# Understanding Nutrient Issues Affecting Ohio's Inland Lakes

**Webcast sponsored by EPA's Watershed Academy**

**Wednesday, November 30, 2016**

**1:00pm – 3:00pm Eastern**

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# Webcast Logistics

- **To Ask a Question** – Type your question in the "Questions" tool box on the right side of your screen and click "Send."
- **To Report any Technical Issues** (such as audio problems) – Type your issue in the "Questions" tool box on the right side of your screen and click "Send" and we will respond by posting an answer in the "Questions" box.

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# Overview of Today’s Webcast

- Evolution of Lake Monitoring Program to address Nutrient Impairment and Harmful Algal Blooms in Ohio Lakes
  - Brief History and Status of Ohio EPA Inland Lake Monitoring;
  - Ohio EPA: Lessons learned from efforts at Grand Lake St. Mary and Buckeye Lake;
  - Ohio EPA: Challenges moving forward
    - Including how to understand and build basic environmental awareness of lake management through basic limnology and building stakeholder support.
- Ohio case studies and lessons learned from:
  - Grand Lake St Mary (GLSM)
  - Buckeye Lake
  - Kiser Lake
  - Lake Alma
- Assessment of current data gaps and monitoring recommendations for filling those gaps
- Recommendations for managing nutrient loading to the lake from the watershed as well as internally to maintain water quality and limit the occurrence of HABs

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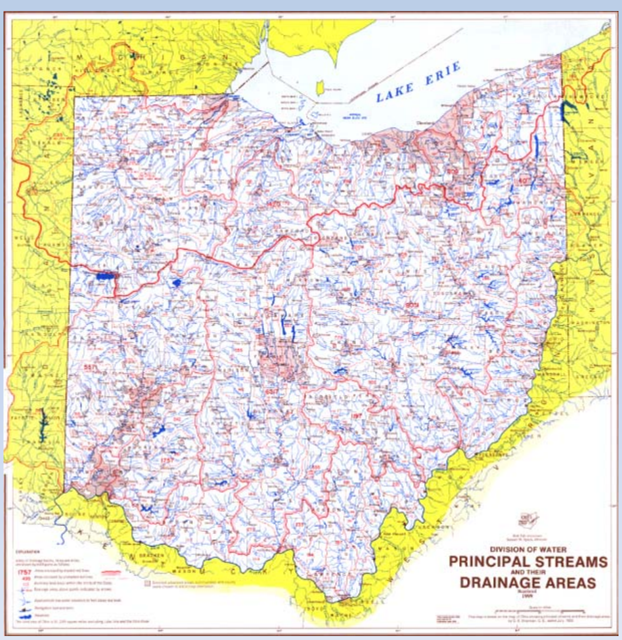
# Ohio’s Water Resources




- More than 58,343 Stream Miles
- Wetlands - 942,155 Acres
- 446 Public Lakes

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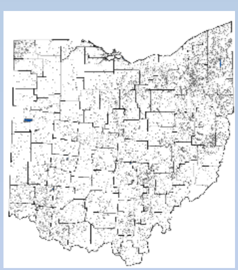
## Bio-assessment for Ohio Rivers and Streams

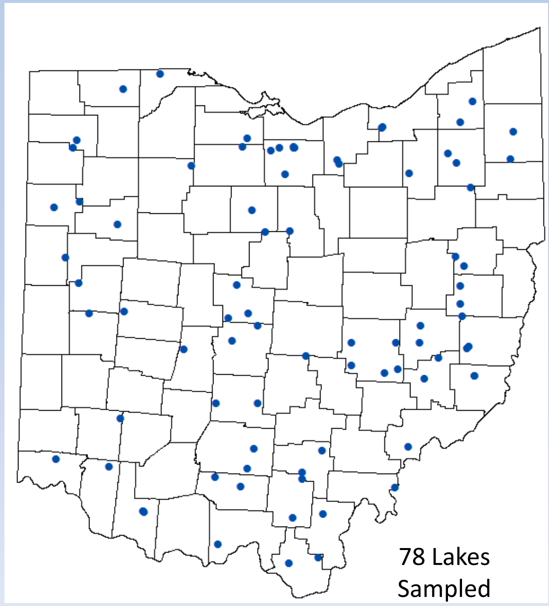
## Inland Lakes In Ohio



- ~50,000 Identifiable Lakes
- 108 Natural Lakes - majority in the WAP Ecoregion
- Dammed Impoundments (63%)—Recreation & PDWS
- Up-ground Reservoirs (19%)—PDWS
- Dugouts (13%)—Private

Sunrise over Alum Creek Reservoir, Delaware County, Ohio—Russ Gibson, Ohio EPA

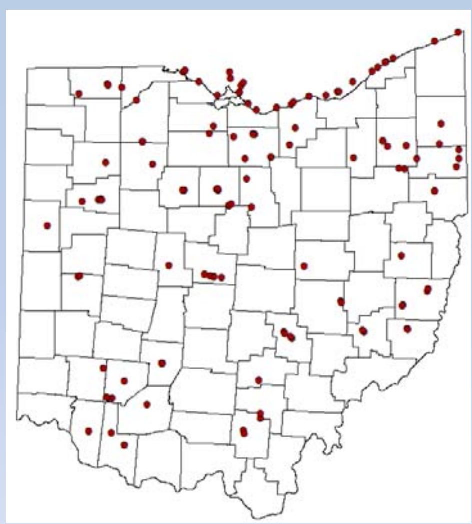
## Inland Lakes and Reservoirs Sampled Since 2008




## Public Drinking Water Supply Lakes and Reservoirs

<u>2016 Integrated Report</u>

- 16 PDWS watersheds "Impaired" due to algae
- 12 Ohio Inland Lakes on the Division of Drinking and Ground Water "Watch List" for algae.
- 5 PDWS watersheds impaired due to Nitrate
- 27 watersheds on the Division of Drinking and Ground Water "Watch List" for Nitrate.



# Inland Lake Monitoring in 2016

- 29 Inland Lakes monitored throughout Ohio in 2016
  - Public Drinking Water Supply (PDWS)—15 lakes
  - PDWS and State Park Recreation Use—3 lakes
  - State Park Recreational Use—10 lakes
  - Recreational Use (private) — 1 lake
  - Data used both for
    - Near-term – information and postings and
    - Long-term – Lake Management planning and plan development

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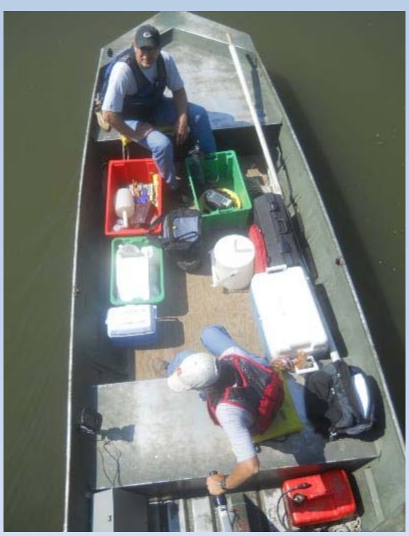

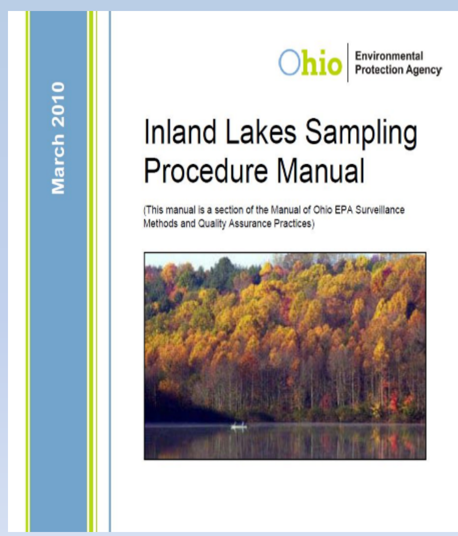


Ohio EPA Inland Lakes Sampling Procedure Manual—May 2016
http://epa.ohio.gov/Portals/35/documents/Inland_Lake_Sampling_Manual.pdf

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# Ohio's Priority Lakes moving forward

- **Tappan Lake** in Harrison county (upper Little Stillwater Creek)
- **W.H. Harsha Lake** in Clermont County (Lucy Run - East Fork Little Miami River)
- **Clyde/Beaver Creek Reservoir** in Seneca County (Beaver Creek, Green Creek)

Basis:

