

# Lake Management Workshop

Ohio Lake Training  
Horace R. Collins Lab



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&

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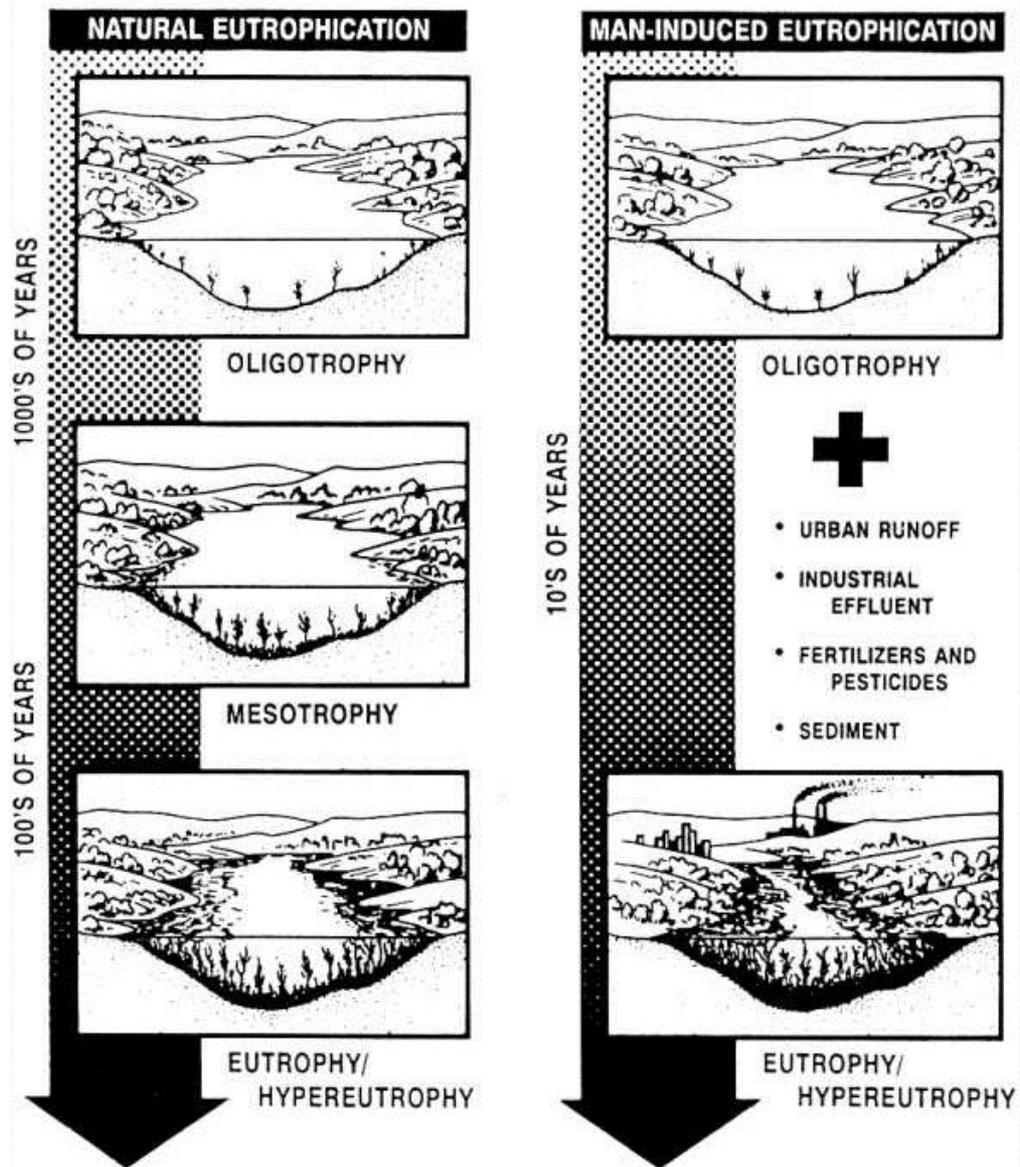
June 15, 2016



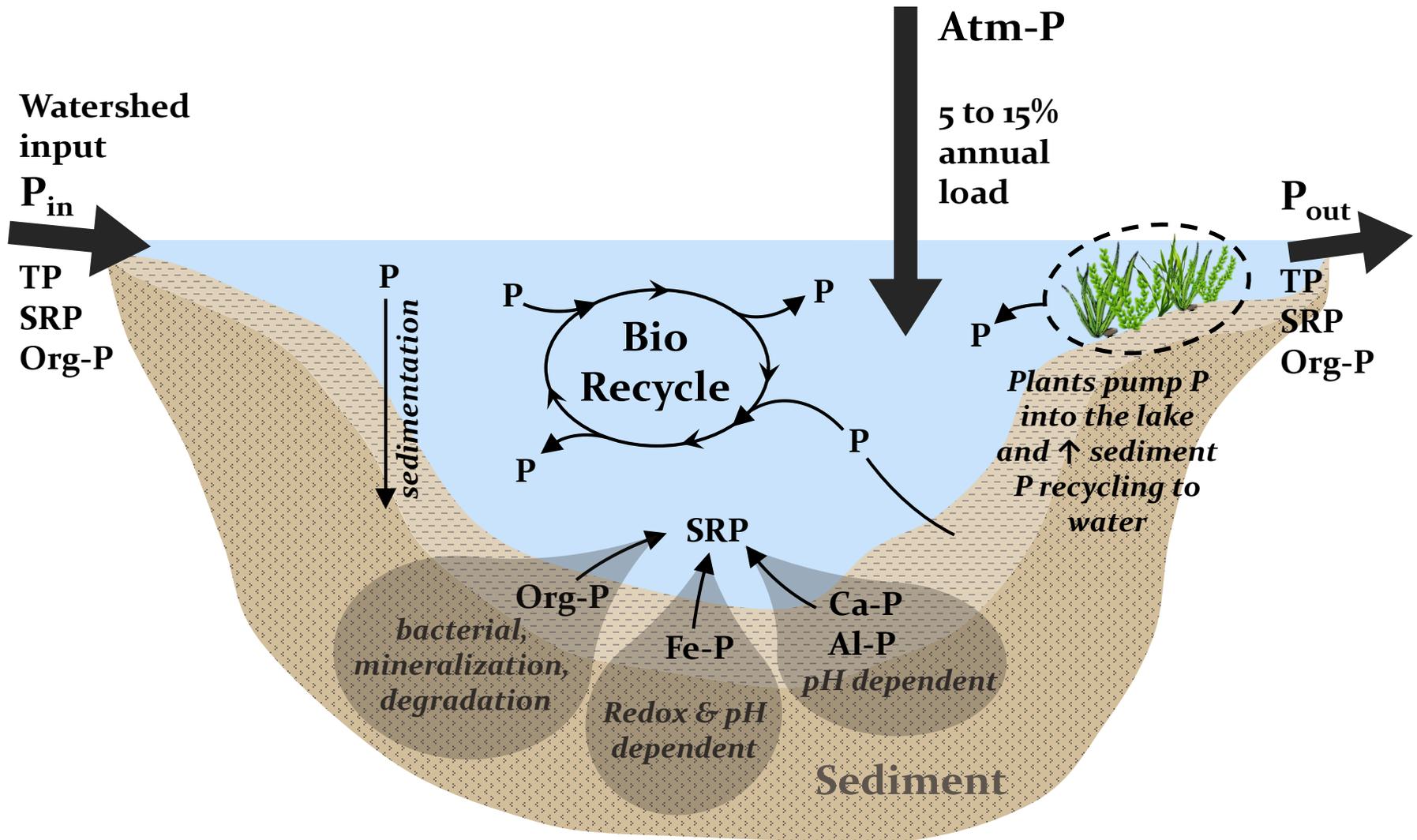
# Introduction

USEPA is providing technical assistance to Ohio to advance the State's nutrient reduction efforts, specifically focusing on reducing the occurrence and impact of harmful algal blooms (HABs) in inland lakes with a priority for lakes that are sources of drinking water.

- Ohio case studies and lessons learned
  - Kiser Lake
  - Lake Alma
  - Rose Lake
- Assessment of current data gaps and monitoring recommendations for filling those gaps
- Evaluation of available data relative to the potential for HABs
- 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



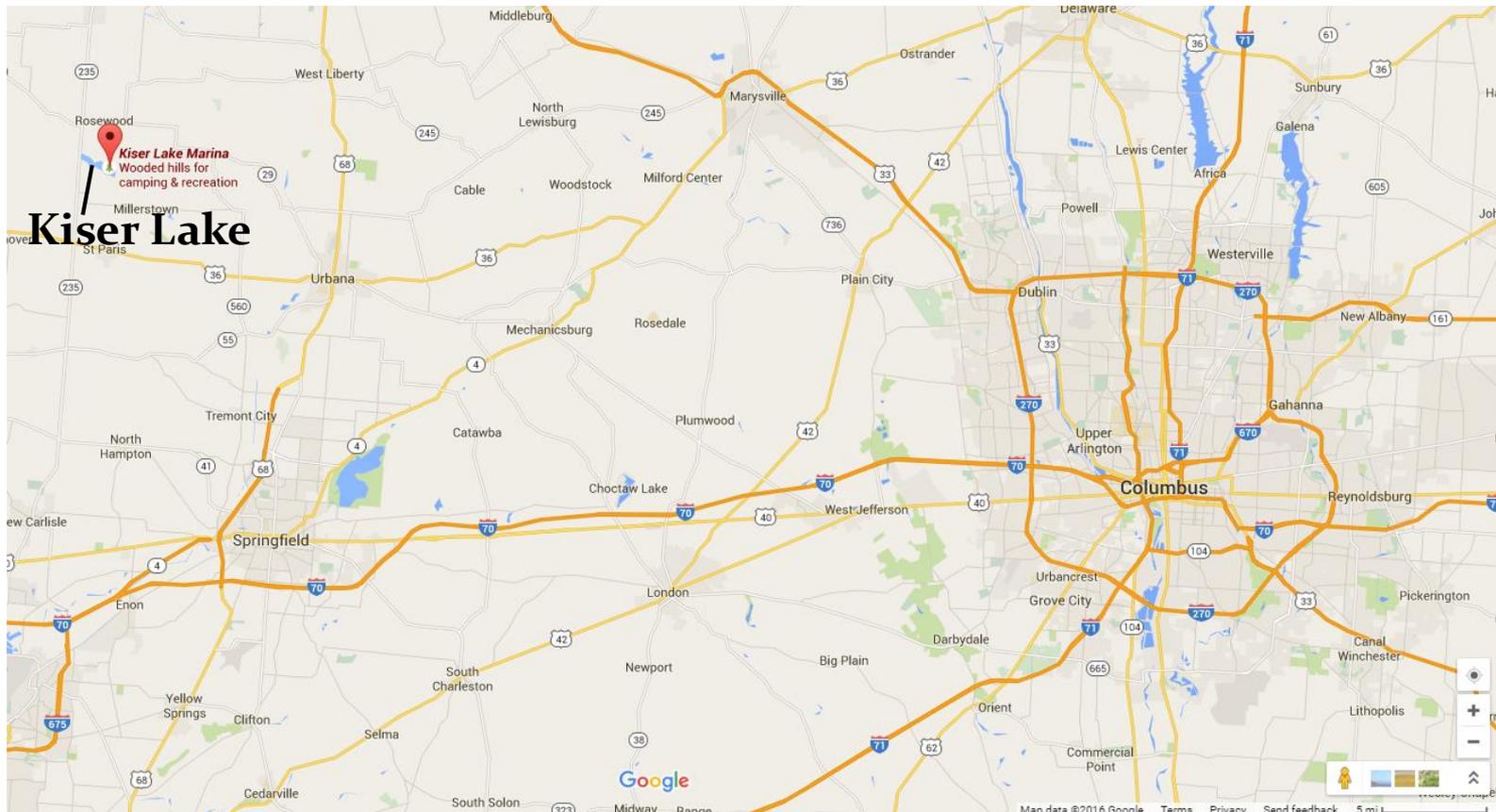
# Phosphorus Cycle



# Kiser Lake

# Kiser Lake

Kiser Lake is located in Champaign County approximately 60 miles northwest of Columbus, Ohio



# Kiser Lake

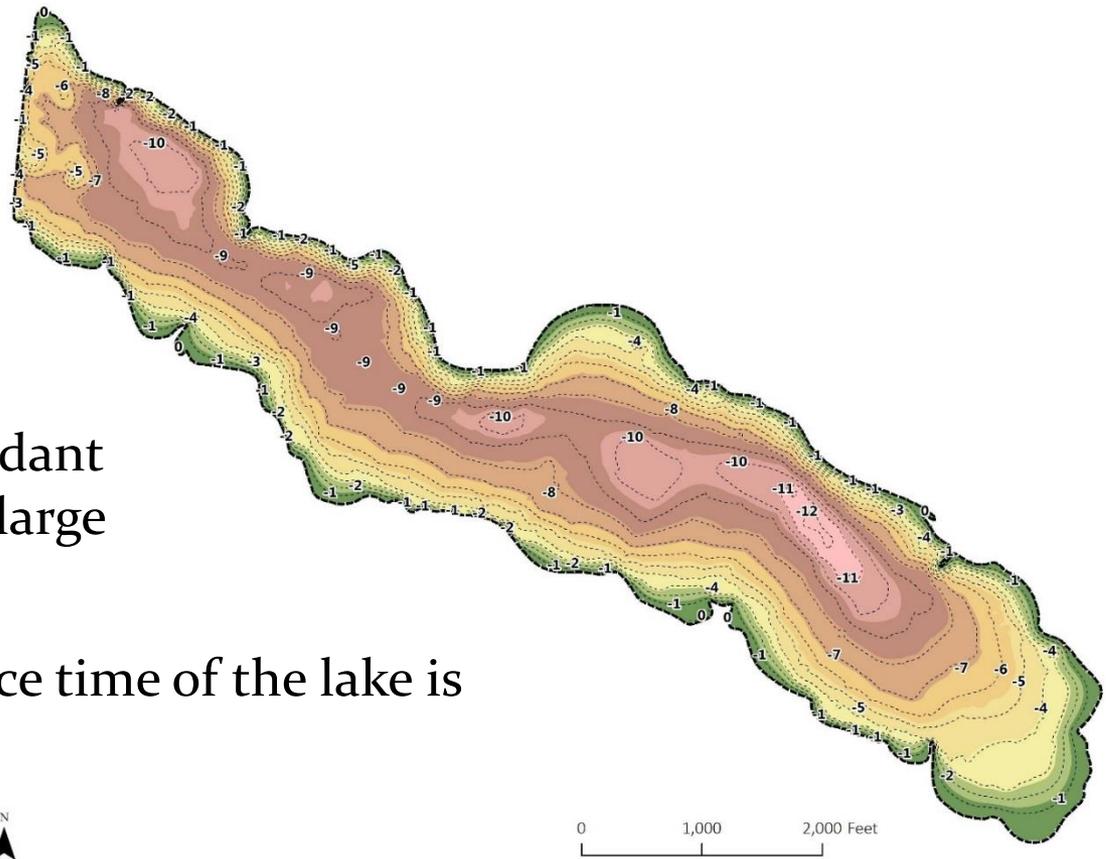


# Kiser Lake



# 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



# Background

- Gently, rolling wooded hills that surround the lake were caused by glacial deposits in the form of end moraines. One end moraine called the Farmersville surrounds the lake on 3 sides.
- The wetlands at Kiser Lake are in the form of fen and wet meadow habitat. Now filled with many plants including pitcher plant, sundew, tamarack and spruce.



