# How to Understand and Manage Your Lake, Part 2

## Nutrient Loading and Monitoring


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# Objectives

- Promote technical understanding to advance Ohio's nutrient reduction efforts
  - Focus on reducing the occurrence and impact of HABs (harmful algal blooms) in inland lakes
  - Priority for lakes that are sources of drinking water
- This webinar is designed to provide a basic understanding of limnological monitoring and and lake management
- Goal is to show audience how to evaluate existing data and identify data needed to define the most effective alternatives to reduce nutrient loads and protect water quality

# Lakes and Reservoirs

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

# Basic Surface Water Understanding

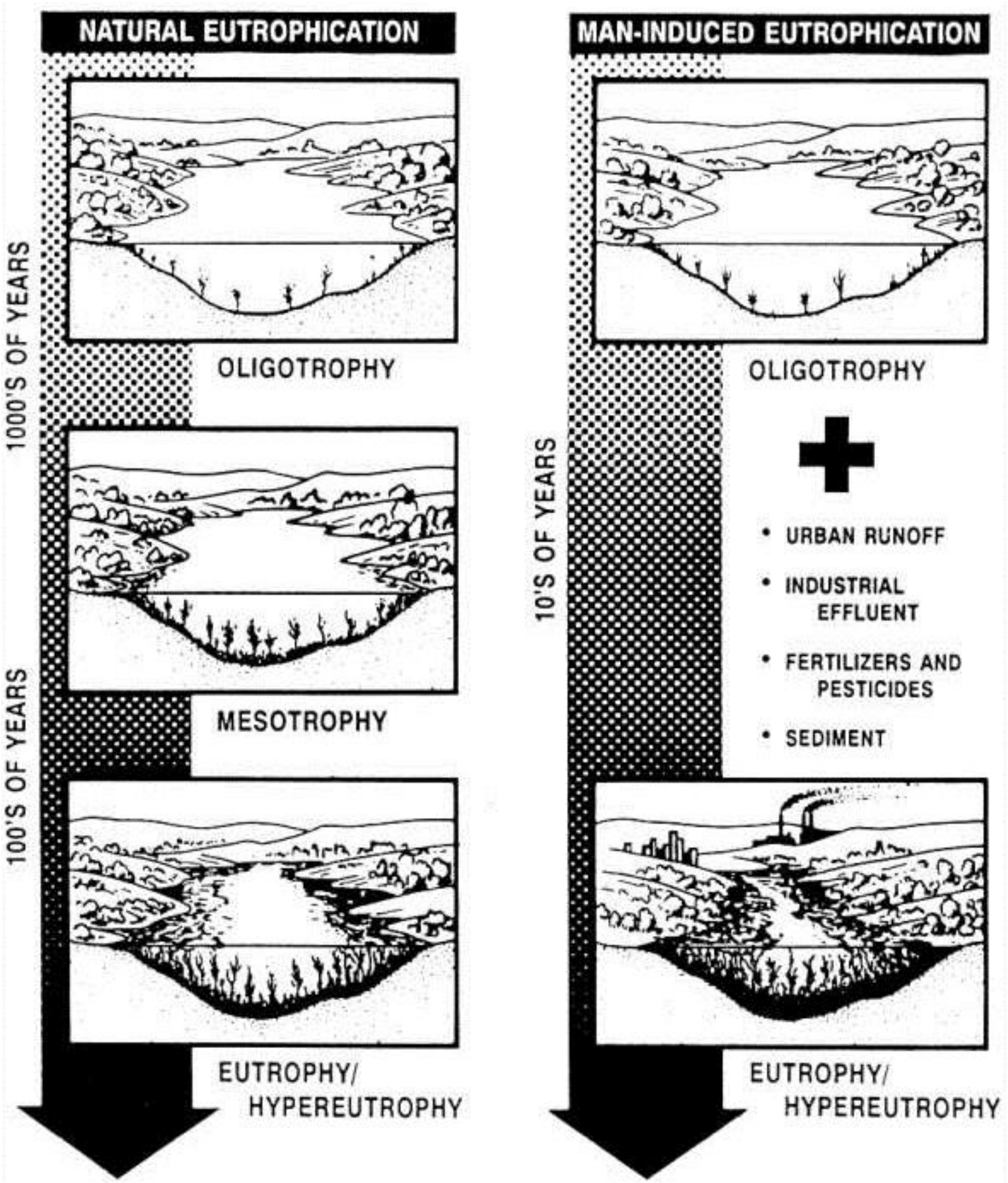
- Lakes and reservoirs are influenced by physical, geochemical, climatic and biological interactions. This includes human activities and land-use!
- Must understand what influences are being transported through the watershed to the water body, and
- How these interact with water body relative to it limnological interactions and pathways.