- Review of the inland lakes or reservoirs that were listed as impaired or on the Watch List for algae indicators in the 2014 Integrated Report; and
- Recent data collected for algae at Public Drinking Water Supplies with intakes drawing from inland lakes or reservoirs that led to the 303(d) impaired listing in the Integrated Report

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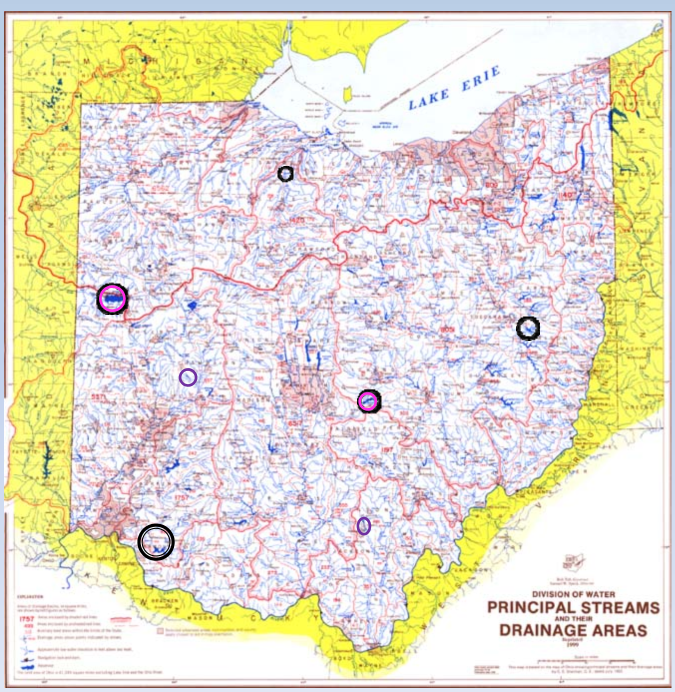


**Tetra Tech assisted-**
**Grand Lake St. Marys (2010)**
**Buckeye Lake (2014)**

**Alma (2016)**
**Kiser (2016)**

**OEPA Priorities:**
**Harsha, Clyde, Tappan (OEPA 2016 IR)**

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Grand Lake St. Marys

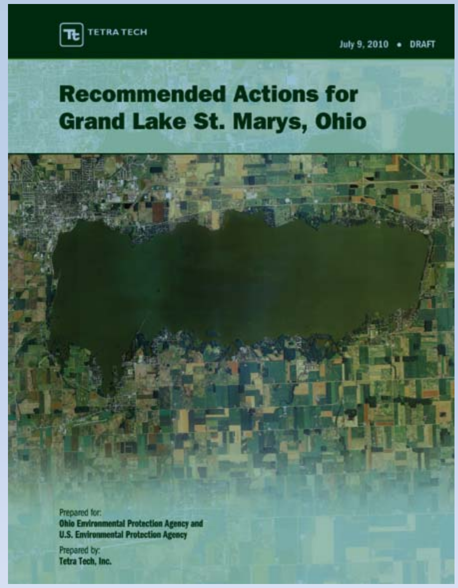

<u>Recommended Actions:</u>

<u>In-lake</u>

- Lake Treatment with Alum
- Dredging sediments
- Site Specific aeration (channels)

<u>Watershed</u>

- Wetland treatment trains
- Education/Outreach
- Farm Conservation planning
- Installation of conservation practices

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# Buckeye Lake


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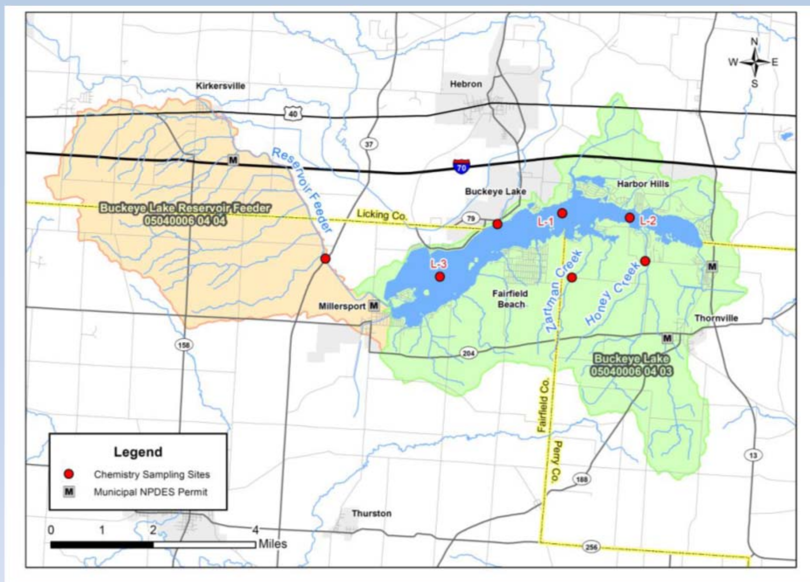


Buckeye Lake Watershed

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## Buckeye Lake: Recommended Nutrient Management Strategies

- Watershed
  - Continue outreach and education
  - Aggressively implement agricultural BMPs
  - Other BMPs constructed wetland areas; streambank erosion reduction & other flow/runoff reduction
- In-lake
  - Treat phosphorus in the sediment (e.g., alum)
  - Manage geese population
  - Dredge sediment

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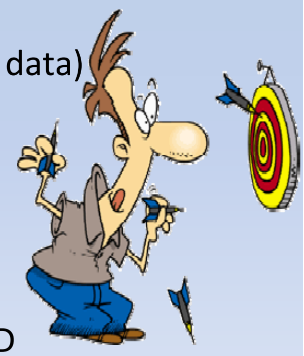
## Developing Lake Management Plans

- It's not just the lake you need to know about
  - Land Use
  - Tributary data (especially high-flow data)
- Engaging Stakeholders
  - Public Officials
  - Water Department Officials
  - State Park Officials
  - Farming Community and local SWCD
  - Lake Association(s)



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## Developing Lake Management Plans

- Allocating sufficient resources to collect the data needed to develop a nutrient assessment can be a challenge.
  - Lake water chemistry and biology
  - Lake Sediment Sampling
  - Bathymetry
  - Inflow and Outflow flow
    - (mass balance)
  - Tributary Sampling
    - High Flow runoff events—challenge to plan and execute

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# Questions?

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## Understanding Lake Ecology to Define and Deal with Issues

*Picture by Snohomish County Surface Water Management*

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# Lakes and Reservoirs

- Lakes and reservoirs are "water containers"
  - But what happens within these containers is not simple
- Ecological conditions are dependent upon many factors
  - Physical
  - Chemical
  - Biological
  - Energy dynamics
  - Human activities and land-use, and
  - Interaction between all of the above

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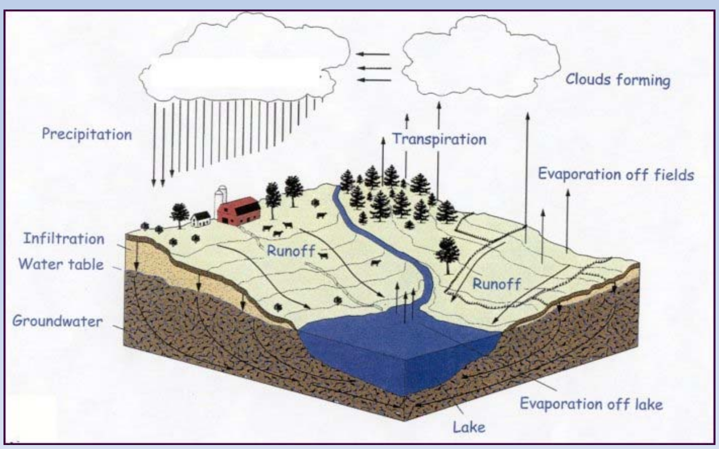
# Water Cycle from a Watershed Perspective

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# Water Cycle Impacts

- Water retention, inflow and outflow define lake and reservoir:
  - Physical morphology and sedimentation rate
  - Rate of chemical interaction
  - Availability of chemicals to drive biological
  - Biological residence time
  - Biochemical feed back rates
- Key factors – Residence Time and Flushing Rate
  - Relative size of watershed versus lake volume and area