# Kiser Lake State Park

- The lake is managed by the Ohio Department of Natural Resources and is part of Kiser Lake State Park
- In 1840, a dam was erected on Mosquito Creek to furnish power for a grist and saw mill. When this operation ceased, most of the lake was lost
- In 1932, The Kiser family offered the state of Ohio several hundred acres of the Mosquito Creek Valley
- Construction of the new dam began in 1938 and all work was completed during 1940

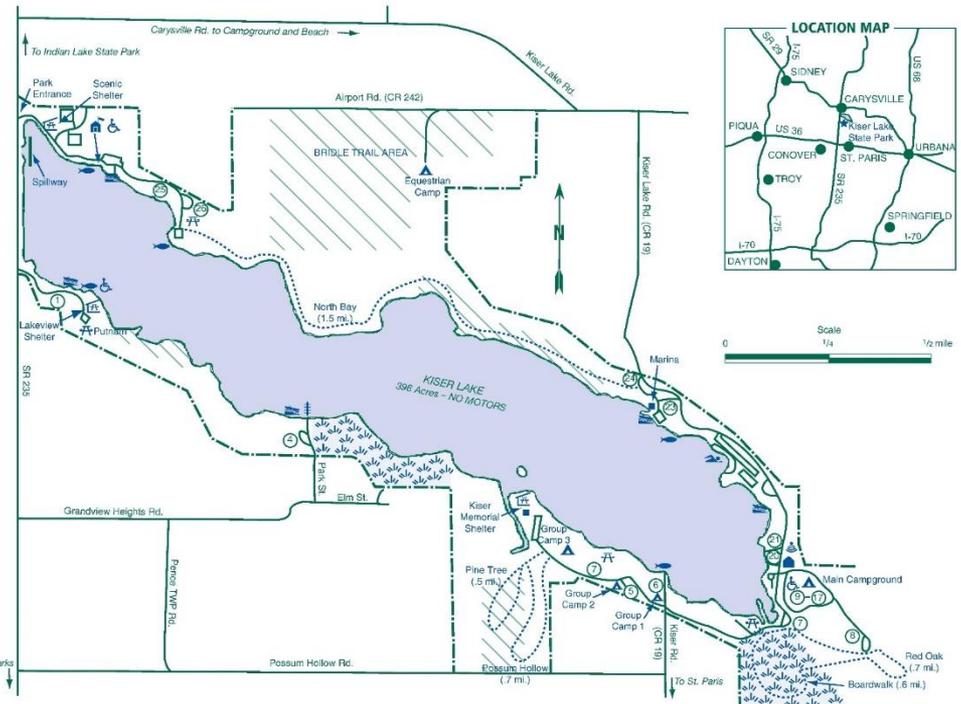
## Kiser Lake State Park

**Park Location:**  
4370 Kiser Lake Road  
St. Paris, Ohio 43072  
(937) 362-3565 - Marina/Camp

**Administrative office:**  
Buck Creek State Park  
1976 Buck Creek Lane  
Springfield, Ohio 45502  
(937) 322-5284 - Buck Creek  
Park Office

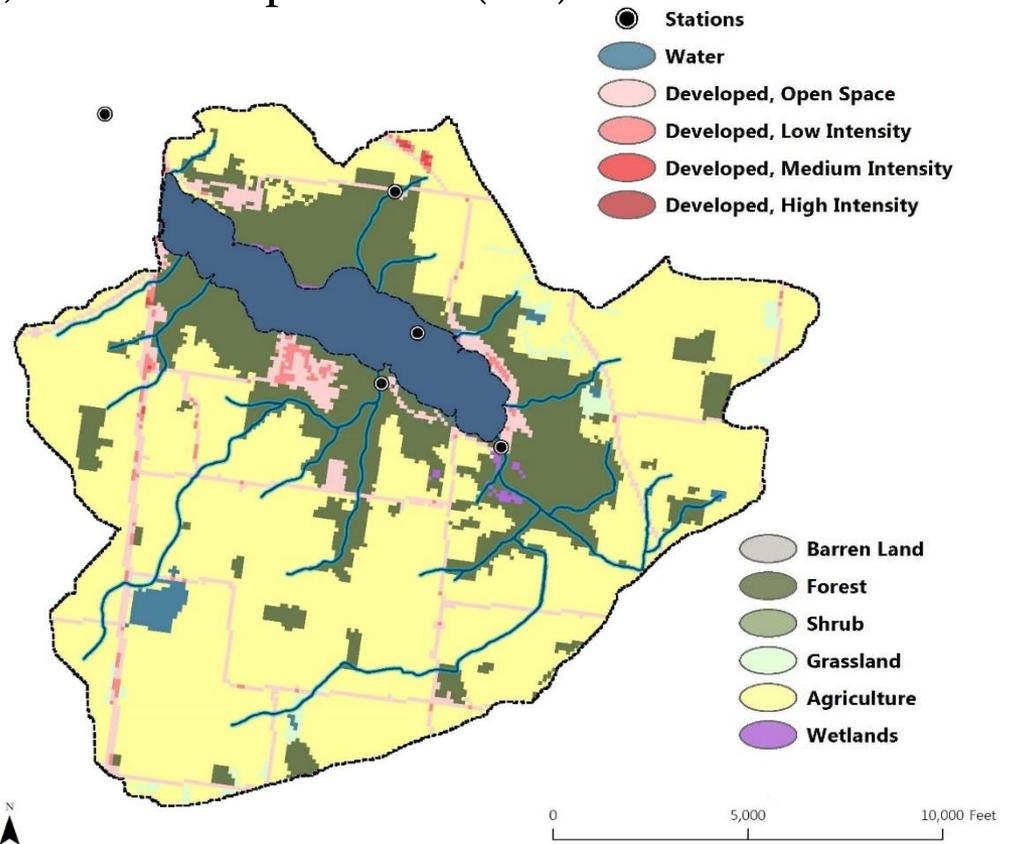


Rev. 10/15



# 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

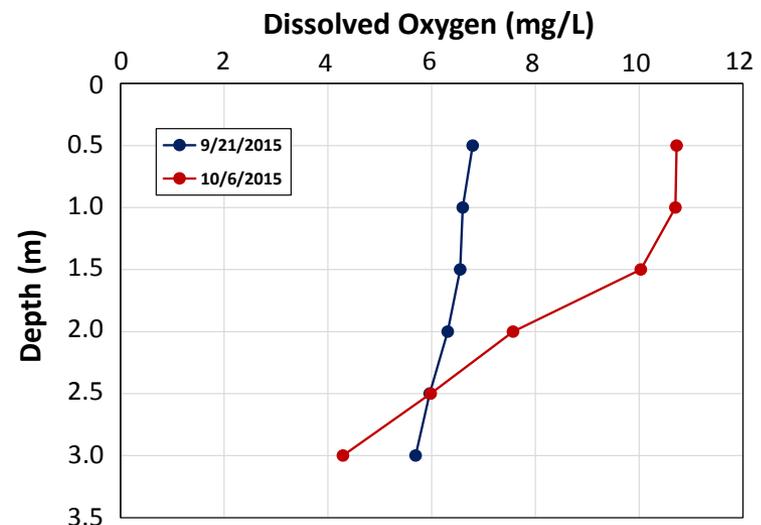
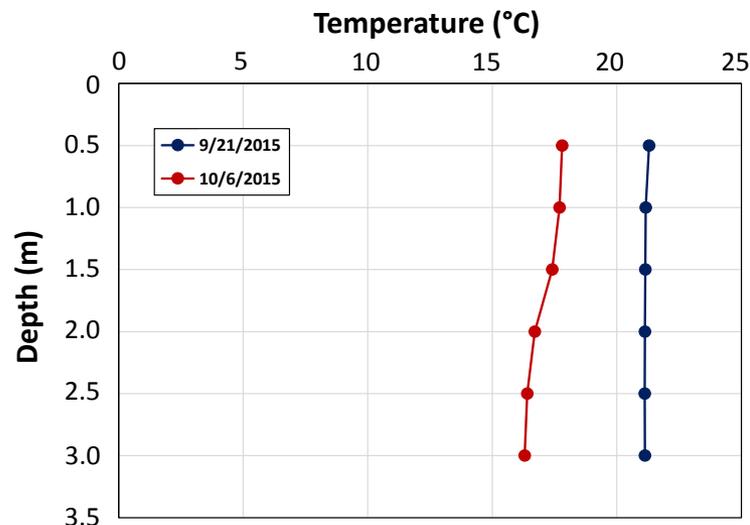
- Water quality monitoring efforts at Kiser Lake by Ohio EPA were most recently conducted in September and October 2015. Historical monitoring efforts at Kiser Lake by Ohio EPA include those conducted in 1977, 1989, 2009, and 2010
- All samples were collected at one main lake station (L-1)
- Kiser Lake trophic state – hypereutrophic
- Lake TP averaged 79 – 99  $\mu\text{g/L}$  ( $> 100 \mu\text{g/L}$ ) summers 1989, 2009, 2010
  - Chl            70 – 87  $\mu\text{g/L}$  ( $> 25 \mu\text{g/L}$ )
  - SD            0.47 – 0.76 m ( $< 1 \text{ m}$ )
- Chl:TP ratio = 0.71 – 1.10; much higher than normal (world avg. 0.35) due to enrichment but within the reality check
  - = **1.6 – 2.1 in 2015** → **TP of 33 and 17  $\mu\text{g/L}$  too low**

# Lake Water Quality

Year	Summer (June -September) Mean		
	TP ( $\mu\text{g/L}$ )	Chl ( $\mu\text{g/L}$ )	Secchi Disk Depth (m)
1989	99	69.7	0.47
2009	91	68.8	0.76
2010	79	86.6	0.54
September, October 2015	10 - 37	46.2, 35.5	0.57, 0.69
June, August 1989 (Fulmer and Cooke)	106, 128	20.6, 109	0.56, 0.51
July 2007 NLA	108	34.8	0.61

# Lake Water Quality

- Recent temperature profiles show a mixed water column
- Dissolved oxygen concentrations in September were slightly lower than saturation (64 to 77%)
- In October they were above saturation (105 to 113%) in the top 1.5 m and below saturation (45 to 79%) in the bottom 2 m. Given the high concentration of chl measured in September and October 2015 it is likely that DO was being driven by photosynthetic activity



# 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

Kiser Lake tests high for bacteria after harmful algal bloom



By Tyler Utzka

Published: July 15, 2015, 11:21 pm | Updated: July 15, 2015, 11:22 pm



# Tributary Water Quality

- Concentrations of phosphorus and nitrogen are high in tributaries

## MOSQUITO CREEK @ KISER LAKE RD. (CO. RD. 19)

Year	Date	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	TKN (µg/L)	NO <sub>2</sub> +NO <sub>3</sub> (µg/L)	NH <sub>4</sub> (µg/L)	Chl (µg/L)	FLOW (cfs)
2010	7/21/2010	ND	ND	240	2,320	90	0	1.782
	8/4/2010*	20	ND	470	1,810	116	0.7	2.15
	8/18/2010	ND	ND	340	2,110	100	0.3	1.111
2015	10/29/2015*	70	45	500	3,700	ND	--	--

## TRIB. TO MOSQUITO CREEK (9.50) NEAR MOUTH (Southeast shore)

Year	Date	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	TKN (µg/L)	NO <sub>2</sub> +NO <sub>3</sub> (µg/L)	NH <sub>4</sub> (µg/L)	Chl (µg/L)	FLOW (cfs)
2010	7/21/2010	ND	ND	ND	120	ND	0	0.124
	8/4/2010*	29	ND	ND	170	ND	1.2	0.141
	8/18/2010	18	ND	240	ND	ND	0.6	0.108
2015	10/29/2015*	171	109	640	1,410	ND	--	--