# Defining Watershed Nutrient Loading

- Need to monitor stream 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.

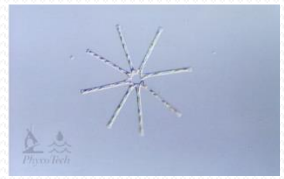
# Watershed Nutrient Loads

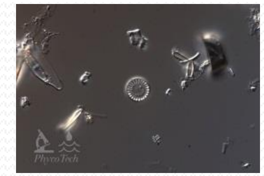
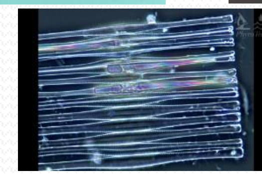
- Watersheds are relatively geological stable for usually thousands of years.
- Hence, the plant communities develop a relatively stable transformation over time.
- Hence, historic background conditions usually generate low levels of nutrients.
- Land-use is a significant modification to background conditions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


NATURAL EUTROPHICATION
MAN-INDUCED EUTROPHICATION
1000'S OF YEARS
100'S OF YEARS
10'S OF YEARS
OLIGOTROPHY
MESOTROPHY
EUTROPHY/
HYPEREUTROPHY
OLIGOTROPHY
• URBAN RUNOFF
• INDUSTRIAL EFFLUENT
• FERTILIZERS AND PESTICIDES
• SEDIMENT
EUTROPHY/
HYPEREUTROPHY

# Phytoplankton Transition

- *Bacillariophyta*
  - *Asterionella formosa*
  - *Aulacoseira granulate*
  - *Cyclotella meneghiniana*
  - *Fragilaria crotonensis*



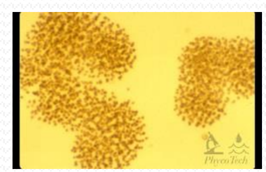



- *Crytophyta*
  - *Cryptomonas erosa*


- *Cyanophyta*
  - *Aphanizomenon flos aquae*
  - *Anabaena circinalis*
  - *Anabaena flos aquae*
  - *Gloeotrichia echinulata*
  - *Microcystis aeruginosa*
  - *Anie, phani and mic produce toxins, i.e. microcystins*







# Nutrient Loading

- The loading of nitrogen and phosphorus can be 20 to 40 times background conditions with certain land-uses.
- Relative to eutrophication:
  - 20 to 40 times the rate of loading and total nutrient delivered to the system will stimulate 20 to 40 times the algal biomass!
  - Even with BMPs in place at 50% nutrient retention that is 10 to 20 times background, at 90% retention it is still 2 to 4 times the background rate!

# 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.

# Reducing P Alone is the Key to Managing Eutrophication in Lakes Especially with Cyanobacteria Blooms

- Some believe N should be reduced, too
  - N reduction improves water quality and can be limiting in the short term, but 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, long-term studies.
    - Reduction of N may also continue to favor N fixers and
    - N reduction can be several times the cost of P reduction alone.
  - There are no cases where N reduction alone have reduced trophic state, but many successful cases of P reduction alone, Schindler lists 35 -Jeppesen et al., 2005.
    - Schindler, D.W.2012. *The dilemma of controlling cultural eutrophication*. Proc.Royal Soc.B.