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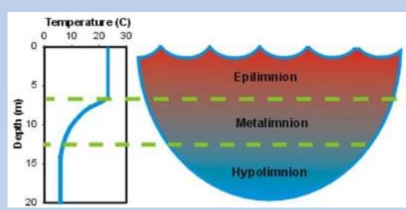
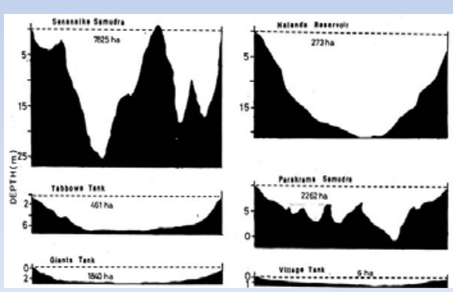
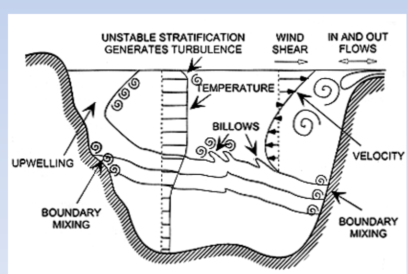
# Morphology and Mixing

- Lake morphology influences physical dynamics
  - Occurrence and stability of stratification
  - Frequency of mixing



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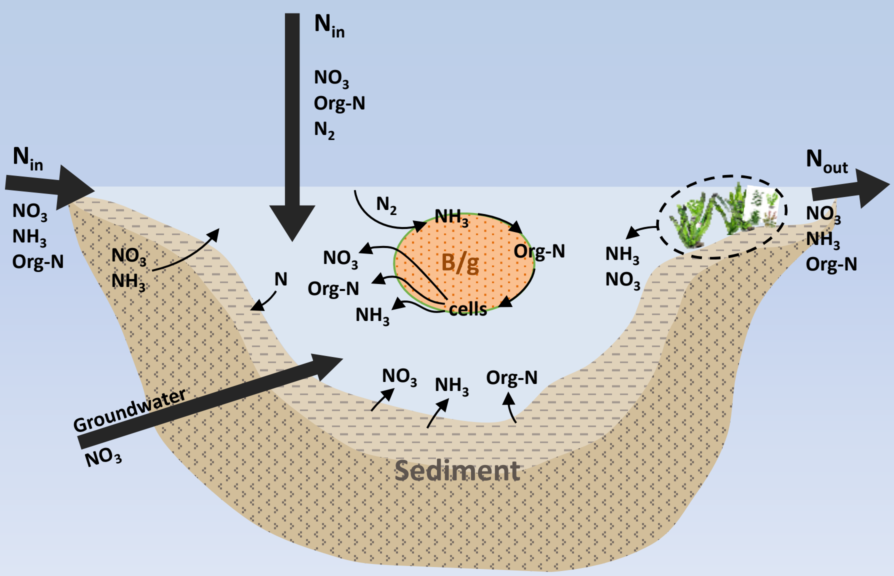
# Nutrient Cycling

Key macronutrients relative to primary productivity (algal and rooted plant growth)

- Carbon
  - Inorganic carbon supply from the atmosphere has more than doubled compared to the quantities available less than 80 years ago (from 180 ppm to 400 ppm for just $CO_2$)
  - No longer limiting
- Silica
  - Not a limiting factor for Cyanobacteria nor truly limiting for most shallow lakes and reservoirs
- **Nitrogen**
- **Phosphorus**


# Nitrogen Cycle

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## Reducing P is the Key to Managing Eutrophication in Over Enriched Lakes with Excessive Cyanobacteria Blooms

- Nitrogen should be reduced, also but:
  - N reduction improves water quality and can be limiting in the short term, but N:P ratio rarely controls cyanobacteria blooms or hypereutrophic conditions, because:
    - Bottle/mesocosom experiments are too short of time frame to allow N-fixation to build up the N supply as observed in whole-lake,
    - Reduction of N may lead to enabling N fixers (cyanobacteria) and,
  - There are no cases where N reduction alone have reduced trophic state, but many successful cases of P reduction alone (over 250 for inaction alone).
  - "…numerous long-term studies of lake ecosystems in Europe and North America show that controlling algal blooms and other symptoms of eutrophication depends on reducing inputs of a single nutrient: phosphorus." Schindler, et al, 2016

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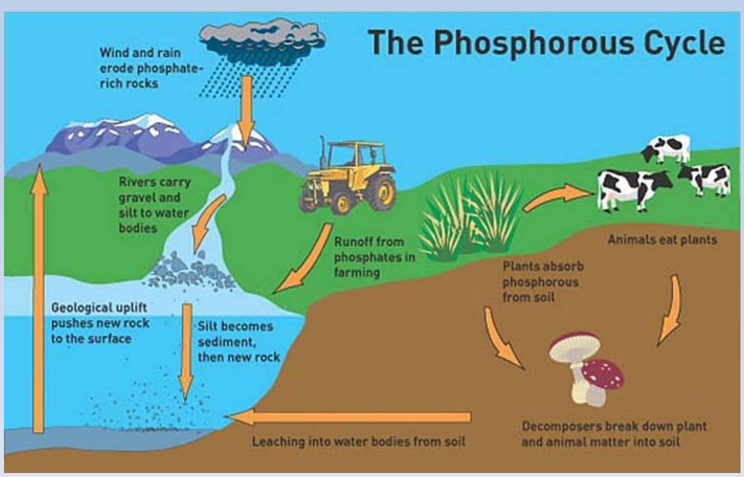
# Phosphorus Cycle Overview