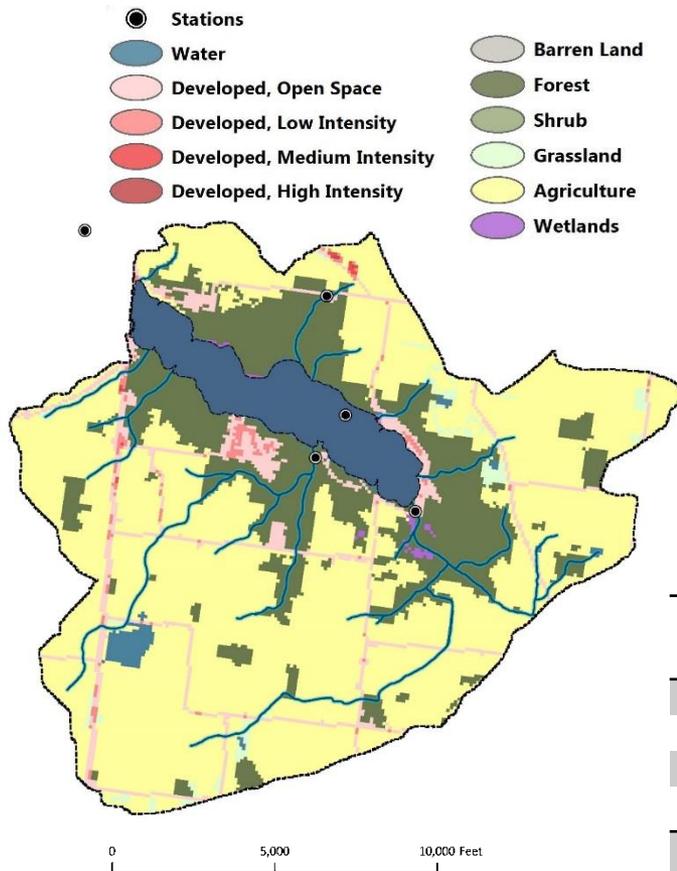
## KISER TRIB. @ SNAPP ROAD (below Dairy Operation in northern part of watershed)

Year	Date	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	TKN (µg/L)	NO <sub>2</sub> +NO <sub>3</sub> (µg/L)	NH <sub>4</sub> (µg/L)	Chl (µg/L)	FLOW (cfs)
2015	10/29/2015*	597	497	1,100	23,500	91	--	--

\* Indicates samples were collected during or immediately following a storm event

# External Loading

- Approximate nutrient loads within the watershed can be estimated according to the relative distribution of land uses within the watershed

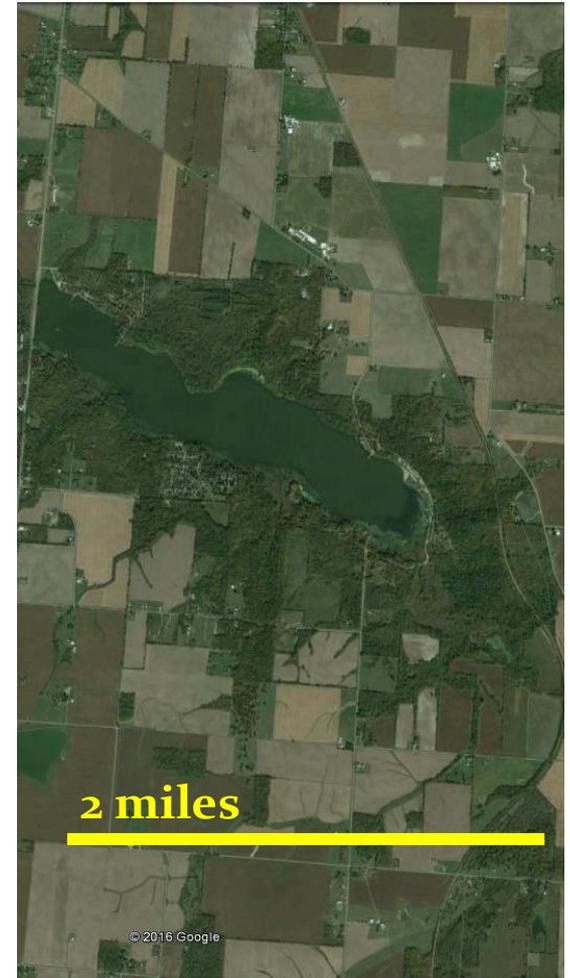


NLCD Land Use	STEPL Land Use	Percentage	Acres
Open Water	Omitted	8.4	448.6
Dev. Open Space	Urban	6.2	331.8
Developed Low Intensity	Urban	0.8	44
Developed Medium Intensity	Urban	< 0.1	3.8
Developed High Intensity	Urban	< 0.1	0.9
Deciduous Forest	Forest	20.8	1107.7
Evergreen Forest	Forest	0.2	13.1
Mixed Forest	Forest	< 0.1	2.7
Grassland/Herbaceous	Pasture	1.3	68.7
Pasture/Hay	Pasture	8.2	436.1
Cultivated Crops	Cropland	53.7	2861.5
Emergent Herbaceous Wetlands	Omitted	0.2	13.1

STEPL Land Use	Total Phosphorus Load (lb/yr)	Total Phosphorus Load (kg/yr)	Percent
Urban	383	174	7.4
Cropland	4297	1949	83.3
Pastureland	322	146	6.3
Forest	154	70	3.0
<b>Total</b>	<b>5156</b>	<b>2339</b>	<b>100.0</b>

# Sources of TP

- Potential TP sources (based on runoff coefficient):
  - Whole watershed: 2339 kg/yr
  - Crop land: 1949 kg/yr
- If whole watershed forest:  $\frac{70 \text{ kg/yr}}{0.21} = 333 \text{ kg/yr}$ 
  - 7x less than with crop (2339 kg/yr)
- Estimates of inflow concentrations if runoff volume ~ 1 m/yr:
  - Watershed: 110  $\mu\text{g/L}$
  - Crop land: 170  $\mu\text{g/L}$
- Observed inflow concentrations in 2015: 70-171  $\mu\text{g/L}$
- Data from 2010 unreliably low: ND – 29  $\mu\text{g/L}$
- 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,  $\text{NO}_3+\text{NO}_2$ ,  $\text{NH}_4$ , and chl
  - Split sample analysis (send samples to two laboratories for QA/QC purposes). Use method with low detection limit

# 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,  $\text{NO}_3+\text{NO}_2$ ,  $\text{NH}_4$ 
  - 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

# Proposed 1-yr Intensive Monitoring

- Collect samples for phytoplankton analysis monthly
  - July 2015 *Microcystis* dominant (Ohio EPA)
- Test for cyanotoxins (microcystin, etc.) if algal blooms or surface scums are observed, or if concentrations of chl exceed 10  $\mu\text{g/L}$
- Conduct an aquatic plant survey each August to map the community structure, density, and coverage of aquatic macrophytes within the lake



# Data Analysis

- Lake: summer (June – September) 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

# Long-Term Monitoring

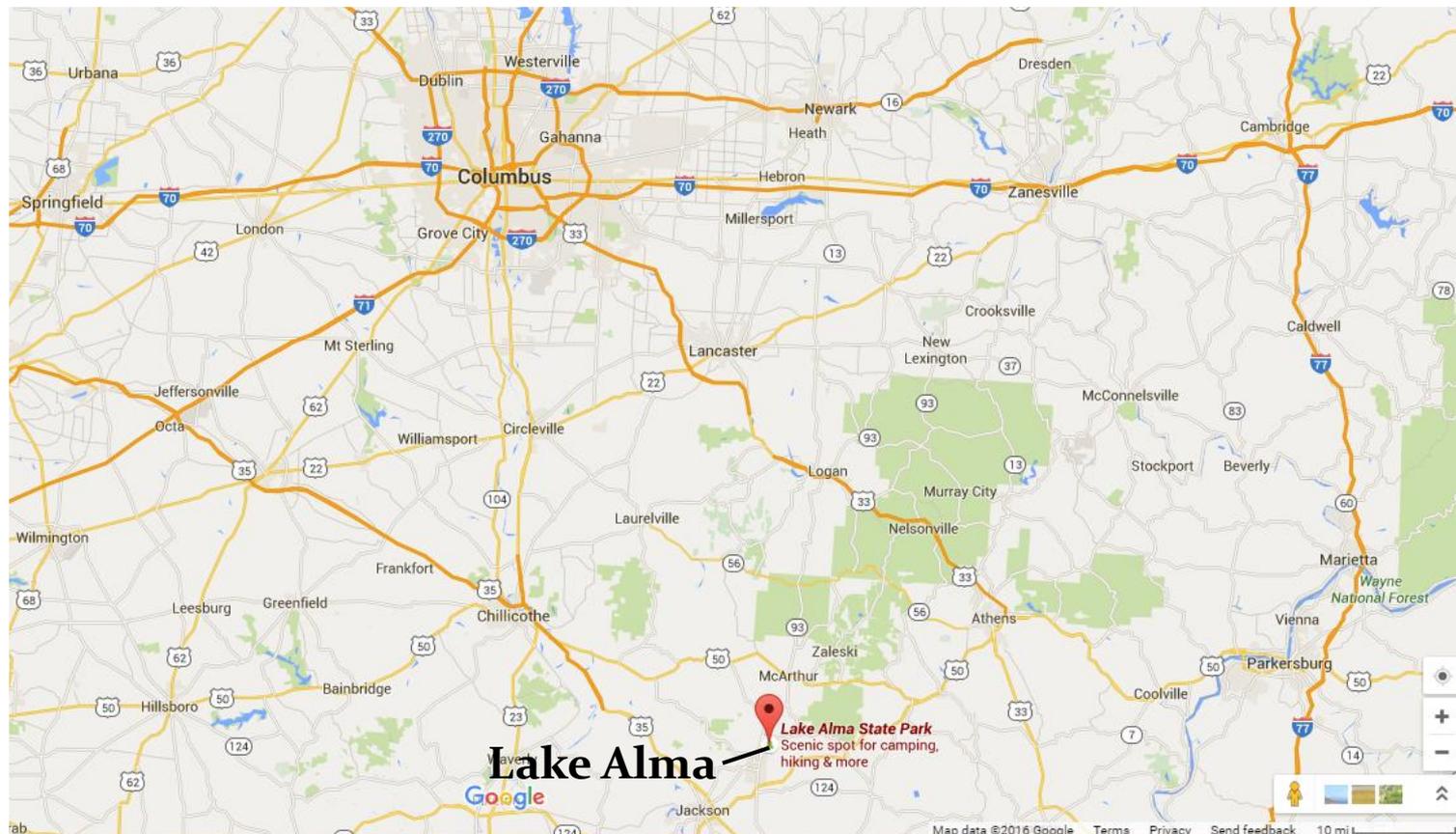
- Continuous gauges on streams and auto-composite TP sampler on major stream
- Twice monthly sampling during summer (May – September), monthly sampling during winter
  - 1 m grab sample and Secchi depth at deep site
  - Sampling conducted by volunteer(s)



# Lake Alma

# Lake Alma

Lake Alma is located on the border of Vinton County and Jackson County in southern Ohio, approximately 60 miles southwest of Columbus, Ohio