# 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.
- Must always address watershed phosphorus control.

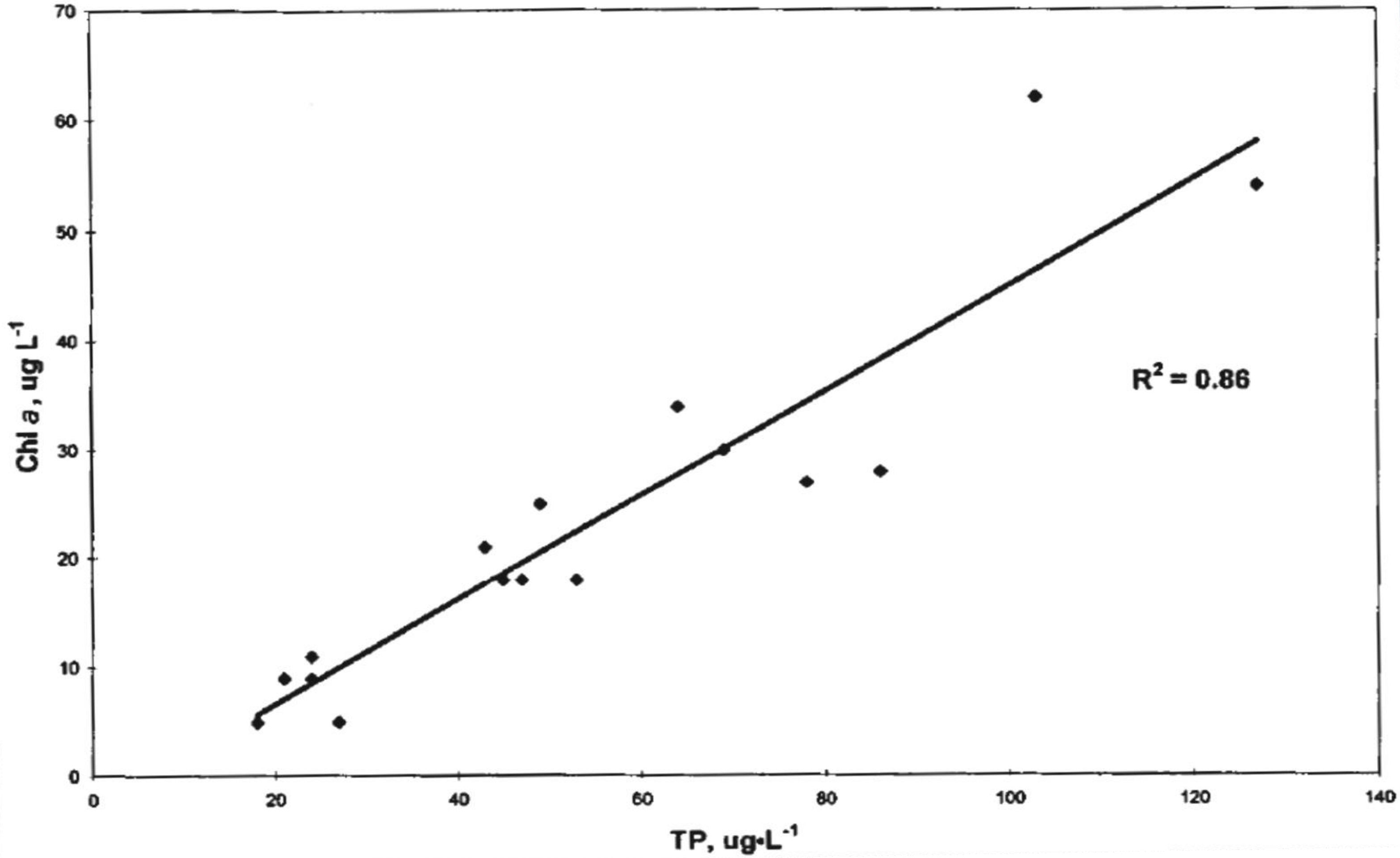
## Once a Lake is Pushed beyond its Eutrophic State by Watershed Abuses: In-Lake Activities Have to be the Center of the Game Plan

