Michigan Chapter SWCS Seminar

A Matter or Balance: Feeding our Crops and Protecting our Waters in a Changing Climate

Kellogg Center, Michigan State University
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Long-term Trends in Agricultural Runoff to Lake Erie: Consequences, Causes, and Remedies

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Southernmost

Land Use
- Intensive General Farming
- Low-Intensity Farming/Pasture
- Coniferous Forest
- Mixed-wood Forest
- Deciduous Forest
- Urban Areas
FIGURE 1. LOCATIONS OF ESTIMATED AGRICULTURAL CONTRIBUTIONS OF TOTAL PHOSPHORUS TO STREAM LOADINGS (by extrapolation, 1976 data).
The Lake Erie Watershed: Sources of Phosphorus Loading

- **P Sources**
  - Atmosphere
  - Lake Huron
  - Nonpoint Sources
  - Point Sources

![Map of the Lake Erie Watershed showing sources of phosphorus loading.](image-url)
There is a long-term record of total phosphorus loading to Lake Erie.
How do we measure nonpoint phosphorus loads?

The Watershed Approach

Watershed boundary

Point source input
Stream gaging/monitoring station

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

Measure total watershed export

Total watershed output - point source inputs nonpoint source output
16 stations
14 with automatic samplers
~ 50% of Ohio’s land area is upstream from a Heidelberg monitoring station.

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 \times volume/unit time

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 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)

610 metric tons of Total Phosphorus
The Sandusky Fremont data set through the 2014 Water Year
• 40 Water Years (1975-2014)
• 18,625 samples analyzed

The Honey Creek data set through the 2014 Water Year
• 39 Water Years (1975-2014)
• 19,878 samples analyzed

These are the largest data sets of their type in the United States, and probably globally.
TP load - 610.1 metric tons

Volume discharged - 1,473.9 million cubic meters

Annual Flow Weighted Mean Concentration (FWMC) of Total Phosphorus

$\frac{610.1 \text{ metric tons}}{1,473.9 \text{ million cubic meters}} = 0.414 \text{ mg/L}$
Relationship of FWMCs, discharge volumes, and loads

Annual Flow Weighted Concentration × Annual discharge volume = Annual Load

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

Which variable can farmer’s impact the most?
• FWMCs?
• Annual Discharge?
What is the average concentration of TP at the monitoring station?

1. Add up all the samples and divide by the number of samples?
   \[
   \frac{155.75}{604} = 0.258 \text{ mg/L}
   \]

2. Flow weighted mean concentration = load /volume
   \[
   \frac{610.1 \text{ metric tons}}{1,473.9 \times 10^6 \text{ m}^3} = 0.414 \text{ mg/L}
   \]

3. Time weighted mean concentration (TWMC)
   \[
   \frac{\text{Sum}(t_i * c_i)}{\text{Sum} (t_i)} = 0.203 \text{ mg/L} \quad (t = \text{time window for each sample})
   \]
From here in the 1960s & 1970s...

With some very good years in between!

... to here in the 2000s

Re-eutrophication of Lake Erie
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 --- Senate Bill 1
From here in the 1960s & 1970s...

... to here in the 2000s

Why?

With some very good years in between!
Target load was first met in 1981.
Now target is only exceeded in wet years with large nonpoint loads
No obvious explanation for re-eutrophication of the Lake based on total phosphorus loads.
Reductions in point source loading through P-removal programs at municipal (and industrial) waste treatment plants and from bans of phosphorus in laundry detergents.

A focus on nonpoint phosphorus control was called for in the 1983 supplement to the Great Lakes Water Quality Agreement of 1978. It called for a 2000 metric ton reductions (1,700 MTA from the US and 300 MTA from Canada.)
What happened?

- Zebra Mussels
- Climate Change
- Detroit
- Lawn Chemicals
- Dissolved P loads
- Combined Sewers
- Dish Washer Detergents
What is “dissolved phosphorus”?

Total Phosphorus Measure = Particulate Phosphorus Calculate + Dissolved Phosphorus Measure

Availability to algae
25% Bioavailable
100% Bioavailable
In the 1980s, total phosphorus loading was dominated by particulate phosphorus.

Particulate phosphorus loading was associated with cropland erosion of suspended sediments.