# Lake Alma



# Lake Alma

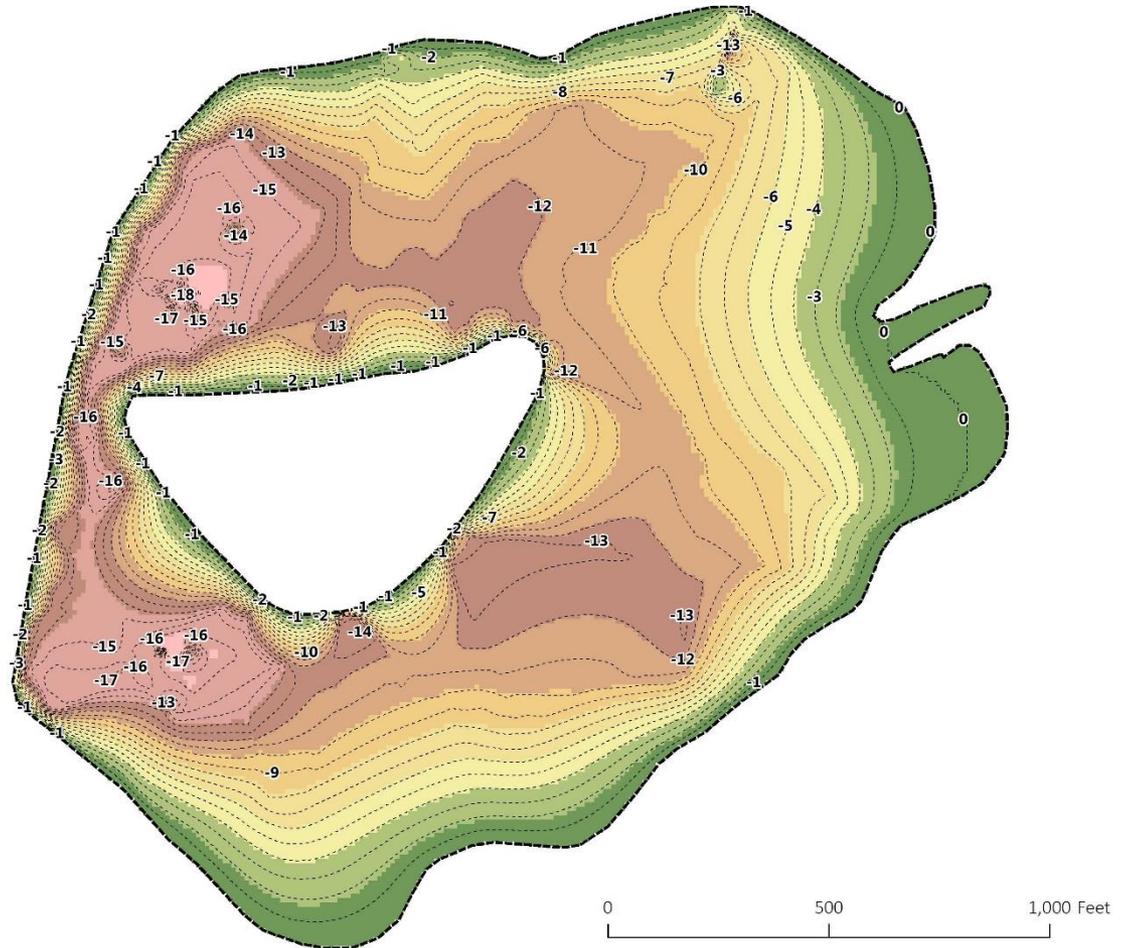


# Lake Alma



# 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



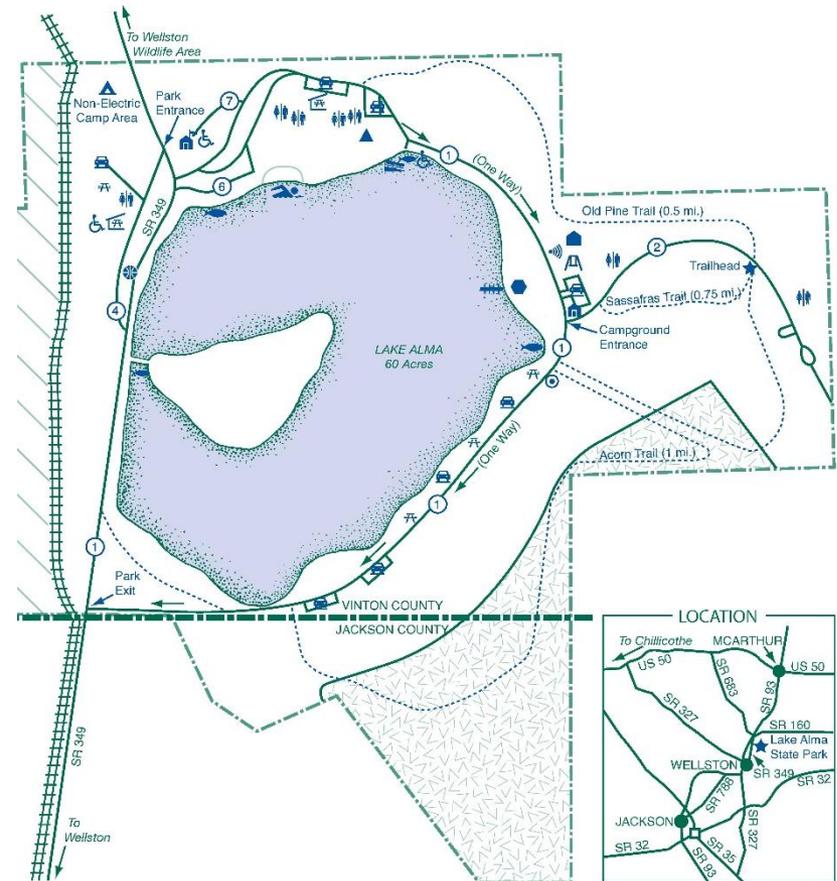
# Background

- In 1901, C.K. Davis, a wealthy coal operator, dammed Little Raccoon Creek to form Lake Alma
- In 1903, he constructed an amusement park on the lake's island. The park boasted a large dance pavilion, an outdoor theater, a merry-go-round, and several other rides
- The property was later purchased by the city of Wellston to serve as a municipal water supply
- The city leases the area to the Ohio Department of Natural Resources Division of Parks and Recreation for operation as a state park



# Lake Alma State Park

- Lake Alma State Park is a popular site for summer recreation
- The park has two camping areas. Vault latrines are located near both camping areas and by the north picnic shelter. Construction of a shower house with flushable toilets and a new dump station will be completed in spring 2016. Sewage is pumped to the Village of Hamden for treatment



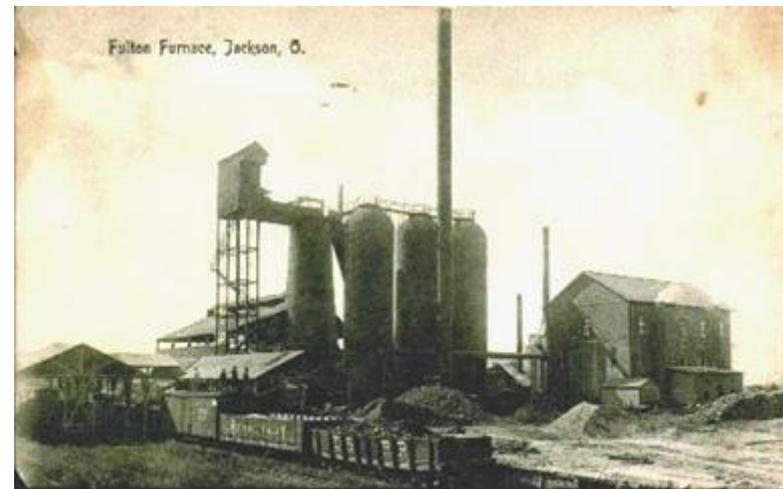
# Lake Alma State Park

- Only non-motorized boats (paddled or powered by electric motors) are permitted on the lake
- State Route 349 runs along the western shore of the lake, overtop the dam
- In spring and summer 2014, the bridge to the island from the western shore of the lake was replaced, and a walking path was constructed along State Route 349 to allow pedestrians to safely access the bridge from nearby parking areas. In addition, trees were removed from the dam for safety, and the spillway of the dam was renovated



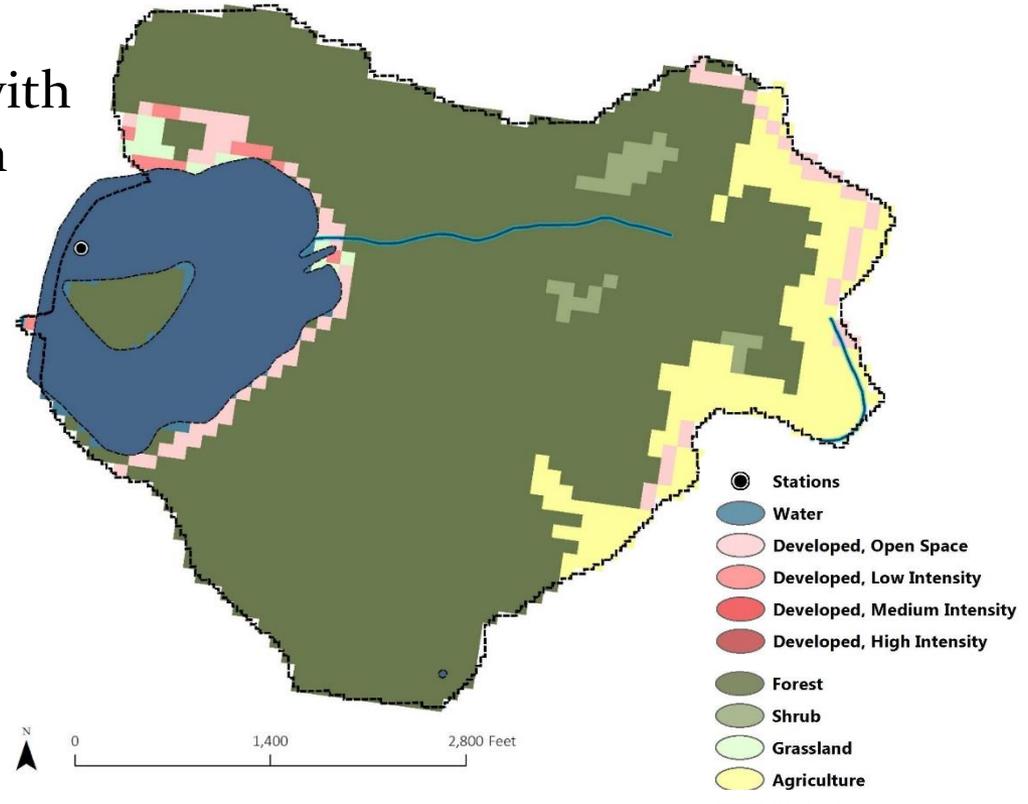
# Lake Alma Watershed Land Use

- 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



# 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%)



# Lake Alma Water Quality

- There is very limited recent or historical water quality data for Lake Alma
- Water transparency and surface concentrations of TP and chl from 1980 indicate that the lake was mesotrophic at the time

Date	Depth	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	TKN (mg/L)	NO <sub>2</sub> +NO <sub>3</sub> (mg/L)	NH <sub>4</sub> (mg/L)	Chl (µg/L)	Secchi (m)	Chl:TP
5/1/1980	surface	10					9.6	4.40	0.96
8/18/1980	surface	20					6.2	2.00	0.31
9/17/2015	0.5	5 (ND) <sup>1</sup>	11.1	1.13	0.05 (ND)	0.025 (ND)	16.9	1.65	3.38 <sup>2</sup>
9/17/2015	4.8	27 <sup>1</sup>	17.1	1.53	0.05 (ND)	0.914			
10/1/2015	0.5	5 (ND) <sup>1</sup>	2.4	0.74	0.05 (ND)	0.087	20.5	1.97	4.10 <sup>1</sup>
10/1/2015	5	674 <sup>1</sup>	733.6 <sup>3</sup>	6.78	0.11	6.03			

<sup>1</sup>TP data are likely underestimations of true concentrations

<sup>2</sup>Calculated using 5 µg/L, half the detection limit.

<sup>3</sup>Sample possibly contaminated by bottom sediments.

# Lake Alma Water Quality

Current status:

- Eutrophic in 2015, based on chl and transparency
  - 1980 – chl ~ 8 µg/L, SD ~3 , TP ~ 15 µg/L
  - 2015 – chl ~ 18 µg/L, SD ~ 1.8 m, **TP ??**

Date	Depth	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	TKN (mg/L)	NO <sub>2</sub> +NO <sub>3</sub> (mg/L)	NH <sub>4</sub> (mg/L)	Chl (µg/L)	Secchi (m)	Chl:T P
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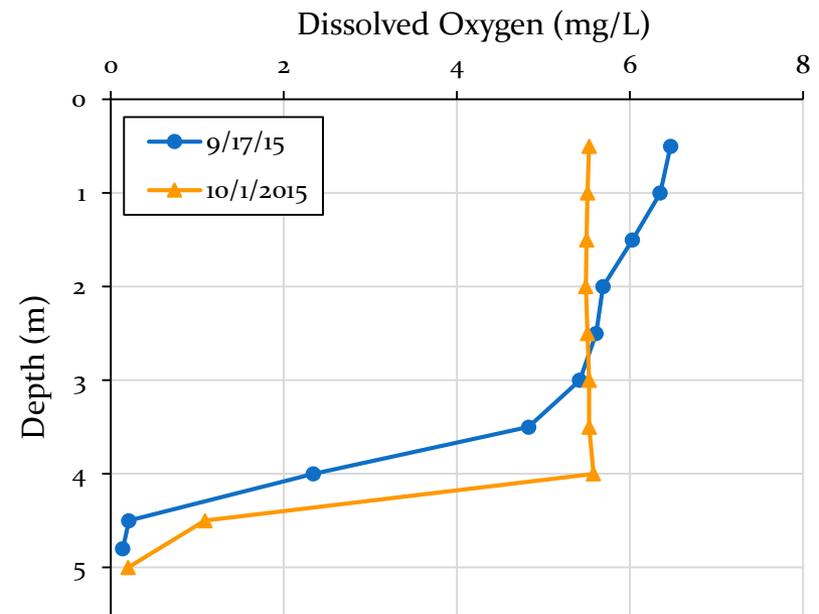
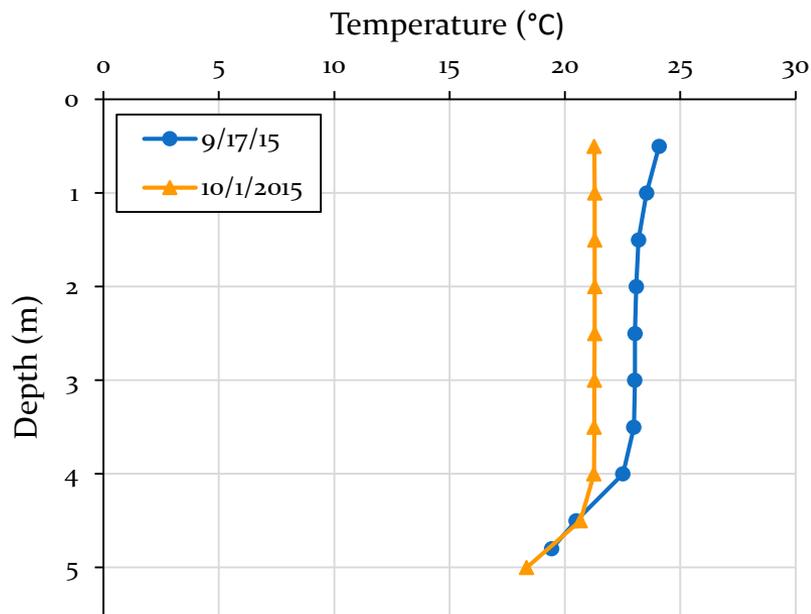
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# Lake Alma Water Quality

- In 2015, the lake was stratified in both September and October, with a distinct thermocline and a rapid decline in concentrations of dissolved oxygen (DO) below 3.5 to 4 m
  - With anoxia, probably high P and available to algae in such a shallow lake



# 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 (µg/L)	Ortho-Phosphorus (µg/L)	TKN (mg/L)	NO <sub>2</sub> +NO <sub>3</sub> (mg/L)	NH <sub>4</sub> (mg/L)	Chl (µg/L)	Secchi (m)	Chl:T P
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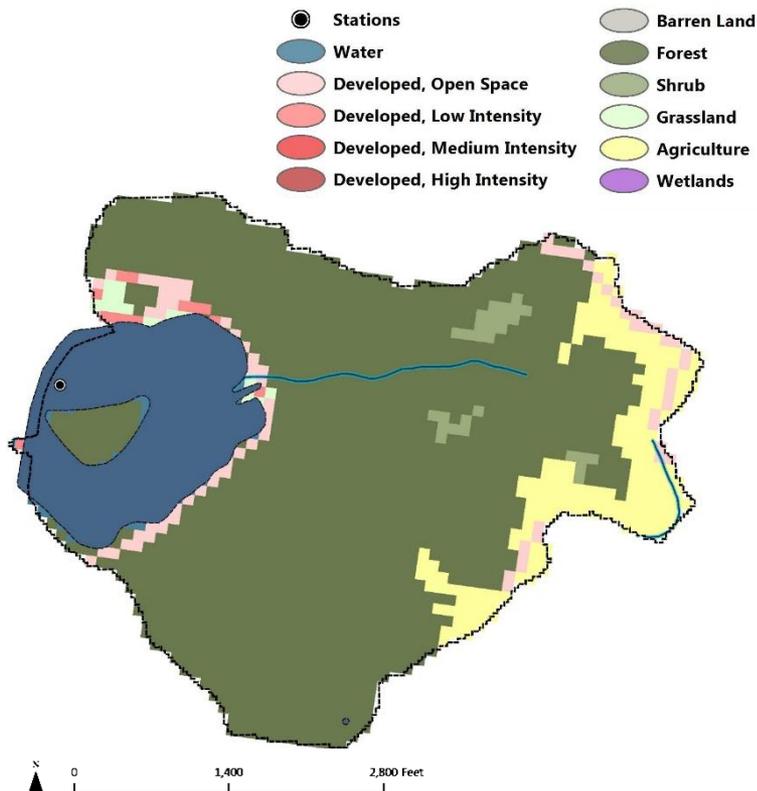
# Lake Alma Water Quality