- 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:***

**<u>It is the quantity and timing of phosphorus availability “within” the lake that is important!</u>**

# 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 external controls




Relationship between mean summer (May-September) TP and chlorophyll a in nine unstratified lake basins

Summer chl was strongly related to summer TP in the 9 unstratified lakes/ basins where summer TP loading was mostly internal and immediately available to algae

# 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

# Lake Quality Monitoring & Assessment

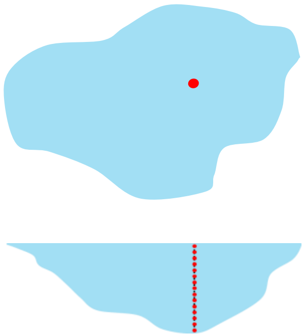
# Monitoring

- 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

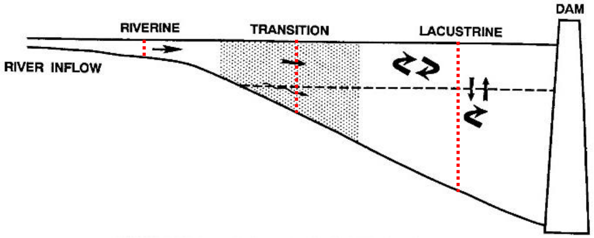
- Sample twice monthly during summer growth period (May-Oct) to catch algal blooms, monthly remainder of year
    - Water column sampling

*Lake*



- One centrally located deep site usually adequate; even large lakes due to wind mixing and circulation