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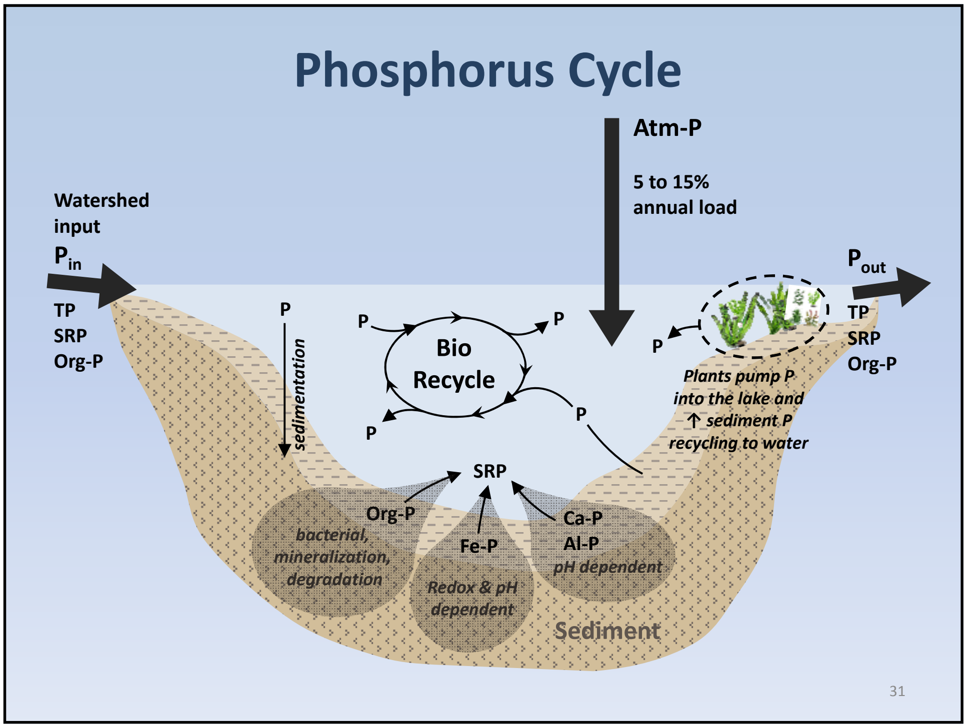
Phosphorus Cycle
Atm-P
5 to 15%
annual load
Watershed
input
P in
TP
SRP
Org-P
P out
TP
SRP
Org-P
P
sedimentation
P
Bio
Recycle
P
P
P
P
Plants pump P
into the lake and
↑ sediment P
recycling to water
SRP
Org-P
bacterial,
mineralization,
degradation
Fe-P
Redox & pH
dependent
Ca-P
Al-P
pH dependent
Sediment
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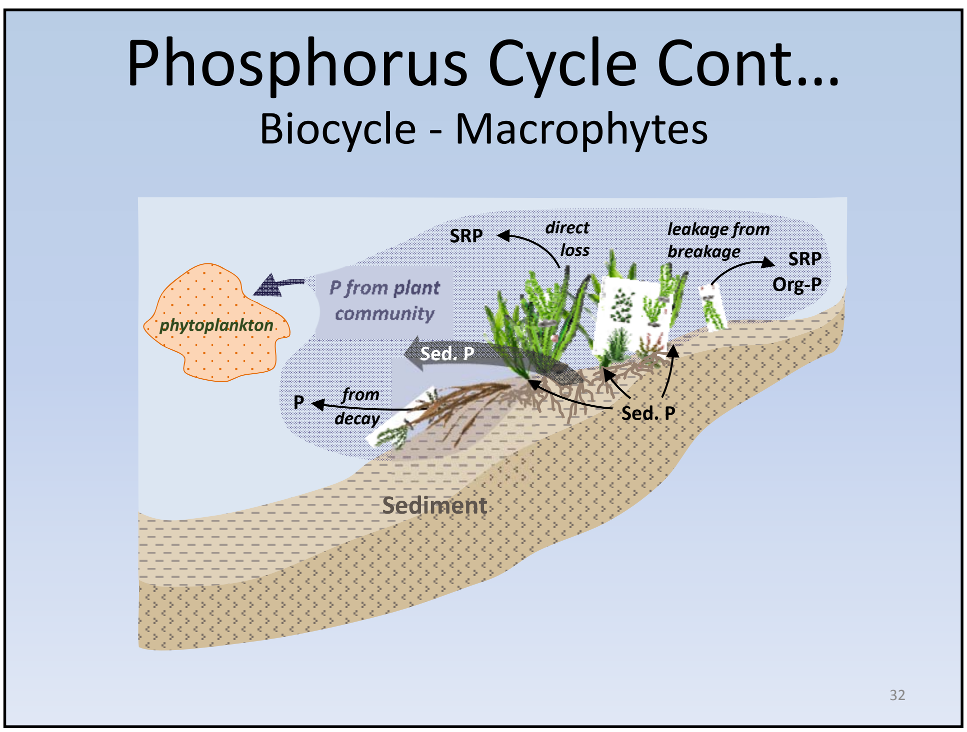
Phosphorus Cycle Cont…
Biocycle - Macrophytes
SRP
direct
loss
leakage from
breakage
SRP
Org-P
phytoplankton
P from plant
community
Sed. P
P
from
decay
Sed. P
Sediment
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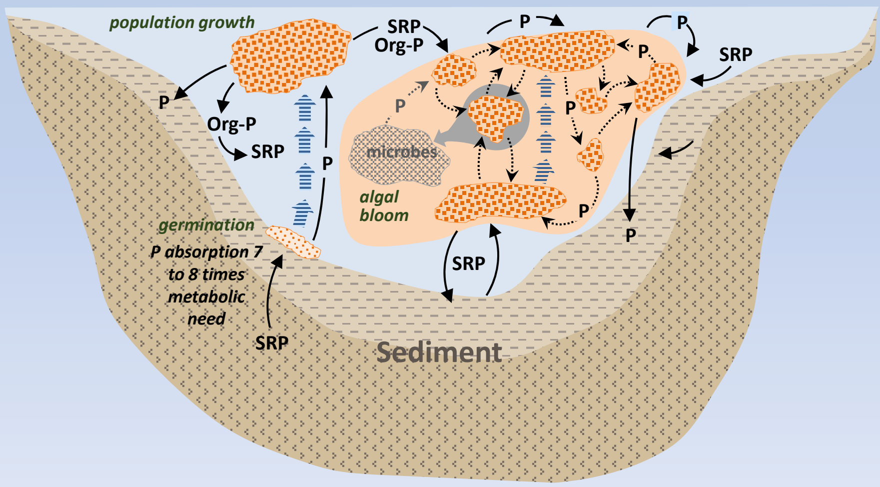
# Phosphorus Cycle Cont.

## Biocycle – Phytoplankton, Cyanobacteria

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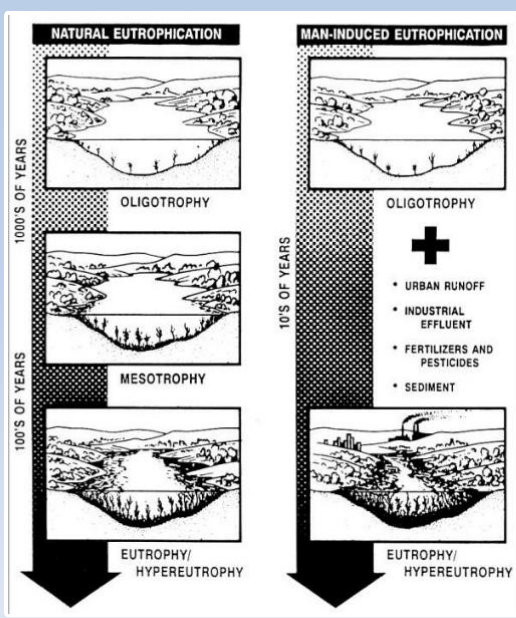


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## Nutrient Loading

- Rate of nutrient loading and the total amount of nutrients delivered to an aquatic system drives its primary production
  - Input (loading) versus concentration
    - An input of 1 kg of P put into a lake can grow 10,000 kg of algal, but that 1 kg of P can recycle within the lake up to 40 times; leading to the production potential of 400,000 kg of algal biomass.
- Hence retention in the lake of external P loading is important to understand.

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## Nutrient Loading cont…

- Human watershed activities can cause loading of nitrogen and phosphorus to be 20 to 40 times background conditions with certain land-uses
- Relative to eutrophication and watershed inputs;
  - Even with Best Management Practices (BMPs) in place that remove 50% of the inflowing nutrients that is still 10 to 20 times background conditions,
    - At 90% flushing of the lake, it is still 2 to 4 times the background rate!

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## Watershed Nutrient Loads

- Watersheds are relatively geologically stable for thousands of years.
  - Plant communities develop a relatively stable transformation over time.
  - Hence, historic background conditions usually generate low levels of nutrients.
- Land-use is a rapid and significant modification to background conditions and nutrient loading reflects this.

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## Defining Watershed Nutrient Loading

- Need to monitor streams and significant stormwater inflows
  - Measure flow, temperature, dissolved oxygen, pH, phosphorus and nitrogen at minimum
  - Measure outlet flows for same parameters
- Understand both shallow groundwater (interflow) and aquifer flow into and out of the lake.
  - Also if possible measure nutrient flux especially coming into the water body.

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## Nutrient Loading cont…

- Things to keep in mind
  - Impervious vs pervious area
  - Vegetated surfaces relative to storage and pollution retention vs non-vegetation surfaces
  - Industrial Surfaces generate up to 20 times that of forested areas in terms of nitrogen and phosphorus
  - Ag lands can generate up to 40 times that of forested areas in terms of nitrogen and phosphorus
  - Suburban and urban land use will generate 10 to 20 times the nutrients over background levels.

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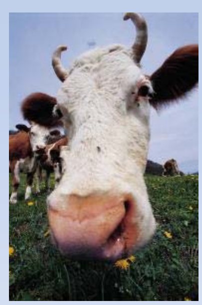
## Watershed Management

- Watershed management of phosphorus loading is the key to slowing accelerated eutrophication
- To prevent or slow premature hypereutrophy, phosphorus loading to lakes and reservoirs must be controlled.
- The watershed is the ultimate source of phosphorus for lakes and reservoirs
  - It is the source of sediment phosphorus,
  - It recharges sediment phosphorus, and
  - This leads to continued internal loading of phosphorus.
- <u>Must always address watershed phosphorus control.</u>



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## Once a Lake is Pushed beyond its Eutrophic State by Watershed Abuses: In-Lake Activities Have to be the Center of the Game Plan

- Primary production and related water quality is a direct function of phosphorus availability
  - Related to when and how much P is available within the lake
  - For many lakes with current or past excess external P loading
    - ***it is not the original source of phosphorus that is important:***

**It is the quantity and timing of phosphorus availability "within" the lake that is important!**

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## In-Lake Quantity and Timing of Phosphorus Availability

- Magnitude of internal P loading
  - Relative to external sources, often is largest contributor
    - Especially in summer
    - Often drives cyanobacteria production
    - Can continue to be the cause of blooms for decades after external loads are reduced
- To maintain beneficial uses, in-lake activities are needed
- Often inactivation of internally loaded phosphorus is essential to success, regardless of watershed controls

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## Internal loading even greater % in many shallow hypereutrophic lakes