- 2010 - 2 probable human illnesses due to algal toxins (ODH)
  - **October 2010 Microcystin concentration of 275  $\mu\text{g}/\text{L}$  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

- Approximate nutrient loads within the watershed can be estimated according to the relative distribution of land uses within the watershed



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	68.7
Pastureland	38.5	17.5	7.8
Forest	86.4	39.2	17.4
<b>Total</b>	<b>495.9</b>	<b>224.9</b>	<b>100</b>

# 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 = 40x forest
- If whole watershed forested, loading 4x less (55 kg/yr) than with current land use (225 kg/yr)
- Need actual observed loading to manage lake water quality

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Pastureland	38.5	17.5	7.8
Forest	86.4	39.2	17.4
<b>Total</b>	<b>495.9</b>	<b>224.9</b>	<b>100</b>

# Nutrient Assessment

- There does appear 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

# 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,  $\text{NO}_3+\text{NO}_2$ ,  $\text{NH}_4$ , 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  $10 \mu\text{g/L}$ . Analysis for algal counts, biovolume, and taxa is expensive
  - If TP can be managed to  $< 20 \mu\text{g/L}$ , cyanobacteria blooms should be relatively low

# 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,  $\text{NO}_3+\text{NO}_2$ ,  $\text{NH}_4$ .
  - 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

# Data Analysis

- Lake: summer (June – September) 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

# Long-Term Monitoring

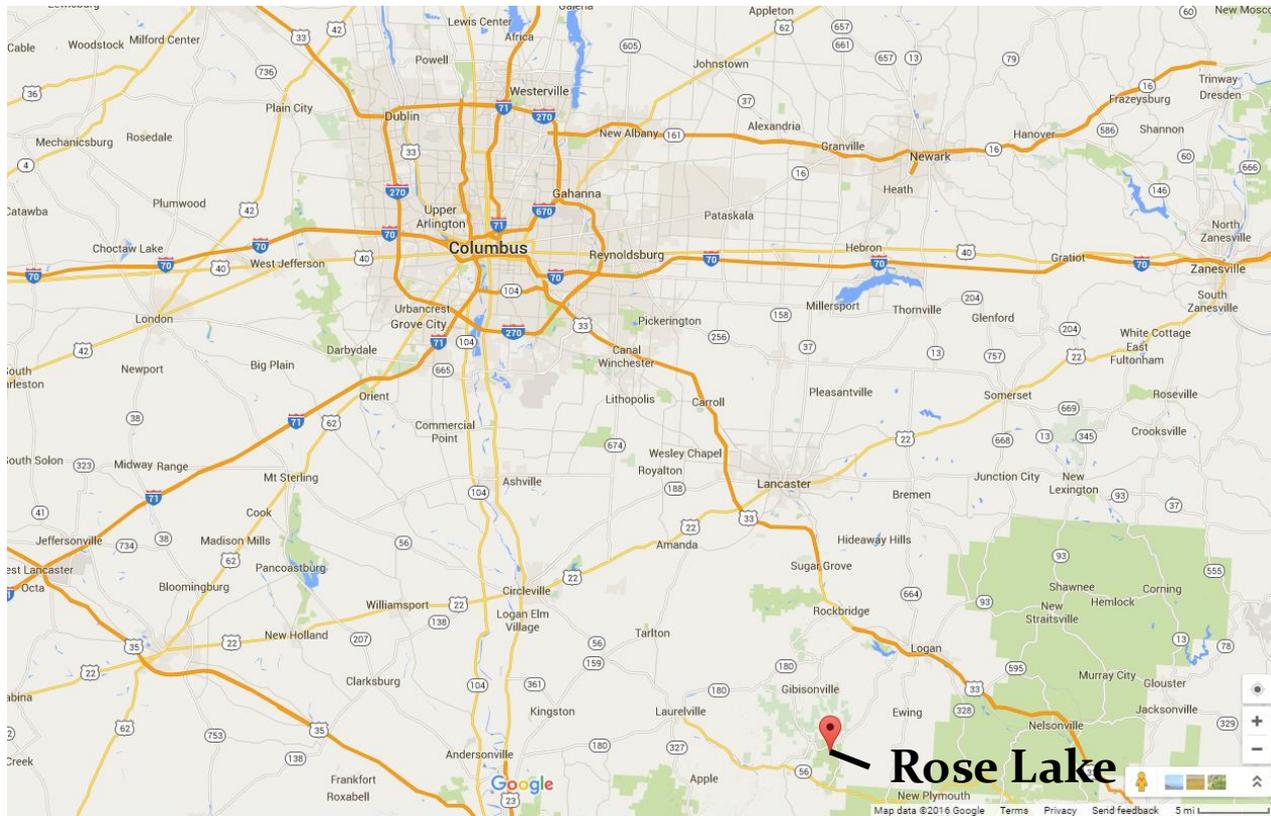
- Continuous gauge on inflow/outflow
- Auto-composite sampler on inflow/outflow
- Twice monthly grab sampling during summer (May – September), monthly sampling during winter
  - Collect at 1 m or take 1-3 m composite with sampling tube
  - Analyze for TP only. TP enough to gauge lake condition
  - Measure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



# Rose Lake

# Background

Rose Lake is a small reservoir located in Hocking County, Ohio, approximately 45 miles southeast of Columbus, Ohio



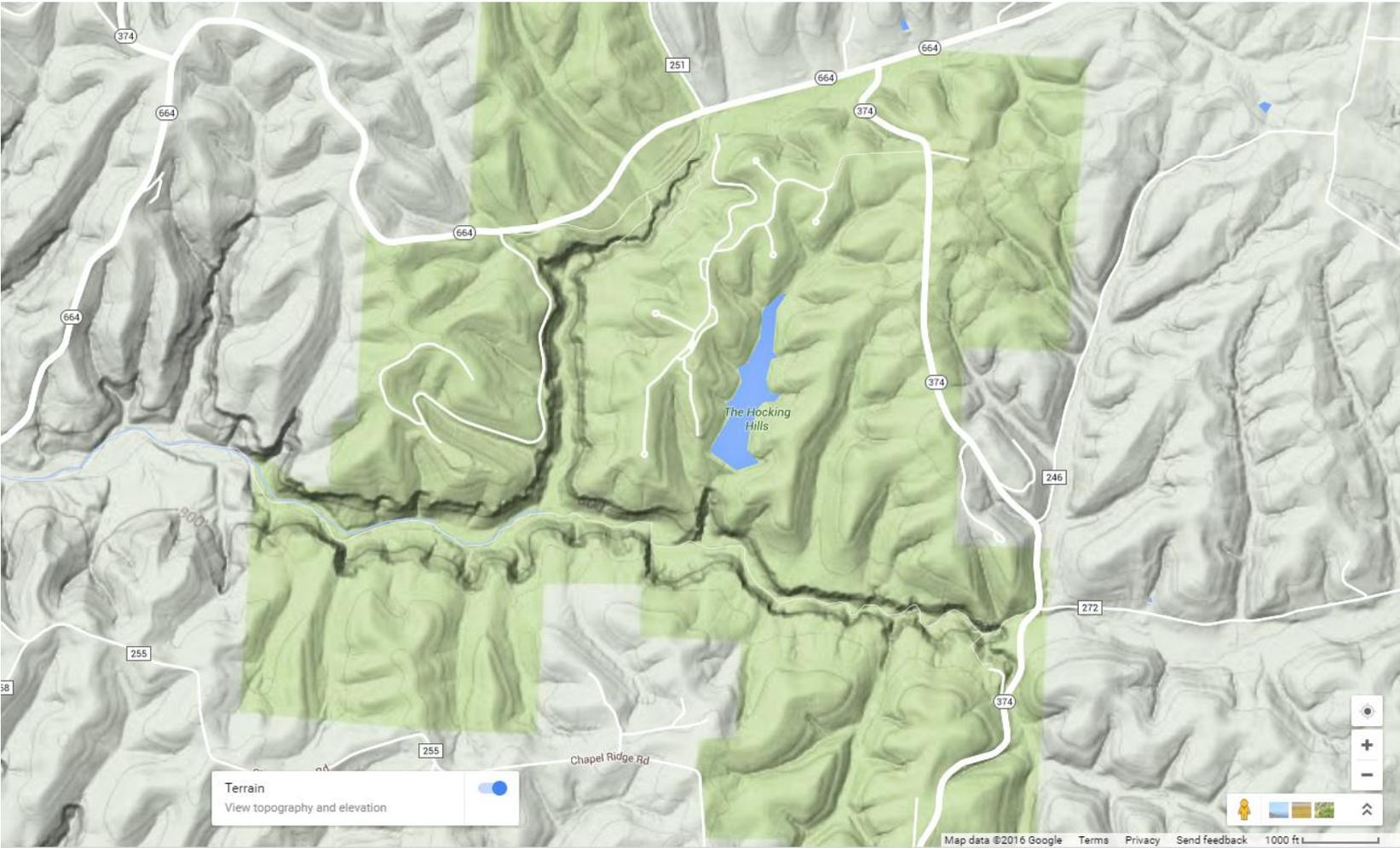
# Rose Lake



# Rose Lake

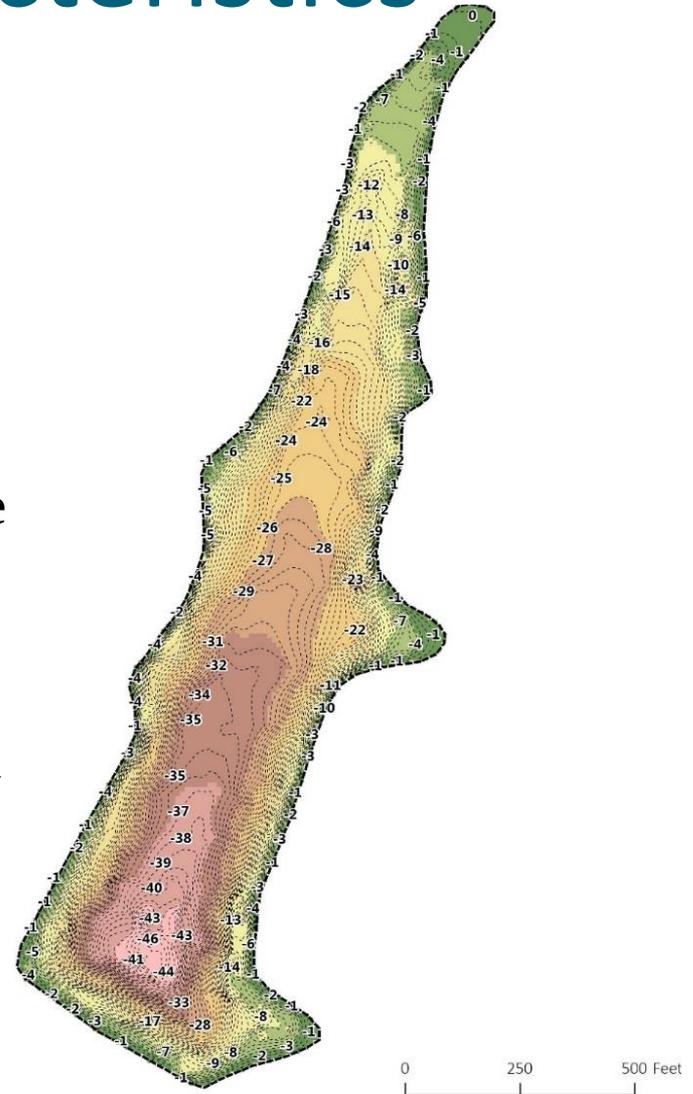


# Rose Lake



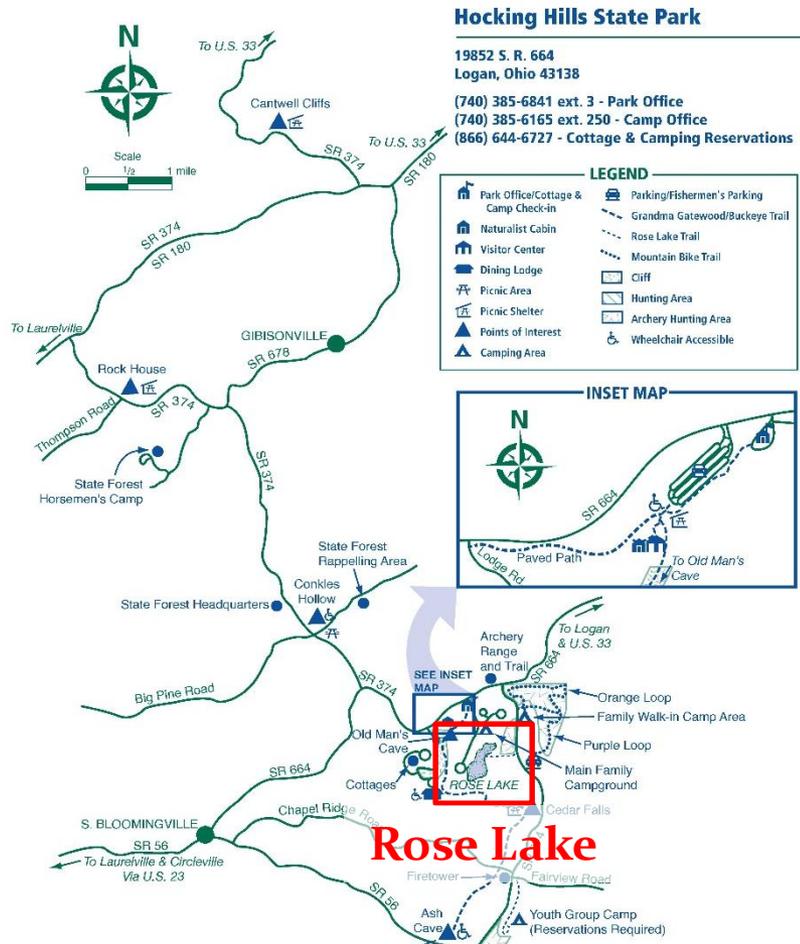
# Rose Lake Characteristics

- The lake has a surface area of 7.7 hectares (19 acres), a mean depth of 6.1 meters (20 feet), and approximately 1.6 km (1 mile) of shoreline
- The lake was formed in 1972 through the construction of a dam on an unnamed tributary to Queer Creek
- The only outlet to the lake is the spillway of the dam, which is located at the south end of the lake