No-till and reduced till agriculture were effective in reducing erosion.
2008 Great Lakes Tributary Total Phosphorus Loads (MTA) - Top 80 Tributaries

Legend
- Total Phosphorus: < 100 MTA
- Total Phosphorus: > 100 MTA
- 500
- 100
- Connecting Channel

Universities of Wisconsin
GREEN BAY
UNITED STATES FISHERIES PROTECTION AGENCY
Sandusky River
1975-2014
Trends in discharge and in phosphorus concentrations and loads.

Increase in Discharge

Decrease in FWMC of Particulate BAP

Large decrease in FWMC of DRP followed by even larger increase

Slight increase in Load of Particulate BAP

Large decrease in DRP load followed by even larger increase
Maumee River

Sandusky River

Honey Creek

Trends in PBAP and DRP loads for three Ag watersheds

All three of our long-term agricultural watersheds have shown similar patterns in particulate bioavailable P loading and DRP loading:

- **Particulate BAP loads** have fluctuated with discharge patterns and shown a small overall increase through 2014.

- **DRP loads** decreased substantially from the mid-1970s to the mid-1990s, then increased by large amounts through the mid-2000s followed by a leveling off to the 2014.

- In terms of bioavailable P loading, DRP now exceeds PBAP in all three rivers.
Why the emphasis on dissolved reactive phosphorus (DRP)?

(It’s a small part of the total phosphorus load)

1. Bioavailability

2. Delivery
Maumee River at Waterville, Average Annual Loads, 2003-2012 WYs

Total Phosphorus at Waterville
2,437 metric tons/year

Chemically Bioavailable Phosphorus at Waterville
1,098 metric tons/year
(45% of TP load at Waterville)

Delivered Bioavailable Phosphorus
772 metric tons/year
(32% of TP load at Waterville)

Assumes 33% delivery of TPP between tributary monitoring station and Western Basin
Dissolved Reactive P.

08/28/2007 – Bridgeman (6 stations)
08/29/2007 – Landsat Image
08/30/2007 – Vincent Transect
Total Phosphorus

08/28/2007 – Bridgeman (6 stations)
08/29/2007 – Landsat Image
08/30/2007 – Vincent Transect
Why did the concentrations of dissolved phosphorus in storm water from agricultural watersheds increase?

- Increased broadcasting of fertilizers
- Phosphorus stratification in cropland soils
- Increased tile drainage
- Increasing phosphorus soil test levels

A quick look at stratification and direct runoff of broadcast fertilizers....
How does phosphorus move from cropland to streams, rivers and lakes? A diagram from the 1970s ...

Interaction of hydrological cycle and land use activities  Nonpoint source pollution

Particulate P
Dissolved P
Have views of phosphorus pathways to water changed?

Dissolving and runoff of broadcast fertilizer granules before incorporation and entering soil – phosphorus complex.
Dissolved P in runoff can increase under no-till management

From Kleinman et al. 2011
Sandusky Watershed **Stratified Soil Testing Program**, supported by GLPF

- **Agronomic soil testing**: Composite of 0-8 inch cores.
- **Environmental soil testing #1**: Composites of 0-2 and 2-8 inch portions of cores.
- **Environmental soil testing #2**: Composites of 0-1, 1-2, 2-5 and 5-8 inch portions of cores.
The extent of P stratification

M3P (ppm)

Core depth (inches)

0-2
2-8
0 25 50 75 100 125 300

0-1
1-2
2-5
5-8

M3P (ppm)

Core depth (inches)

0 25 50 75 100 125 300

0-1
1-2
2-5
5-8
Tri-State Fertilizer Recommendations

Critical STP for corn and soybeans

Critical STP for wheat and alfalfa

No additional P fertilizer recommended

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

Compared to most areas, Ohio’s soil test levels are not excessive!
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.
Fertilizer application on frozen ground
Fertilizer application just before precipitation
Fertilizer application rates versus watershed export rates --

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

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 P₂O₅ per acre, 20.8 lbs P per acre)

Can we reduce a current loss rate of <2% by 40-80%? … no small task.
Maumee River, DRP loading rate and cumulative loads, 2011 and 2012 WY

**DRP loading rate, metric tons/day**

- **SRP loading Rate, 2011 WY**
- **SRP cumulative load**

**March 1-June 30 load**

**Date, 2011 water year, Maumee River at Waterville**

**March 1 - June 30 loads.**

**Date, 2012 WY, Maumee River at Waterville**

**Bloom severity for western Lake Erie from satellite (Cl of 1 ~ 10^{06} cells)**

**2011**

**2013**
Questions?

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