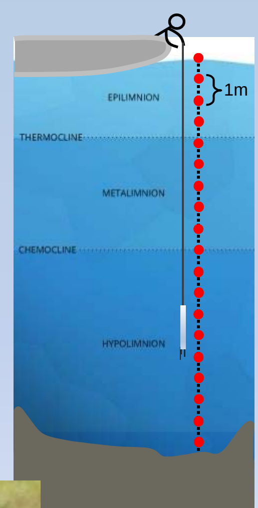
| Lake | Area (ha) | Mean Depth (m) | $TP_1$ µg/L | % Internal Load[1] |
|---|---|---|---|---|
| Upper Klamath Lake, OR | 26,800 | 2.0 | 120 | 80[1], 59[2] |
| Arresø, DK | 4,100 | 2.9 | 430 | 88[1], 71[2] |
| Vallentuna, SK | 610 | 2.7 | 220 | 95[1], 87[2] |
| Søbygaard, DK | 196 | 1.0 | 600 | 79[1], 55[2] |
| GLSM, OH | 5,200 | 1.6 | 187 | 90[1], 25[2] |

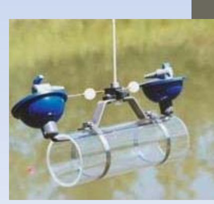
[1]Summer (4 months)
[2]Annual



## Monitoring

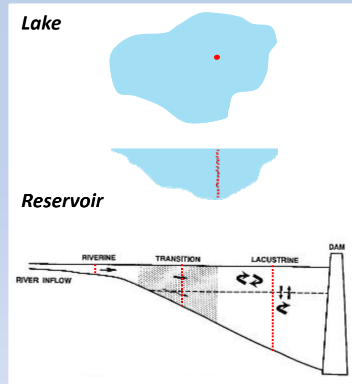
- Water column profiling
  - Multi-parameter water quality sonde
- Continuous monitoring (temperature, dissolved oxygen)
  - Onset Hobo temperature loggers, Tidbits
  - Onset DO loggers
- Water quality grab sampling
- Sediment sampling
  - Grab or sediment cores
- Bathymetric mapping
- Aquatic plant mapping



# Monitoring

- Sample twice monthly during summer growth period (May-Oct); Monthly remainder of year
- One centrally located deep site usually adequate; even large lakes due to wind mixing and circulation
- Multiple sites, at least one in each of three zones (riverine, transition, and lacustrine) in reservoirs if elongated and formed by dams on relatively large rivers
- Lake inflows and outflow(s) should be sampled coincidentally for nutrient budgets (see below)

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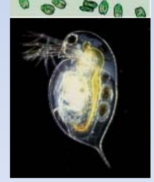
# Parameters

- TP, SRP, nitrate+nitrite-N, and TN should be determined at 0.5 or 1 m below the surface, 1 m above the bottom and at least 5 m intervals throughout the water column
  - A 1 m sample may be adequate in shallow lakes, although a bottom (1 m above bottom) sample is recommended if the deep site is 4-5 m
- Chlorophyll and algal cell counts + biovolumes of at least important taxa should be determined at a minimum of 1 depth in the epilimnion of stratified lakes or in the full water column of shallow lakes

- Vertical net hauls for zooplankton within the epilimnion and metalimnion in stratified lakes and whole water column of shallow lakes with enumerations of total animals and Cladocerans separately



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## Data QA/QC

- Field Replicates/Duplicates
  - Water column profiling (every 10$^{th}$ measurement)
  - Water quality grab sample (at least one each sampling event or 1/20 samples)
- Field equipment blanks
  - One each sampling event
- QA/QC laboratory data
  - Review lab performance metrics; lab blanks, spikes, dupes
- **Perform a Reality Check**
  - Chl:TP ratios
  - World wide average = 0.3; Range from 0.3 to 1.0 (as high as 1.5)

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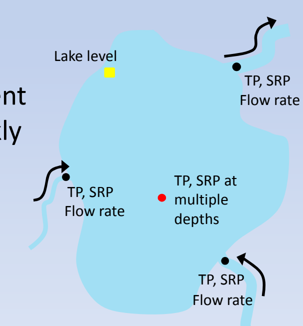
## Water and Nutrient Budgets

- External TP loading calculated using water inflows and outflow from the lake and the TP content of that water. Sample frequency should be continuous for flow (inflows and outflow if possible), and lake level

- TP content should be determined weekly or twice monthly all year. If possible, storm event sampling should be added to baseflow weekly or twice monthly monitoring.

- Budgets are possible from less intensive monitoring, but often have large errors

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## Water and Nutrient Budgets

- The water budget is determined using the following equation, with time intervals according to inflow sampling frequency:

$$\Delta Storage = Q_{in} - Q_{out} \pm GW + (Precip*SA) - (Evap*SA)$$

$Q_{in}$ = all inflows (tributaries, point sources)

$Q_{out}$ = all outflows (lake outlet, withdrawls)

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## Water and Nutrient Budgets

- With a balanced water budget and TP content of inflows, the lake, and outflow, the TP mass balance can be determined according to:

$$\Delta TP_{\mathrm{Lake}} = TP_{in} - TP_{out} - TP_{sed}$$

All in mass (kg)

$\Delta TP_{Lake}$ = whole-lake TP content (volume-weighted)

$TP_{in}$ = all external TP inputs

$TP_{out}$ = output from lake

$TP_{sed}$ = sedimentation in the lake

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## Water and Nutrient Budgets

- Rearranging the TP mass balance equation will allow determination of net (sediment P release minus sedimentation) internal loading on chosen time step :

$$TP_{sed} = TP_{in} - TP_{out} - \Delta TP_{\mathrm{Lake}}$$

$TP_{sed}$ = sedimentation in the lake

$TP_{in}$ = all external TP inputs
$TP_{out}$ = output from lake
$\Delta TP_{Lake}$ = whole-lake TP content

All in mass (kg)

A **negative** $TP_{\mathrm{sed}}$ indicates that $TP_{\mathrm{out}}$ and/or $\Delta TP_{Lake}$ exceeds the external input of $TP_{\mathrm{in}}$ and there is net internal loading.

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## Water and Nutrient Budgets

- These budgets can be used to develop a rather simple dynamic (weekly or two-week time step), seasonal, either two layer or whole-lake, mass balance TP model that is easily calibrated to observed lake data
- Such a model has practical and realistic use in managing TP in lakes and reservoirs. The model computes gross (before sedimentation loss) TP internal loading.
- Predicted average season TP concentrations can then be used to estimate average chl concentrations and transparency
- Lake response can be predicted before and after restoration treatment

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## Example Phosphorus Budget Detail for Grand Lake St. Marys

| Source | TP Phosphorus Loading (kg) | Percent of Total TP Load | Percent of Summer TP Load |
|---|---|---|---|
| Direct Precipitation | 1,230 | 2.1% | 1.4% |
| Chickasaw Creek | 8,930 | 15.6% | 1.0% |
| Chickasaw WWTP | 236 | 0.4% | 0.0% |
| Barnes Creek | 796 | 1.4% | 0.2% |
| Beaver Creek | 7,996 | 14.0% | 1.3% |
| Montezuma WWTP | 1,332 | 2.3% | 0.0% |
| Burntwood Creek | 2,320 | 4.1% | 0.5% |
| Coldwater Creek | 10,802 | 18.9% | 2.1% |
| St. Henry's WWTP | 1,046 | 1.8% | 0.6% |
| Little Chickasaw Creek | 3,230 | 5.6% | 0.5% |
| Prairie Creek | 2,619 | 4.6% | 0.5% |
| Ungaged Basin | 1,964 | 3.4% | 0.3% |
| Elks ADF | 1 | 0.0% | 0.0% |
| Marion Local School ADF | 27 | 0.0% | 0.0% |
| Northwood WWTP | 162 | 0.3% | 0.2% |
| **Total External Load (5/1/2010 to 5/13/2011)** | **42,691** | **74.6%** | -- |
| **Total External Load (6/12 to 9/17/2010)** | **1,380** | -- | **8.7%** |
| | | | |
| **Internal Load (6/12 to 9/17/2010)** | **14,552** | **25.4%** | **91.3%** |
| | | | |
| **Total P Load (5/1/2010 to 5/13/2011)** | **57,243** | **100.0%** | |
| **Total P Load (6/12 to 9/17/2010)** | **15,933** | **27.8%** | |

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## Model Prediction of Phosphorus Concentration in GLSM


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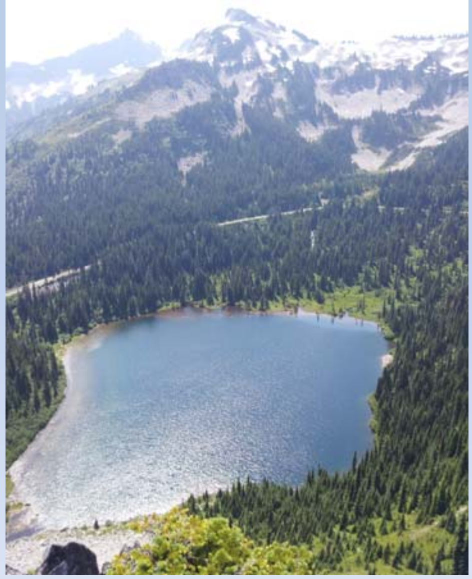
Questions