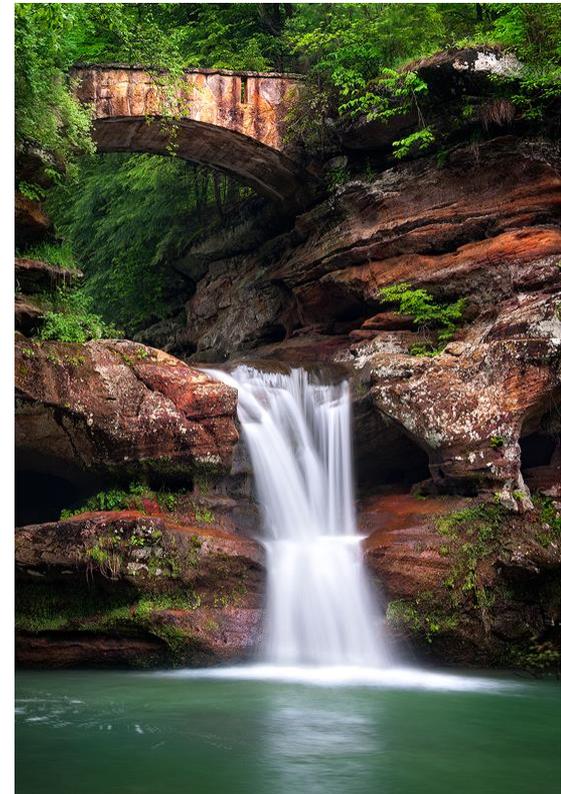
# Rose Lake Characteristics

- The lake is located in Hocking Hills State Park
- No motorized boats are allowed on the lake, and swimming is prohibited
- The lake has a normal assemblage of warmwater sport fish including largemouth bass, bluegill, red-ear sunfish, crappie, channel catfish, and bullhead catfish (ODNR stocks the lake with trout and fingerling channel catfish)



# Background

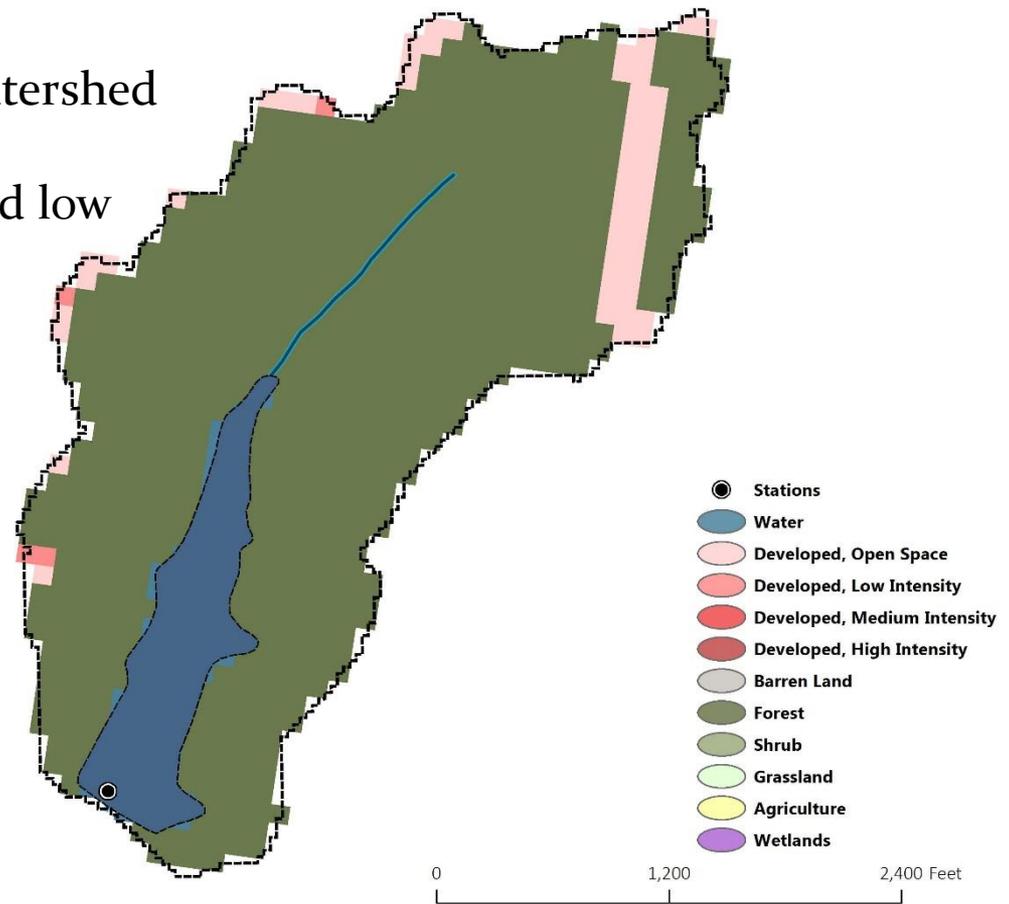
- Rose Lake is managed by the Ohio Department of Natural Resources (ODNR), Divisions of Parks and Recreation and Wildlife
- Hocking Hills State Park is a popular site for recreational camping and hiking as a result of the unique rock formations found in this area
- One of the trails within the park circuits the lake, and at the east end of the lake, the trail is steep and is susceptible to erosion. Approximately two years ago, straw bales were installed along this portion of the trail. The bales are maintained and/or replaced as needed



# Rose Lake Watershed Land Use

The Rose Lake watershed is approximately 198 acres, and is composed primarily of forested land (84.7%)

- The remaining 15.3% of the watershed consists of open water (8.8%), developed open space (6%), and low intensity development (0.5%)
- The lake is part of the larger Salt Creek watershed, which provides surface water to three public water systems, one of which is the state park facility. The intake for the water supply is located about five feet below the normal lake surface



# Rose Lake Water Quality

## Current Status:

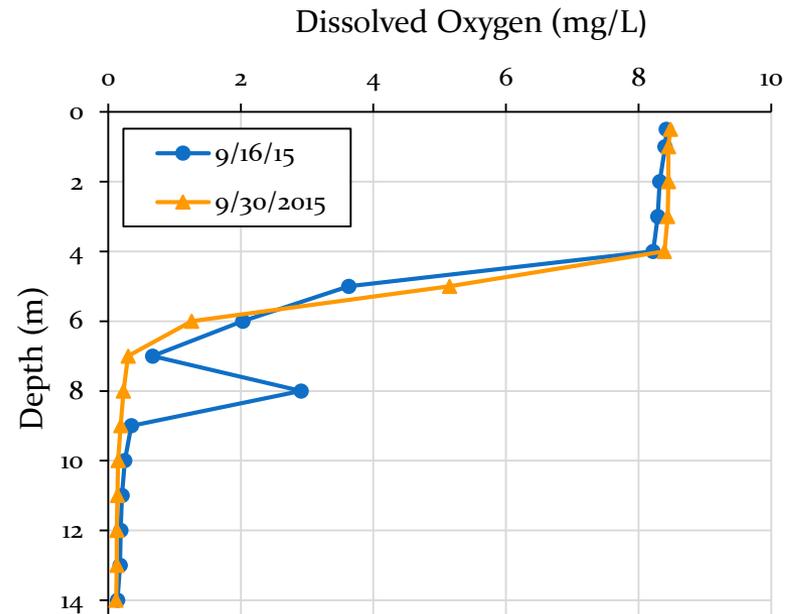
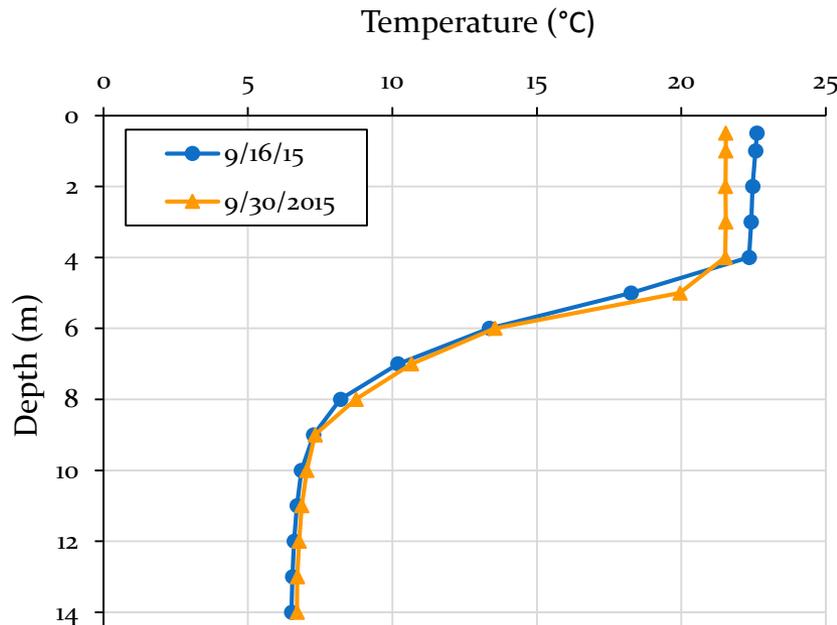
- Limited data from 2005 and 2015 indicate that the lake is of generally high quality with respect to nutrients, algae (chl), and transparency

Date	Depth	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	TKN (mg/L)	NO <sub>2</sub> +NO <sub>3</sub> (mg/L)	NH <sub>4</sub> (mg/L)	Chl (µg/L)	Secchi (m)	Chl:TP
6/27/2005	surface	5 (ND)		0.26	0.05 (ND)		1.36	5.20	0.27
8/24/2005	surface	5 (ND)		0.4	0.05 (ND)		2.34	6.80	0.47
9/16/2015	0.5	5 (ND)	2	0.22	0.05 (ND)	0.025 (ND)	4.6	4.84	0.92 <sup>1</sup>
9/16/2015	14	10	3.6	1.12	0.05 (ND)	0.809			
9/30/2015	0.5	5 (ND)	1.9	0.10 (ND)	0.05 (ND)	0.025 (ND)	4.8	3.30	0.96 <sup>1</sup>
9/30/2015	14	5 (ND)	2.3	0.10 (ND)	0.05 (ND)	0.643			

<sup>1</sup>Calculated using 5 µg/L, half the detection limit.

# Rose Lake Water Quality

- The hypolimnion, however, was depleted of dissolved oxygen by summer's end, which may be partly attributed to very strong stratification



# Rose Lake Water Quality

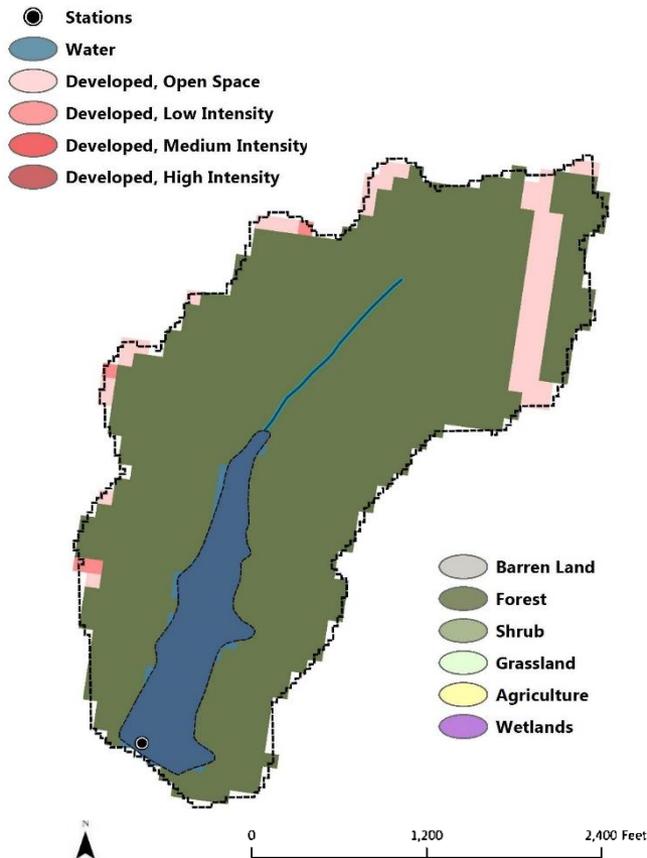
- Transparency was markedly greater in 2005 (5.2 – 6.8 m) than in 2016 (4.6 – 4.8 m), although all measurements indicate oligotrophy
- These are indicative of high quality, but are inadequate to establish a reliable status for the lake from which to judge the effects of any future land-use changes that may increase the transport of nutrients that would degrade quality

Date	Depth	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	TKN (mg/L)	NO <sub>2</sub> +NO <sub>3</sub> (mg/L)	NH <sub>4</sub> (mg/L)	Chl (µg/L)	Secchi (m)	Chl:TP
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9/30/2015	14	5 (ND)	2.3	0.10 (ND)	0.05 (ND)	0.643			

<sup>1</sup>Calculated using 5 µg/L, half the detection limit.