*Reservoir*

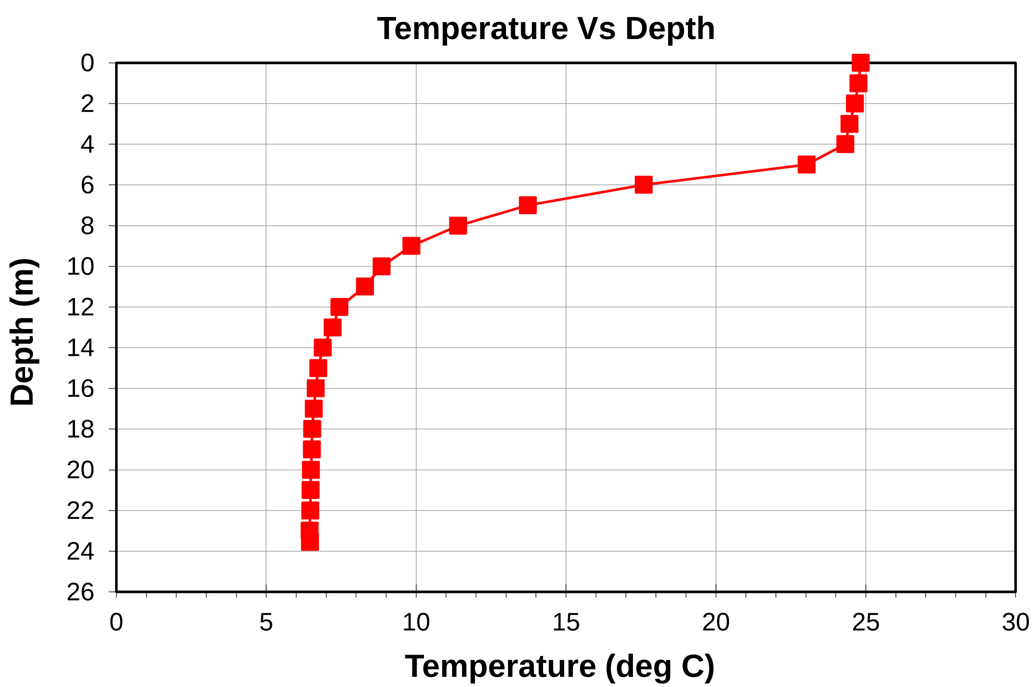


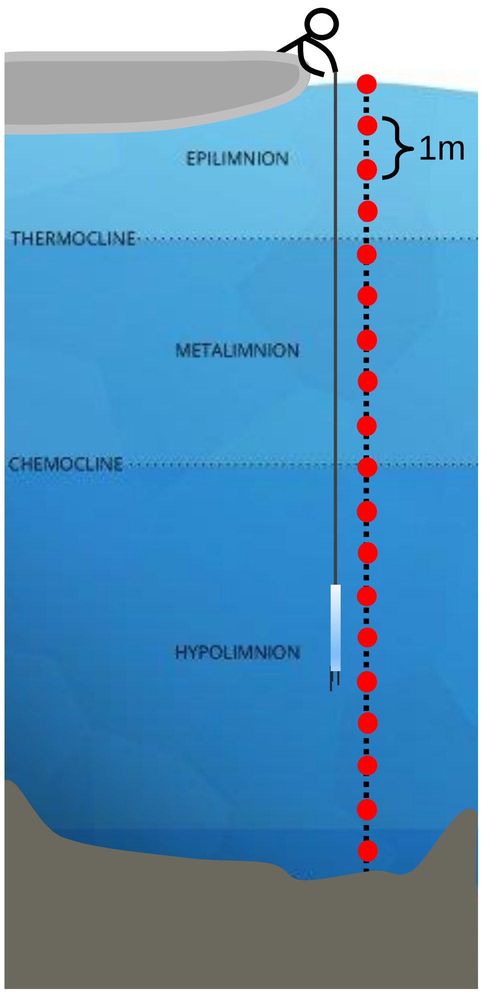

- Multiple sites, at least one in each of three zones (riverine, transition, and lacustrine) in reservoirs if elongated and formed by dams on relatively large rivers

- Lake inflows and outflow(s) should be sampled coincidentally for nutrient budgets (see below)

