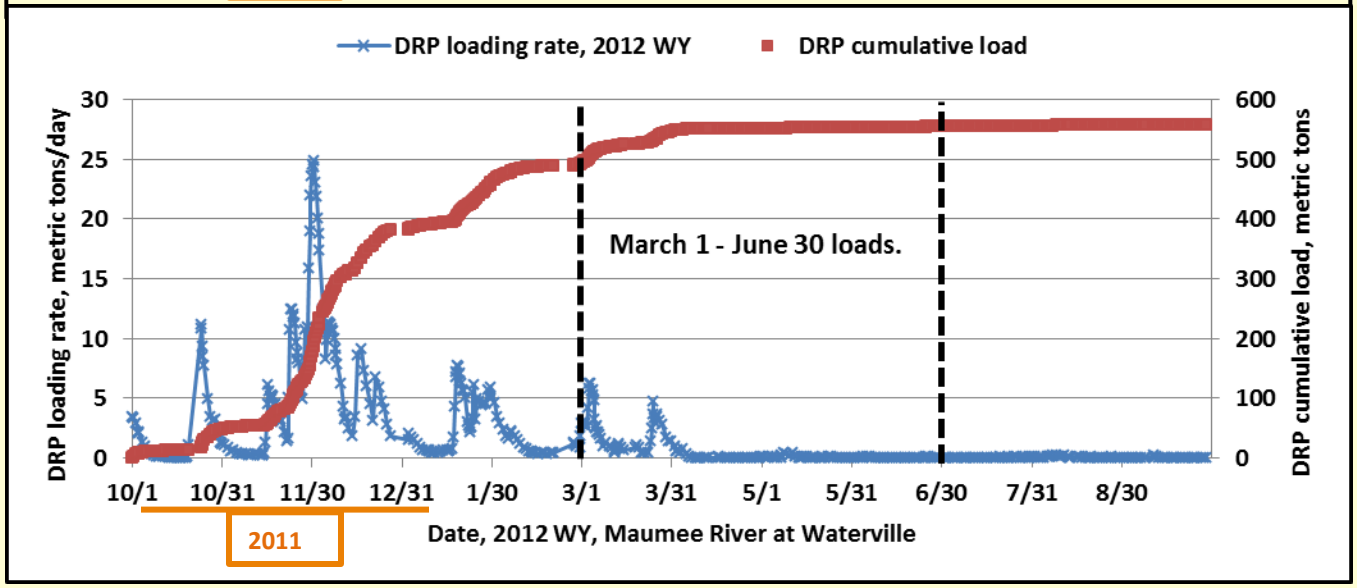
From Kleinman et al. 2011

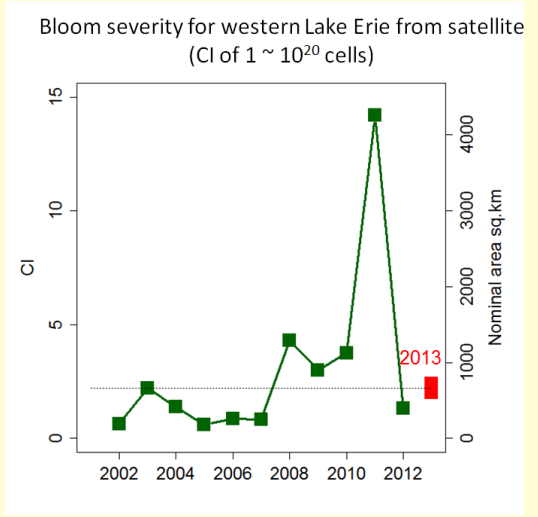
Dissolved P in runoff can increase under no-till management

Maumee River, DRP loading rate and cumulative loads, 2011 and 2012 WY









What portion of "re-eutrophication" can be attributed to increased DRP loading?

A comparison of average annual total and bioavailable phosphorus loading from the Maumee River for two time periods (loading units of metric tons per year).

	P-form	1992-96	2010-14	% Change
Total	TPP	1,578 (87%)	1,604 (75%)	2%
Phosphorus	DRP	228 (13%)	530 (25%)	132%
Loading	TP	1,806	2,134	18%
Bioavailable	PBAP	395 (63%)	401 (43%)	2%
Phosphorus	DRP	228 (37%)	530 (57%)	132%
Loading	TBAP	623	931	50%
	TBAP/TP	35%	44%	

Phosphorus control programs: Phase 3 –

… reducing the concentrations of dissolved phosphorus in agricultural runoff.

Where are we in the Phase 3 process?

- Planning phase
- Early implementation

Likely components of Phase 3

- Nutrient management – the 4-Rs
- Water management
- No-till/reduced till management
- Cover crops
- Conservation cropping systems
- Comprehensive soil health
- Targeting
- Off-field treatment (wetlands, etc.)

Shifts in multiple components of crop production systems … no silver bullet.