# External Loading

- Approximate nutrient loads within the watershed can be estimated according to the relative distribution of land uses within the watershed



Land Use	STEPL Land Use	Percentage (%)	Acres
Open Water	Omitted	8.83	17.5
Dev. Open Space	Urban	6.00	11.9
Developed Low Intensity	Urban	0.45	0.9
Deciduous Forest	Forest	62.40	123.6
Evergreen Forest	Forest	22.31	44.1

STEPL Land Use	Total Phosphorus Load (lb/yr)	Total Phosphorus Load (kg/yr)	Percent (%)
Urban	13.4	6.1	26.1
Forest	37.8	17.2	73.9
<b>Total</b>	<b>51.2</b>	<b>23.2</b>	<b>100</b>

# Monitoring and Assessment

Year-long moderately intensive study needed to accurately determine:

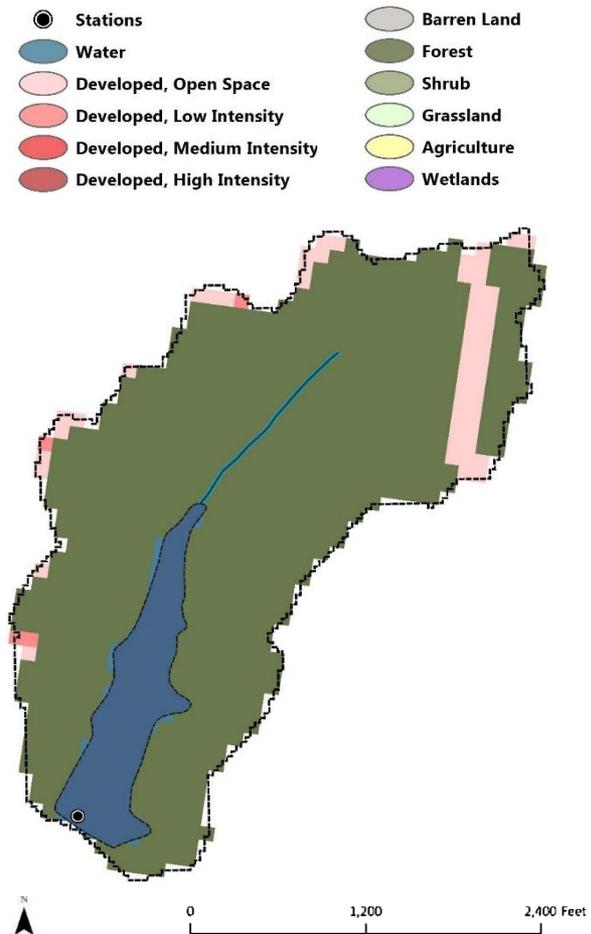
1. Average epilimnetic summer TP, chl, and transparency from twice monthly sampling at 1 and 4 m from May to October, and monthly November-April, at one central, deep site
2. Sample at 8 and 12 m for TP
3. Continuously gauge inflow stream and outflow. Sample for TP in streams concurrent with lake sampling. Purpose is to determine TP loads. Continuous, once per day, sample collection device for TP is recommended
4. TP mass balance; input, output, in-lake sediment-water exchange computed on 2-week intervals
5. TP and chl should be determined at 2 and 1  $\mu\text{g/L}$  detection limits to accurately assess the lake status and TP mass balance, especially since the lake is probably oligotrophic

These data/assessment provide a baseline for future management to protect the lake's quality

# Monitoring and Assessment

## Land Use:

- Determine watershed areas of specific land use as was done previously to indicate changes in TP input if increased development is anticipated or occurs
- Runoff or yield coefficients from respective land uses can be established from literature values that are calibrated to observed total loading



# Monitoring and Assessment

Continuous, post intensive study monitoring:

1. One sample at 1 m for TP, twice monthly, May – September, collected by volunteer(s) if possible
2. Transparency (Secchi disk depth), concurrently



# Monitoring and Assessment

An anoxic hypolimnion with very low P is unusual, because lake sediments usually yield high rates of P release under anoxia

- This may indicate loading of organic matter (leaf detritus?) that depletes DO, but contributes little TP
- Relatively low pH levels suggest that humic acid concentrations (i.e., brown color) may be high and could represent a source of dissolved organic matter



# Lake Management

# 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 \$

# 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

# 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

# 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

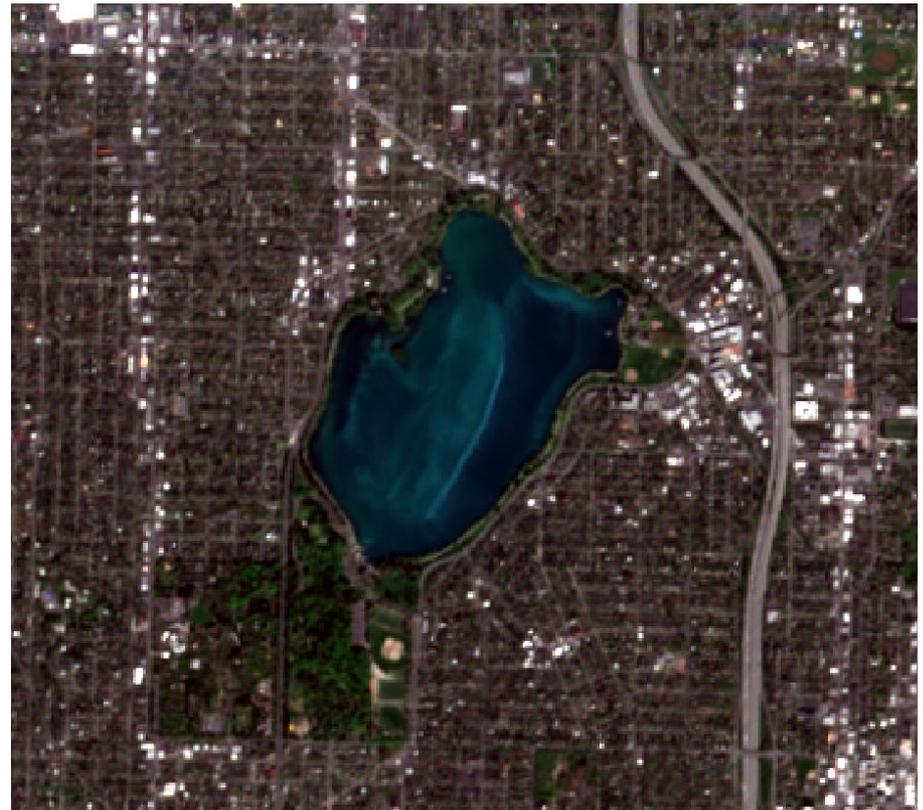
# Hypolimnetic Aeration

- 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)



# Phosphorus Inactivation

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





# Phosphorus Inactivation with Aluminum, Iron, Lanthanum, and Calcium Salts

Why not polymers?

<i>Implementation Strategy</i>	<i>Trivalent Metal</i>			
	Al	Ca	Fe	La
<b>Water Column Stripping</b>	5	2	3	3
<b>External/Lake Loading Maintenance Treatments</b>	5	1	2	2
<b>Sediment Inactivation</b>	5	1	1	2
<b>Phosphorus interception</b>	5	2	5	1
<b>Combination</b>	5	2	2	2
<b>Ponds</b>	5	1	3	4

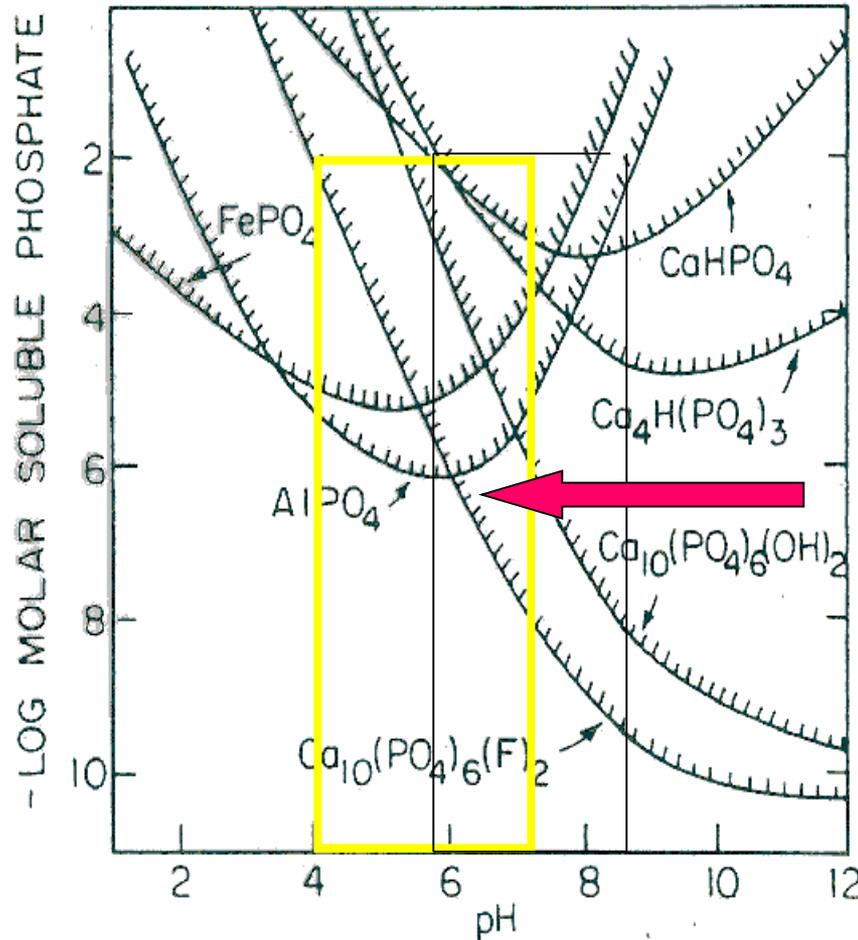
Rating with 5 highest and 1 lowest

# 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

**Yellow Area = Typical Soil pH**

**Black Area = Typical Water pH**



**Within the pH Range of Most Soil and Water, Aluminum Phosphate Minerals are the Least Soluble of the Common Phosphate Precipitates**

*Aquatic Chemistry*  
An Introduction Emphasizing  
Chemical Equilibria in Natural Waters

WERNER STUMM  
Professor, Dr. to Federal Institute of Technology, Zurich  
JAMES J. MORGAN  
Professor of Paleontology and Geology, Science  
College, University of Toronto

# 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

# Aluminum Sulfate

- Advantages
  - Inexpensive
  - Widely Available
  - Handles Variable Water
  - Broad Application Window
  - Effective at Organic Removal
  - Binds Phosphorus Even in Anoxic Conditions



# 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

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

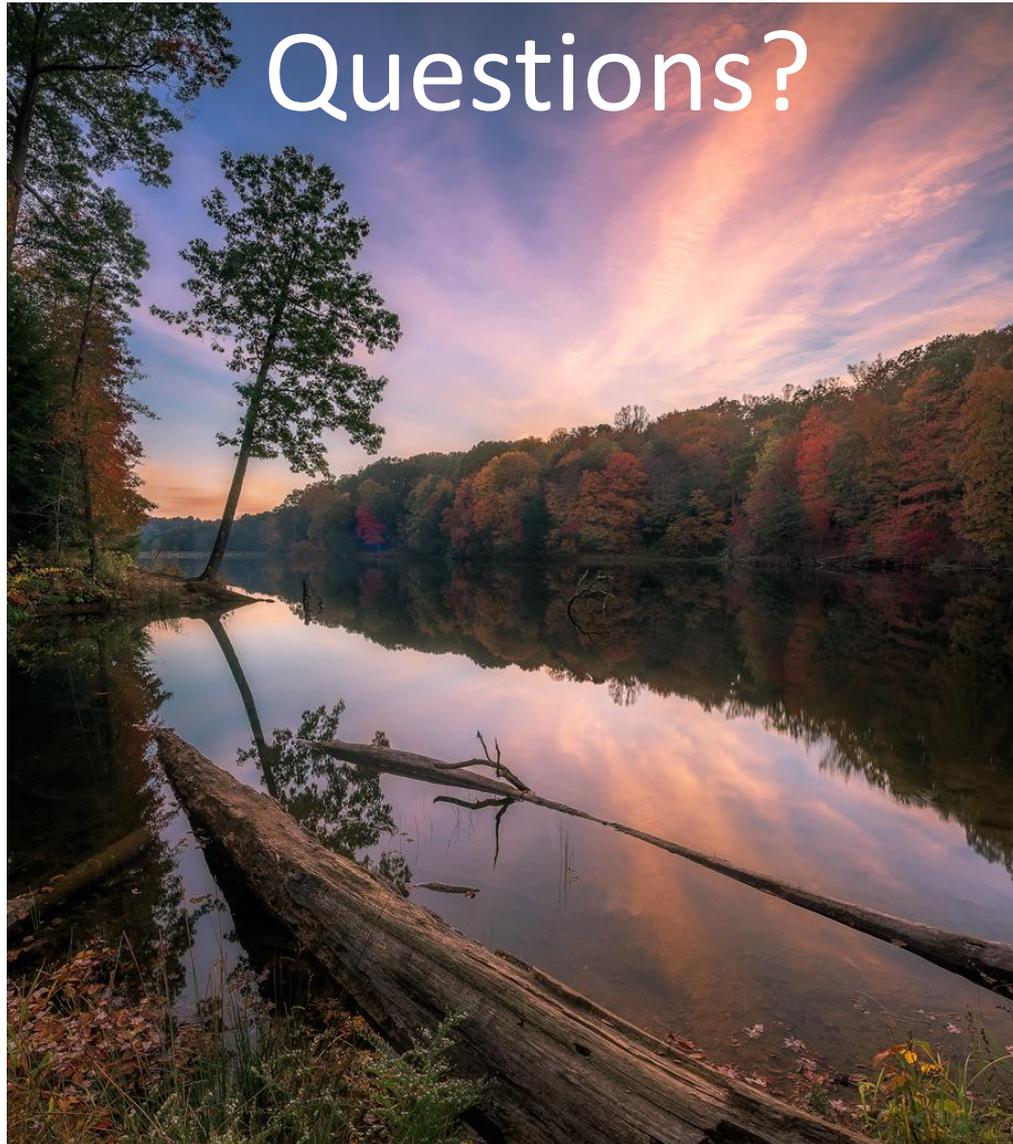
- Al-P and floc layer settles at  $\sim 1.5$  cm/yr, is mixed by bioturbation and is gradually covered with new sediment (Cooke, et al., 2005)
- Additional treatments probably necessary:
  - Long Lake-Kitsap: 1980, 1991, 2007
  - Green Lake: 1991, 2004, 2016
    - After 2004 alum treatment Green Lake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



# Summary

- Internal P loading in shallow lakes may be more important than external P loading in summer algal bloom production
- 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

Questions?