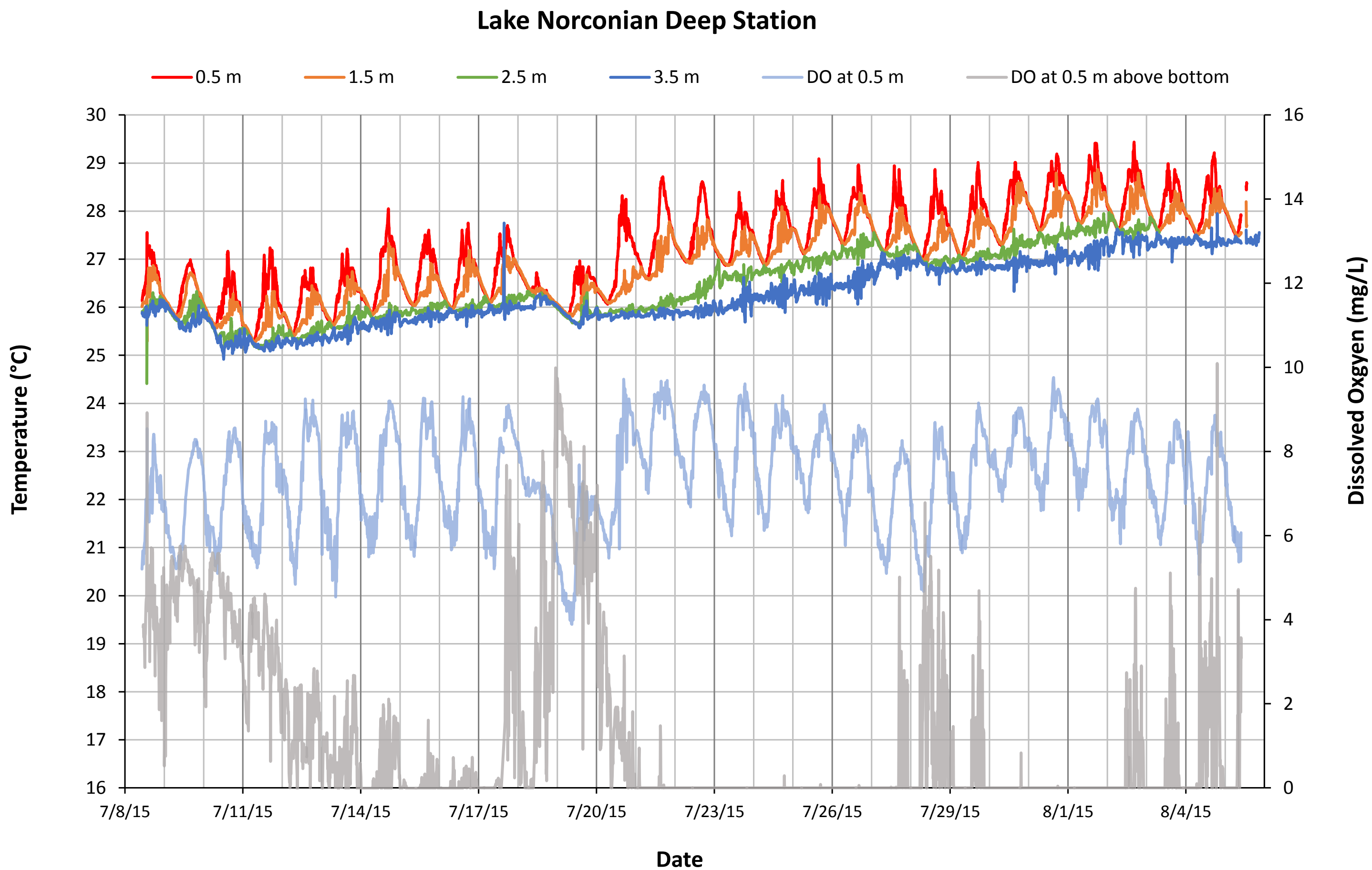
# Water Column Sampling

- Water transparency (Secchi Disk)
- Water column profile constituents:
  - DO, temperature, pH, and conductivity at 1-2 m intervals



# Continuous Monitoring

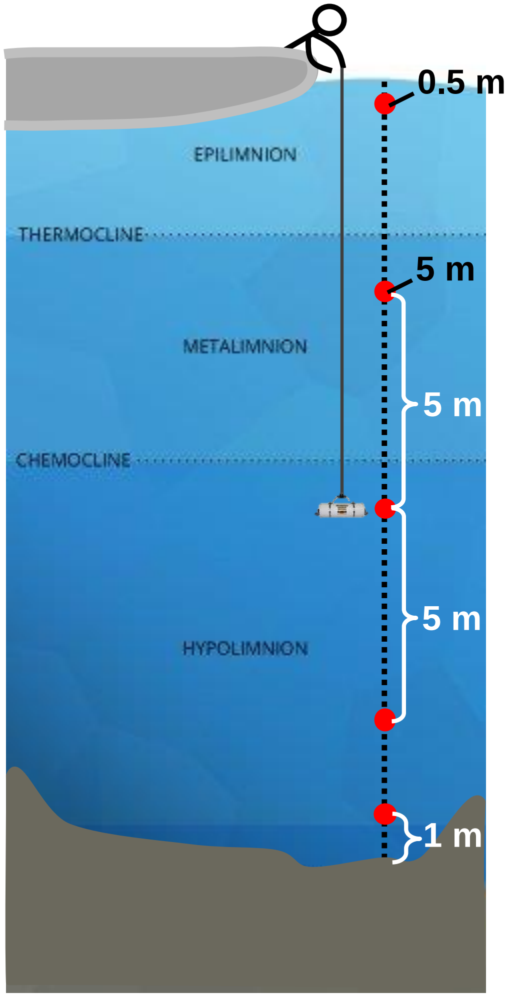



- Determine depth of mixing, mixing patterns, diurnal fluctuations, hypolimnion depth, and depletion rate of DO