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# Kiser Lake

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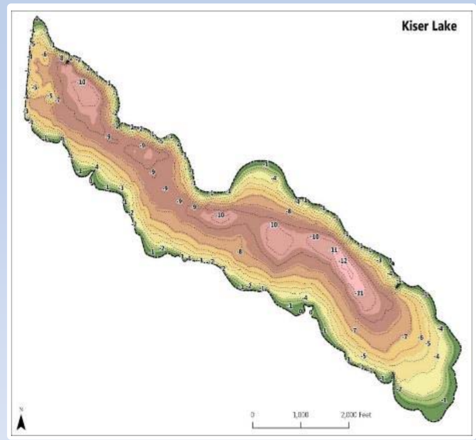
# Kiser Lake Characteristics

- The lake has a surface area of 159 hectares (394 acres)
- Mean depth is approximately 1.9 m (6.2 feet)
- There are 8.9 km (5.5 miles) of shoreline
- The lake is relatively shallow, and has abundant vegetation, including large areas of lily pads
- The hydraulic residence time of the lake is 0.45 to 0.58 years
- In 1840, a dam was erected on Mosquito Creek

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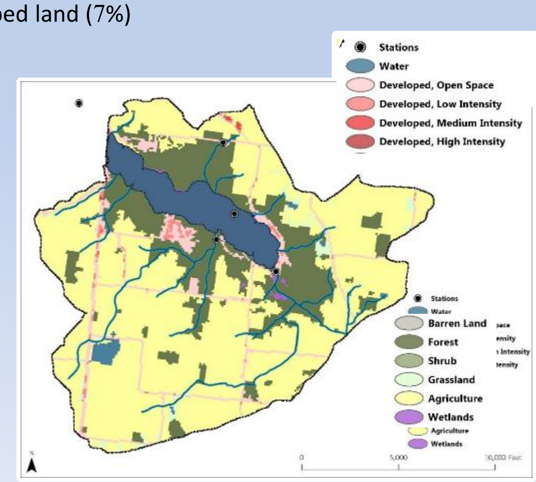
# Kiser Lake Watershed Land Use

- The Kiser Lake watershed is approximately 2158 hectares (5,332 acres) and primarily consists of cultivated cropland (54%). The remainder is hay/pasture (8%), forest (21%), and developed land (7%)
- The Village of Grandview Heights is on the south side of the lake. This community has around 70 homes and uses on-site sewage systems.
- There are approximately 100 additional homes within the watershed
- Near the northern edge of the watershed there is an unregulated animal feeding operation



# Lake Water Quality

- Water quality monitoring efforts at Kiser Lake by Ohio EPA were most recently conducted in September and October 2015. Historical monitoring efforts at Kiser Lake by Ohio EPA include those conducted in in 1977, 1989, 2009, and 2010
- All samples were collected at one main lake station (L-1)
- Kiser Lake trophic state – hypereutrophic
- Lake TP averaged 79 – 99 µg/L (> 100 µg/L) summers 1989, 2009, 2010

| | |
|---|---|
| Chl | 70 – 87 µg/L (> 25 µg/L) |
| SD | 0.47 – 0.76 m (< 1 m) |

- Chl:TP ratio = 0.71 – 1.10; much higher than normal (world avg. 0.33) due to enrichment but within the reality check

Chl:TP ratio = **1.6 – 2.1 in 2015 ⇨ TP of 33 and 17 µg/L too low relative to historical data**

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# Toxic Algae Blooms

- Nuisance algal blooms caused by excess nutrient concentrations have become more common at Kiser Lake and in some cases have produced toxins (i.e. microcystin)
- In July 2015, microcystin was detected in samples collected at the Kiser Lake State Park Beach above both the Recreational Public Health Advisory (6 µg/L) and the Recreational No Contact Advisory (20 µg/L) concentrations
- The state of Ohio issued only a public-health advisory because there were no reported probable cases of human illness or pet deaths as a result of the bloom



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## Sources of TP

- Potential TP sources (based on runoff coefficient):
  - Whole watershed: 2339 kg/yr
  - Crop land: 1949 kg/yr
- If whole watershed forest: $\frac{70\ kg/yr}{0.21} = 333\ kg/yr$
  - *7x* less than with crop (2339 kg/yr)
- Estimates of inflow concentrations if runoff volume ~ 1 m/yr:
  - Watershed: 110 µg/L
  - Crop land: 170 µg/L
- Observed inflow concentrations 2015: 70-171 µg/L
- Data from 2010 unreliably low: ND – 29 µg/L
- Internal loading probably large: lake TP too large to be due to inflow TP only, although data sparse




## Nutrient Assessment

- The Mosquito Valley was historically a low marshy area, dotted with numerous springs
- Given this, as well as Kiser Lake's historical hyper-eutrophic water quality conditions, the lake morphometry, and the abundant aquatic vegetation, internal loading of phosphorus is most likely occurring and has been for some time
- Shallow lakes with enriched sediments (due to a history of high external loading) typically have extensive phosphorus recycling
- Internal phosphorus mechanisms in shallow lakes, like Kiser Lake, include sediment release through iron-redox reactions, wind resuspension, cyanobacteria uptake and migration, bacteria mineralization of sediment phosphorus, and bioturbation
- Without additional lake phosphorus samples as well as a phosphorus mass balance model, the magnitude and timing of internal loading cannot be determined

# Proposed 1-yr Intensive Monitoring

- Twice monthly monitoring and sample collection in Kiser Lake from March through October (critical period is the growing season from May – September), monthly during the remainder of the year
- Conduct monitoring at main lake station
  - Collect samples from 0.5 m below surface and 0.5 m above bottom
  - Determine temperature, pH, DO, and specific conductivity at 0.5-m intervals throughout the water column
  - Record Secchi disk depth at same time
- Analyze water samples for TP, SRP, TN, $NO_3$+$NO_2$, $NH_4$, and chl
  - Split sample analysis (send samples to two laboratories for QA/QC purposes). Use method with low detection limit

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# Proposed 1-yr Intensive Monitoring

- In conjunction with lake sampling, collect monthly samples from the major tributaries to Kiser Lake, including the 3 that were sampled in October, 2015. Analyze for TP, SRP, TN, $NO_3$+$NO_2$, $NH_4$
  - Also collect 2 or 3 samples during > 6 storm events to capture runoff inputs
  - Ideally, install an automatic, composite sampling device in major stream
  - Measure flow in tributaries at time of sampling
- Gather information necessary to develop a water budget for the lake and to determine hydraulic residence time:
  - Install continuous flow loggers in Mosquito Creek (the largest tributary to Kiser Lake) in order to obtain records of lake inflow. Install staff gauges on smaller tributaries
  - Install and maintain level loggers in the lake near the dam and in the outlet structure to obtain records of both lake level and outflow

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# Proposed 1-yr Intensive Monitoring

- Collect samples for phytoplankton analysis monthly
- Test for cyanotoxins (microcystin, etc.) if algal blooms or surface scums are observed, or if concentrations of chl exceed 10 μg/L
- Conduct an aquatic plant survey each August to map the community structure, density, and coverage of aquatic macrophytes within the lake

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# Data Analysis

- Lake: Summer means for TP, chl, and SD
- Construct water budget and TP mass balance on 2-week intervals; may need ground water TP concentration if significant in the water budget
  - Calculate summer internal loading, knowing input, output, and change in storage
  - Anoxia may exist temporarily near bottom in deep pockets (~3 m) during calm periods – may not show from two-week interval DO profiles
- Calibrate a seasonal mass balance model by selecting appropriate TP settling rates
  - Predict effects of:
    1) Reduced external load
    2) Reduced internal load
    3) Other scenarios
- Evaluate the cost benefit and sustainability of management alternatives both in the watershed and in-lake based upon predicted outcomes for HAB control.