# References

Cooke, G.D., E.B. Welch, S.A. Peterson, and S.A. Nichols. Restoration and Management of Lakes and Reservoirs. 3<sup>rd</sup> Edition. Talyor & Francis. Boca Raton, FL. pp. 591.

Fulmer, D.G. and G.D. Cooke. 1990. Evaluating the Restoration Potential of 19 Ohio Reservoirs. Lake and Reservoir Management. 6:2; 197-206.

Nürnberg, GK. 1996. Trophic state of clear and colored soft and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Lake and Reserv. Manage. 12:423-447.

Ohio Department of Natural Resources (ODNR). 2016. Kiser Lake State Park History & Natural Features. <http://parks.ohiodnr.gov/kiserlake#history>

Ohio EPA. 2009. 2009 Study Plan for Kiser Lake Champaign County. Ohio EPA Division of Surface Water, SW District Office.

Ohio EPA. 2016. Ohio Algal Toxin Results from Lake Erie, State Park Beaches, Inland Lakes, and Public Water Supplies – 2010 to Present. Excel spreadsheet. <http://www.epa.ohio.gov/HABAlgae.aspx>

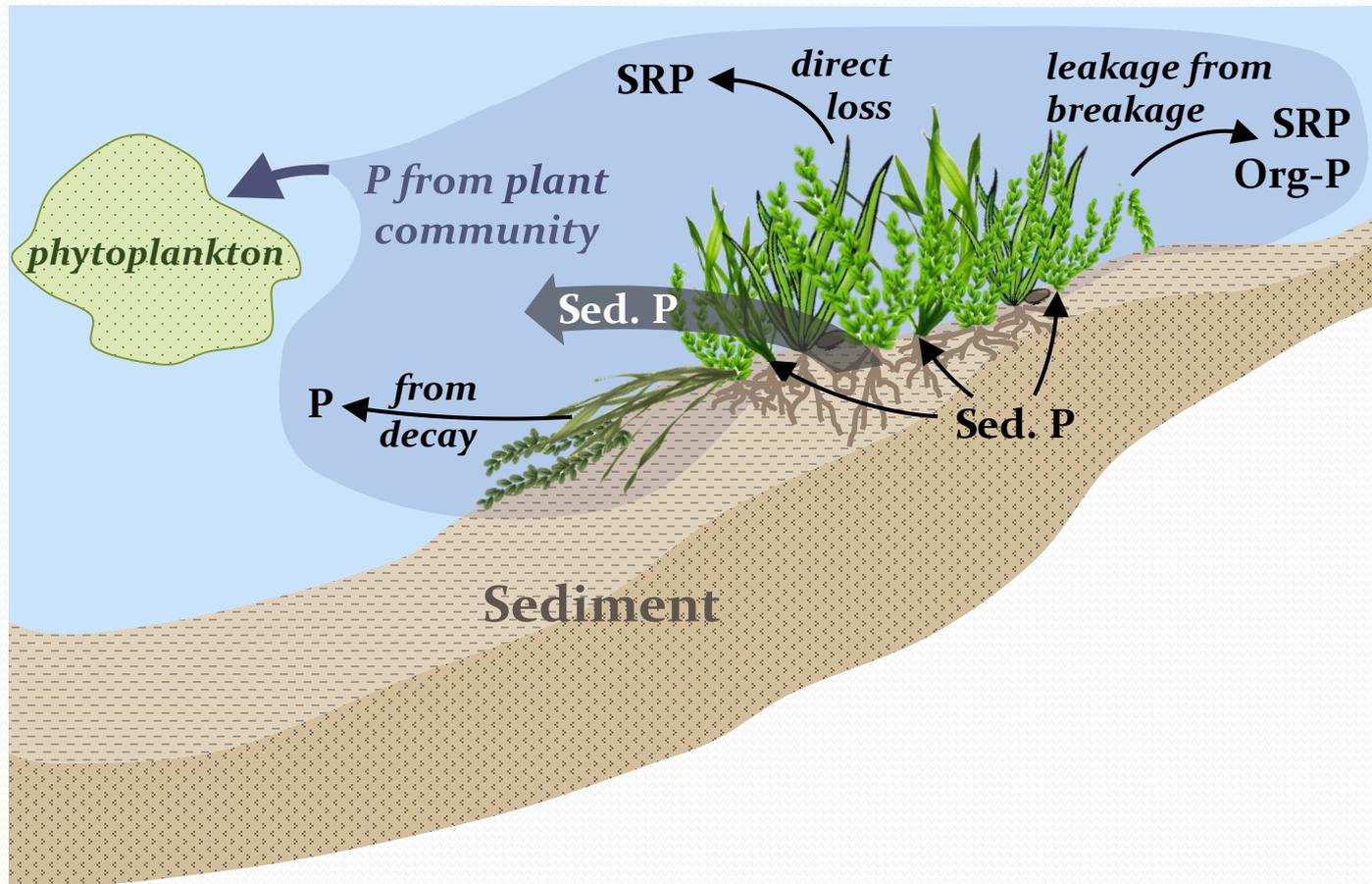
Shaver, Jeremiah. "Improvement Projects Ongoing at Lake Alma State Park." The Jackson County Times-Journal. 21 Oct. 2013.

# Image Citations

- [https://upload.wikimedia.org/wikipedia/commons/8/8a/Kiser\\_Lake\\_from\\_the\\_south.jpg](https://upload.wikimedia.org/wikipedia/commons/8/8a/Kiser_Lake_from_the_south.jpg)
- Google Earth
- Google Maps
- <http://parks.ohiodnr.gov/kiserla>
- <http://trekohio.com/2013/09/09/kiser-lake-wetlands-state-nature-preserve/>
- <http://wtdn.com/2015/07/15/kiser-lake-tests-high-for-bacteria-after-harmful-algal-bloom/>
- [http://media.cmgdigital.com/shared/lt/lt\\_cache/thumbnaill/960/img/photos/2015/07/14/cb/99/071515-kiser-lake-1.jpg](http://media.cmgdigital.com/shared/lt/lt_cache/thumbnaill/960/img/photos/2015/07/14/cb/99/071515-kiser-lake-1.jpg)
- [http://trekohio.com/wp-content/uploads/201308\\_img\\_3656\\_9610035468.jpg](http://trekohio.com/wp-content/uploads/201308_img_3656_9610035468.jpg)
- [https://www.bae.ncsu.edu/topic/wetlands/technical\\_data/phase\\_2/isco2.JPG](https://www.bae.ncsu.edu/topic/wetlands/technical_data/phase_2/isco2.JPG)
- <http://www.isco.com/webproductimages/3700C.jpg>
- [http://www.athensconservancy.org/aaorg/Lake\\_Alma3.jpg](http://www.athensconservancy.org/aaorg/Lake_Alma3.jpg)
- <http://www.raccooncreek.org/atwhistory.aspx>
- [http://www.hauntedhocking.com/Haunted\\_Ohio\\_Jackson\\_County\\_Lake\\_Alma.htm](http://www.hauntedhocking.com/Haunted_Ohio_Jackson_County_Lake_Alma.htm)
- [http://www.hauntedhocking.com/Haunted\\_Ohio\\_Jackson\\_County\\_Lake\\_Alma\\_lake-agma-with-boat.jpg](http://www.hauntedhocking.com/Haunted_Ohio_Jackson_County_Lake_Alma_lake-agma-with-boat.jpg)
- <http://www.thetelegramnews.com/SiteImages/Article/19763a.jpg>
- [http://parks.ohiodnr.gov/Portals/parks/PDFs/parks/Maps/Lake\\_Alma/lakealmaparkmap.pdf](http://parks.ohiodnr.gov/Portals/parks/PDFs/parks/Maps/Lake_Alma/lakealmaparkmap.pdf)
- <http://bloximages.chicago2.vip.townnews.com/timesjournal.com/content/tncms/assets/v3/editorial/c/ac/cacieebe-8a78-5425-895d-61e320cdbccd/5265c8b626db4.image.jpg>
- [http://cdn.ohio.org/cdn/farfuture/cVMYwSlJgm5ZPLjA\\_n6Sj31BcwLz6wEaWTy-VcflQw/mtime:1442445068/sites/default/master/files/styles/profile\\_slider/public/profiles/photos/profile\\_photo/listing\\_4562--profile\\_large--11139.jpg?itok=phULmSsE](http://cdn.ohio.org/cdn/farfuture/cVMYwSlJgm5ZPLjA_n6Sj31BcwLz6wEaWTy-VcflQw/mtime:1442445068/sites/default/master/files/styles/profile_slider/public/profiles/photos/profile_photo/listing_4562--profile_large--11139.jpg?itok=phULmSsE)
- [http://trekohio.com/wp-content/uploads/201204\\_rose-lake\\_6890768538.jpg](http://trekohio.com/wp-content/uploads/201204_rose-lake_6890768538.jpg)
- <http://www.backcountrygallery.com/wp-content/uploads/2011/03/upper-falls.jpg>
- <http://courses.washington.edu/uwtoceo6/webg3/images/secchi2.jpg>
- [http://rmbel.info/wp-content/uploads/2013/04/RMB\\_secchi.jpg](http://rmbel.info/wp-content/uploads/2013/04/RMB_secchi.jpg)
- [http://www.photography-match.com/views/images/gallery/leaves\\_in\\_lake.jpg](http://www.photography-match.com/views/images/gallery/leaves_in_lake.jpg)
- <http://i.imgur.com/rQq2kkD.jpg>

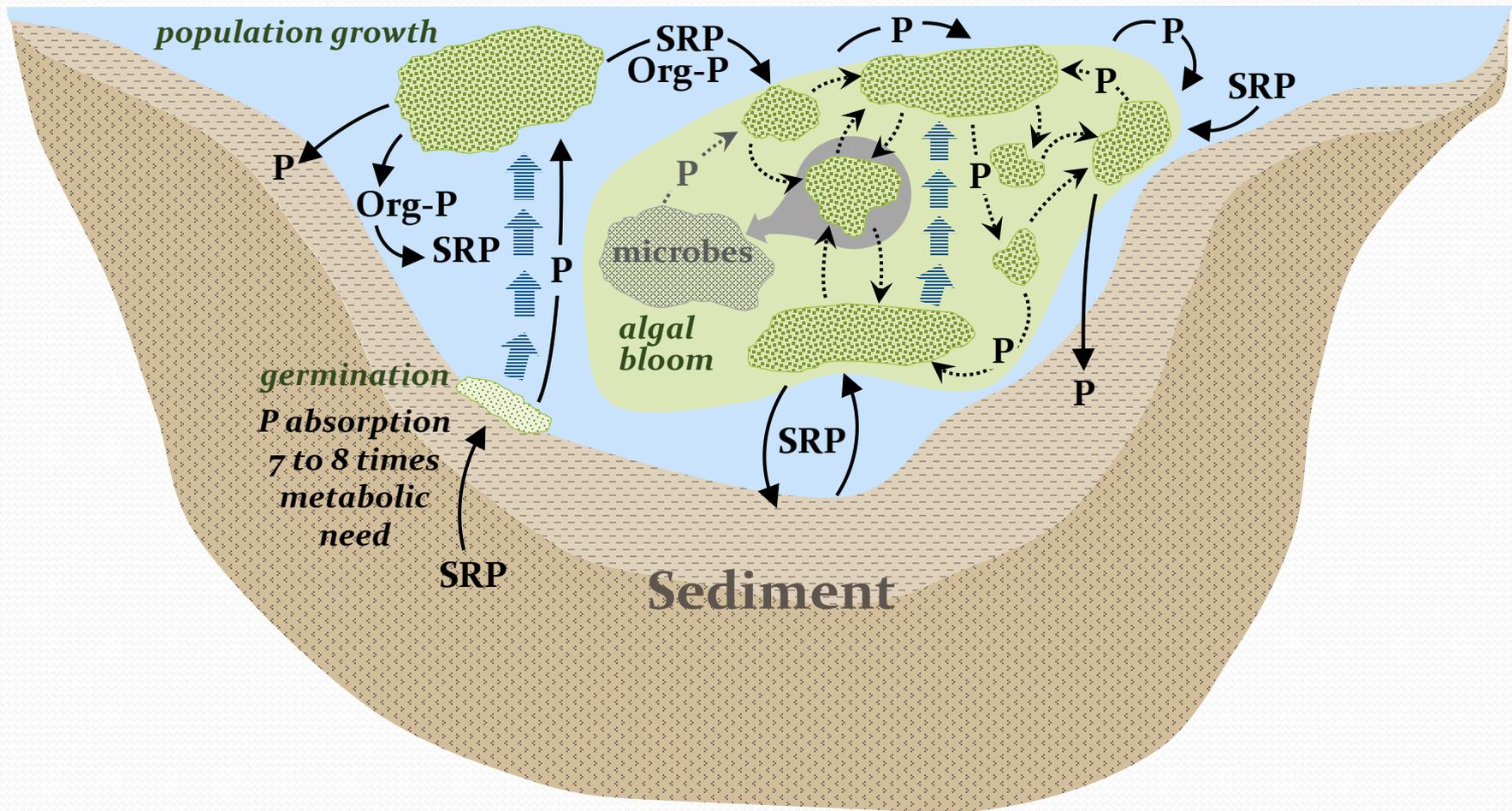
# Phosphorus Cycle Cont...

## Biocycle - Macrophytes



# Phosphorus Cycle Cont.

## Biocycle – Phytoplankton, Cyanobacteria



# Prairie Creek Wetland Treatment Train



- 200 acres
- Began treating water in June 2013
- 1.3 MGD pumped through alum dosing station, settlement ponds, and wetlands
- Alum was not used until Fall 2013

Photos: Milt Miller,  
GLSM Restoration  
Commission

# Wetland Cells of BMP Treatment Train



Photos: Milt Miller, GLSM Restoration Commission

- Nitrogen into GLSM from Prairie Creek decreased average of 41%
- Dissolved P into GLSM decreased average of 65%
- Total P into GLSM dropped almost 75%

# The One Practice with Measureable WQ Improvements



Summer 2015  
Prairie Creek  
Treatment Train and  
expansion

Ohio EPA have funded through  
319 grants additional treatment  
trains on larger tribs