# Sample Collection

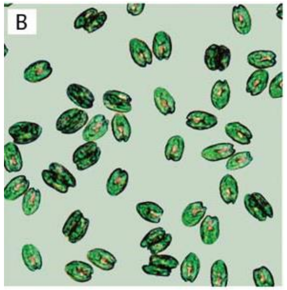
- Water column samples for laboratory analysis
  - Van Dorn bottle collection at specific depths

  - From the surface, using grab sampling techniques or direct immersion



# Parameters

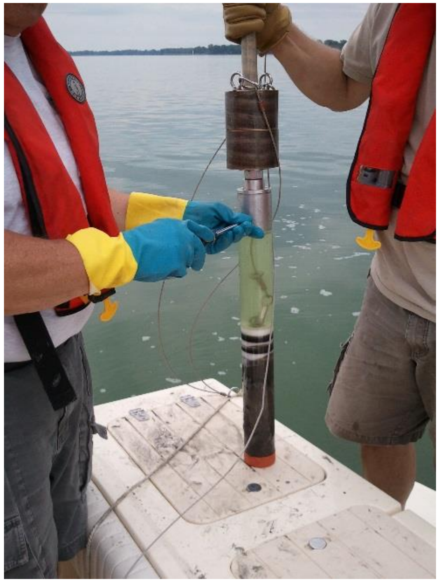
- TP, SRP, nitrate+nitrite-N, and TN should be determined at 0.5 or 1 m below the surface, 1 m above the bottom and at least 5 m intervals throughout the water column
  - A 1 m sample may be adequate in shallow lakes, although a bottom (1 m above bottom) sample is recommended if the deep site is 4-5 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

# Sediment Sampling

- Sediment grab samples or sediment cores
- 1 to 3 locations within a small lake
- Several locations in large lakes
  - Deep vs. Shallow
  - Bays
  - Near Inlets
- Ideally analyzed 2 cm segments of 30+cm sediment core
- Phosphorus fractions
  - TP, Loosely sorbed-P, Organic-P, Biogenic-P, Fe bound-P, Al bound-P, Ca bound-P
  - Total Al, Total Fe
  - % Water, % Solids
- Other metals or priority pollutants if necessary or known contamination

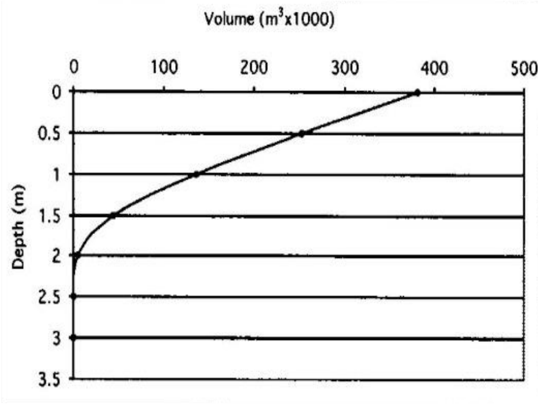


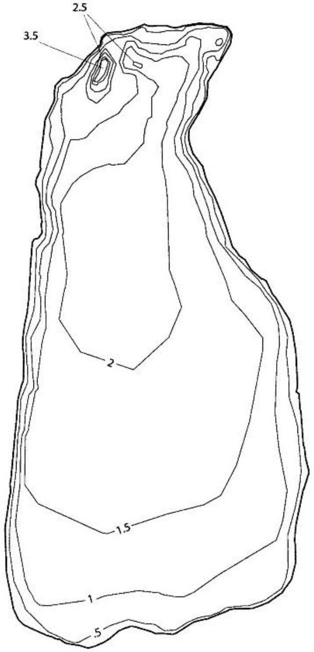
# Data QA/QC

- Field Replicates/Duplicates
  - Water column profiling (every 10th 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)