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# Lake Alma

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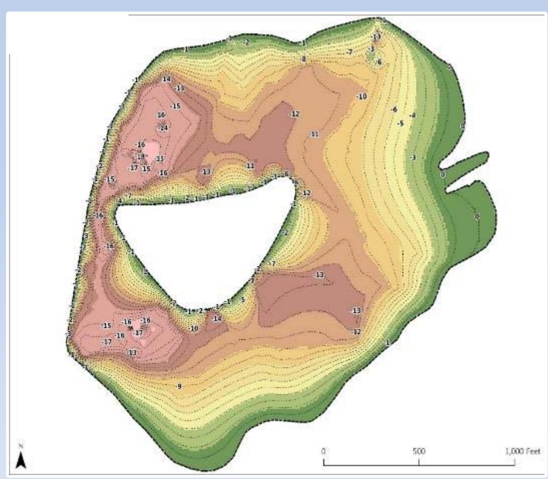
# Lake Alma Characteristics

- The lake has a surface area of 26 hectares (64 acres)
- Mean depth is approximately 2.5 m (8.2 feet). Max. 5 m
- There are 2.4 km (1.5 miles) of peripheral shoreline
- The lake also has a small island with 0.8 km (0.5 miles) of shoreline
- Used periodically and historically as a water supply for the City of Wellston, OH

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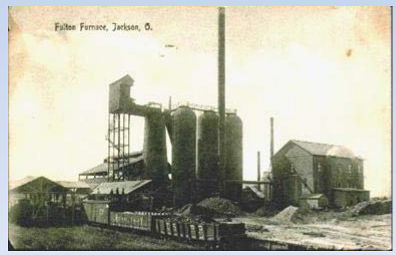
## Lake Alma Watershed Land Use

- Lake Alma is part of the larger Raccoon Creek watershed. Historically, this region of Ohio was home to a booming mining industry
- As a result of this mining legacy, two impoundments remain in the eastern part of the watershed on the hillside above Lake Alma
- In the mid-1990s, heavy rainfall caused these impoundments to be breached on two occasions. The resulting runoff drained into Lake Alma, and contributed high loads of sediment to the lake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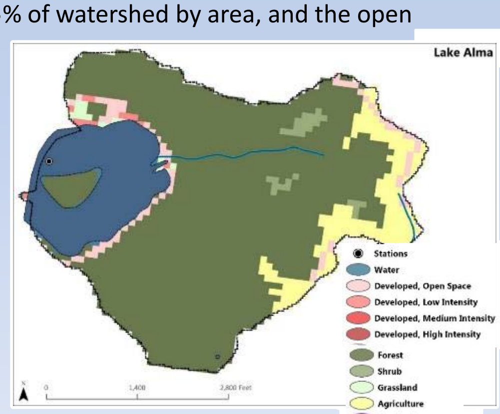
## Lake Alma Watershed Land Use

- The Lake Alma watershed is 184 hectares (455 acres), and is predominantly forested (71%), with mixed oak composition
- Lake Alma itself makes up 13% of watershed by area, and the open space and low intensity development associated with the state park comprise an additional 4%
- The eastern portion of the watershed contains some shrub/scrub land (1.4%), as well as agricultural land, consisting of cultivated crop land (7%) and pasture land (2%)

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# Lake Alma Water Quality

- The 2015 water transparency and chl data together suggest that the lake is currently meso-eutrophic
- Low TP concentrations are not in line with this assessment, but they are likely an underestimate of true concentrations and are of little use for evaluating water quality in Lake Alma
  - [TP] < [Ortho-phosphorus] on two dates. TP must be underestimated because ortho-phosphorus is a fraction of TP, and a part cannot be greater than the whole
  - Deep sample on 10/1/2015 may have been contaminated with bottom sediments

| Date | Depth | Total Phosphorus 10 | Ortho-Phosphorus (µg/L) | TKN (mg/L) | $NO_2$+$NO_3$ (mg/L) | $NH_4$ (mg/L) | Chl (µg/L) | Secchi (m) | Chl:TP |
|---|---|---|---|---|---|---|---|---|---|
| **5/1/1980** | surface | **(µg/L)** | | | | | 9.6 | 4.40 | 0.96 |
| **8/18/1980** | surface | 20 | | | | | 6.2 | 2.00 | 0.31 |
| **9/17/2015** | 0.5 | 5 (ND)[1] < | 11.1 | 1.13 | 0.05 (ND) | 0.025 (ND) | 16.9 | 1.65 | 3.38[2] |
| **9/17/2015** | 4.8 | 27[1] | 17.1 | 1.53 | 0.05 (ND) | 0.914 | | | |
| **10/1/2015** | 0.5 | 5 (ND)[1] | 2.4 | 0.74 | 0.05 (ND) | 0.087 | 20.5 | 1.97 | 4.10[1] |
| **10/1/2015** | 5 | 674[1] < | 733.6[3] | 6.78 | 0.11 | 6.03 | | | |

[1]TP data are likely underestimations of true concentrations
[2]Calculated using 5 µg/L, half the detection limit.
[3]Sample possibly contaminated by bottom sediments.

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# Lake Alma Water Quality

- 2010 - 2 probable human illnesses due to algal toxins (ODH)
  - **October 2010 Microcystin concentration of 275 µg/L at Dog Park**
- Recent (2013 – 2015) algal toxin data for Lake Alma all below detection limit except for September 2015 when Microcystin at detection limit

- Samples are collected at three sites within the lake, including the park beach
- Overall, it is difficult to assess the ecological condition of Lake Alma without a larger and more robust water quality dataset for the period of stratification

# External Loading

- Lake Alma watershed 71% forested, only 7 % cropland
- Inflow TP ~ 125 µg/L if runoff 1 m/yr
- Forest runoff = 30 µg/L, cropland runoff = 1,200 µg/L. TP Ag = 40*x* forest
- If whole watershed forested, loading 4*x* less (55 kg/yr) than with current land use (225 kg/yr)
- Need actual observed loading to manage lake water quality

| NLCD Land Use | STEPL Land Use | Percentage (%) | Acres |
|---|---|---|---|
| **Open Water** | Omitted | 13 | 59.2 |
| **Dev. Open Space** | Urban | 4 | 18.2 |
| **Developed Low Intensity** | Urban | 1.6 | 7.3 |
| **Mixed Forest** | Forest | 71 | 323.1 |
| **Pasture/Hay** | Pasture | 2 | 9.1 |
| **Cultivated Crops** | Cropland | 7 | 31.9 |
| **Shrub/Scrub** | Pasture | 1.4 | 6.4 |

| STEPL Land Use | Total Phosphorus Load (lb/yr) | Total Phosphorus Load (kg/yr) | Percent (%) |
|---|---|---|---|
| **Urban** | 30.2 | 13.7 | 6.1 |
| **Cropland** | 340.8 | 154.6 | 7.8 |
| **Pastureland** | 38.5 | 17.5 | 68.7 |
| **Forest** | 86.4 | 39.2 | 17.4 |
| **Total** | 495.9 | 224.9 | 100 |

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# Nutrient Assessment

- There does appears to be a significant difference between surface and bottom TP concentrations in Lake Alma, although the number of surface and bottom samples collected is low (n = 2)
- Internal phosphorus mechanisms in Lake Alma most likely include sediment release through iron-redox reactions, cyanobacteria uptake and migration, bacteria mineralization of sediment phosphorus, and bioturbation via grass carp
- Given the low DO concentrations observed in September and October 2015 it is assumed that internal loading of phosphorus is occurring at Lake Alma. Given the small watershed and lack of major inflow internal loading is most likely the dominant source of loading to Lake Alma
- Without additional lake phosphorus samples as well as a phosphorus mass balance model, the magnitude and timing of the internal loading cannot be determined

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## Proposed 1-yr Intensive Monitoring

- Twice monthly monitoring and sample collection in Lake Alma from March through October (critical period is the growing season from May – September), monthly during the remainder of the year
- Conduct monitoring at deep site
  - Collect samples from 1, 3 and 4.5 m below surface
  - Determine temperature, pH, DO, and specific conductivity at 0.5-m intervals throughout the water column
  - Record Secchi disk depth at same time
- Analyze water samples for TP, SRP, TN, $NO_3$+$NO_2$, $NH_4$, and chl
  - Split sample analysis (send samples to two laboratories for QA/QC purposes). Use method with low detection limit
- Test for cyanotoxins (microcystin, etc.) if algal blooms or surface scums are observed, or if concentrations of chl exceed 10 μg/L. Analysis for algal counts, biovolume, and taxa is expensive
  - If TP can be managed to < 20 μg/L, cyanobacteria blooms should be relatively low

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## Proposed 1-yr Intensive Monitoring

- Collect monthly samples from the minor tributary to Lake Alma, if flowing at time of lake sampling. Analyze for TP, SRP, TN, $NO_3$+$NO_2$, $NH_4$.
  - Also collect 2 or 3 samples during storm events to capture runoff inputs
  - Ideally, install an automatic, composite sampling device in major stream
  - Measure flow in tributary at time of sampling
- Gather information necessary to develop a water budget for the lake and to determine hydraulic residence time:
  - Install continuous flow logger in minor tributary to Lake Alma to obtain records of lake inflow
  - Install and maintain level loggers in the lake near the dam and in the outlet structure to obtain records of both lake level and outflow
- Conduct an aquatic plant survey each August to map the community structure, density, and coverage of aquatic macrophytes within the lake

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# Data Analysis

- Lake: Summer means for TP, chl, and SD
- Loading:
  - Water budget, calculate ground water quantity and sample GW for TP (wells, seepage meters, etc.)
  - Mass balance for TP (calculated internal loading) on 2-week intervals
- Calibrate seasonal mass balance model for whole lake TP. Lake too shallow to assume permanent whole-summer stratification
  - Select appropriate TP settling rate and calculate gross internal loading
  - May be possible to calculate sediment P release rate from "hypolimnion" (4 – 5 m) TP with time, if stratification persists
- Evaluate management alternatives with TP model
- Evaluate the cost benefit and sustainability of management alternatives both in the watershed and in-lake based upon predicted outcomes for HAB control.



# Long-Term Monitoring

- Continuous gauge on inflow/outflow
- Auto-composite sampler on inflow/outflow
- Twice monthly grab sampling during summer (May – September), monthly sampling during winter
  - Collect at 1 m or take 1-3 m composite with sampling tube
  - Analyze for TP only. TP enough to gauge lake condition
  - Measure Secchi depth concurrently
  - Enlist volunteer(s) to conduct sampling
- Collect grab samples from inflow/outflow at same time

## IN-LAKE MANAGEMENT ALTERNATIVES

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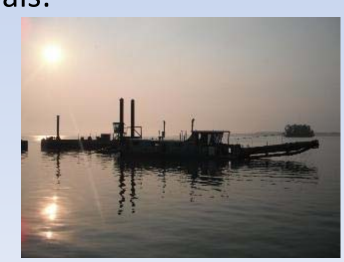
## Sediment P Removal Dredging

- Dredging is a good restoration approach
- Advantages:
  - Directly removes P
  - Potentially restores sediment characteristics,
    - Lower TOC, P, aerial hypolimnetic oxygen deficit (AHOD)…
  - Longevity dependent upon watershed loading and flushing rate.
- Risk factors relative to achieving goals:
  - Area dredged
  - Depth of sediment removal
  - Completeness of aerial removal
  - Handling of dredged material
  - Cost management



## Dredging Continued

- Critical factors to address for ensure successful dredging
  - Sediment data to define:
    - Area(s) to be dredged
    - Depth of sediment to be removed
    - Characteristic of sediment remaining
      - Predict period and nature of new equilibrium relative to nutrient cycling
      - Is P inactivation needed to prevent cyanobacteria blooms in response to dredging
      - Dredged sediment management requirements
  - Sediment disposal
  - Total life cycle cost $

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## Hypolimnetic Withdrawal

- Key for this technique is the rate volume drawn relative to P influx of P from the sediments
  - The net extraction of P from the lake has to be 15 times the internal loading rate
    - Prevent post-turnover bloom
    - Spring pre-stratification
    - Mid summer diffusion, wind transfer to epilimnion or cyanobacteria vertical transfer of P from hypolimnion
- To maintain lake level and stratification must inject low P water into the hypolimnion
  - Must offset P loading from injection water

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## Dilution

- Supply low nutrient
- Increase outflow of P
- Reduction in available P in water column
- Dilution volume needed; 2 to 15% of lake water volume per day
- For large lakes low nutrient water supply usually in short supply and/or expensive
- Dilution must decrease water column P, but must also increase effective P flushing

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## Aeration and Circulation

- Three basic processes for effective implementation
  - Mixing depth
    - Light limitation
    - Speed of circulation
  - Control of redox with iron in 15:1 minimum ratio (Fe:P)
  - If mineralization of P dominated by organic release light is critical to limit photosynthesis or can see increase in algal production
  - In shallow large lakes with significant wind induced fetch mechanical or aeration induced mixing and oxygenation rarely reduces algal production

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## Hypolimnetic Aeration

- Phosphorus release that is Iron controlled best application
- Must circulate hypolimnetic volume at least every 13 days
- Must maintain DO at least 4 mg/L
- Iron in both water column and sediment must be in excess of 15:1 (Fe:P)

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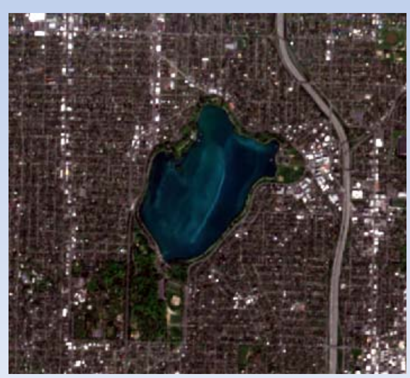
## Phosphorus Inactivation

- Most effective in-lake management action today
- Effective in both stratified and unstratified lakes
- Treatment strategies
  - Interception
  - Water column stripping
  - Maintenance
  - Inactivation



## Alum or Ca, Fe, La Lake Treatment for Phosphorus Control - Common Approaches

- All applications strategies share
  - **Metal** is active ingredient
  - **Capture**
    - Chemically binds with phosphorus
  - **Transport**
    - Removal from water (sludge)
    - Distributed to lake sediments
  - **Inactivation**
    - Reducing bioavailability of phosphorus

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## Phosphorus Inactivation Factors

- Redox Sensitivity
  - Fe high
  - Al, La, Ca low
- Capturing P generated from P organic mineralization
  - Al high
  - La assumed high
  - Ca and Fe poor performance
- pH within the Sediment
  - Most sediment pH range Al binds to P and maintains bond best as a function pH and available Al density.

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## Aluminum Sulfate

- Phosphorus Control Since 1960s
- Aluminum Precipitates with Phosphorus from pH 2 to pH 9
- Aluminum Phosphate is Very Insoluble
  - Al is Not Easily Leached
  - P is Not Easily Resolubilized
- Other Phosphorus Precipitants are Less Effective

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## In-lake Treatments are NOT One Time Activity - Just Like Watershed BMPs

- Al-P and floc layer settles at ~1.5 cm/yr, is mixed by bioturbation and is gradually covered with new sediment (Cooke, et al., 2005)
- Additional treatments probably necessary:
  - Long Lake-Kitsap: 1980, 1991, 2007
  - Green Lake: 1991, 2004, 2016
    - After 2004 alum treatment Green Lake experience first HAB in summer of 2012
    - Iron-P in sediment converted to Al-P since the 2004 treatment
- GLSM 2012 treatment

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# Summary

- Internal P loading in shallow lakes may be more important than external P loading in summer algal bloom production in the short-term
- In shallow lakes even modest flux rates from sediments result in high water column concentrations due to shallowness that may lead to HAB
- Watershed BMPs will only address part of the increase in external P loading due to land-use compared to historical P loading
- Phosphorus inactivation has been proven effective in shallow lakes, regardless of the level of watershed management, in reducing internal P loading and HABs
- Phosphorus inactivation is also effective in deep stratified lake where hypolimnetic P becomes available to drive Cyanobacteria blooms
- Must always work with watershed BMPs to reduce overall loading to lakes and reservoir for long-term management success.

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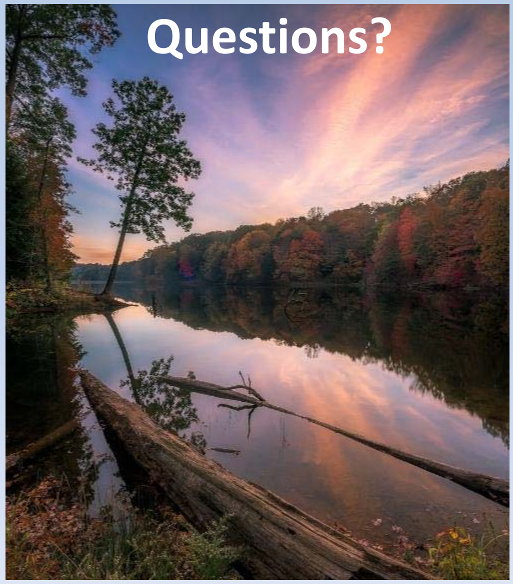


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