# Morphometry

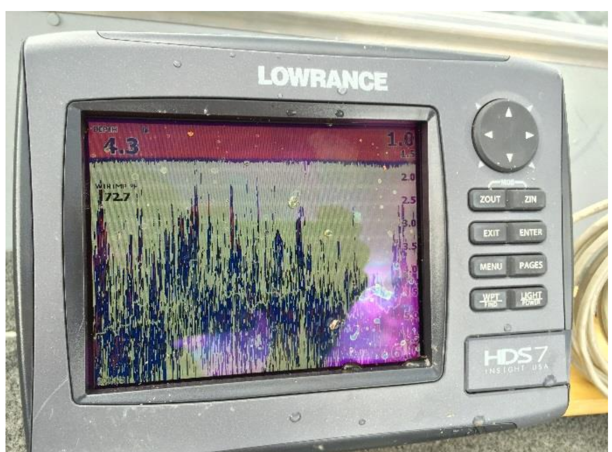
- Bathymetric mapping
  - Multi-beam with side scan
  - Single scan (BioSonics)
  - Off the shelf echosounders (Lowerance depth finder, BioBase)
- Hypsographic curves of volume vs depth to volume-weight constituents in the epilimnion and hypolimnion and whole lake, or whole-lake only if unstratified

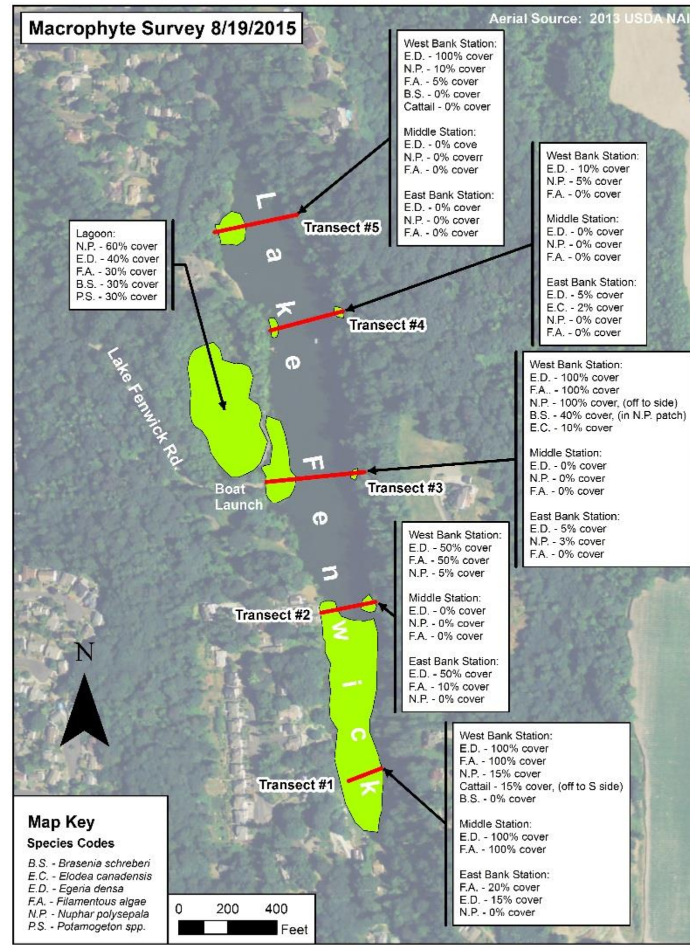


# Aquatic Plant Mapping

- Plant distribution, species composition, abundance and relative percent cover
- Transect and Point Survey
- Biovolume of submersed plant community (BioSonics, BioBase)
    - Verify and identify plants with rake toss



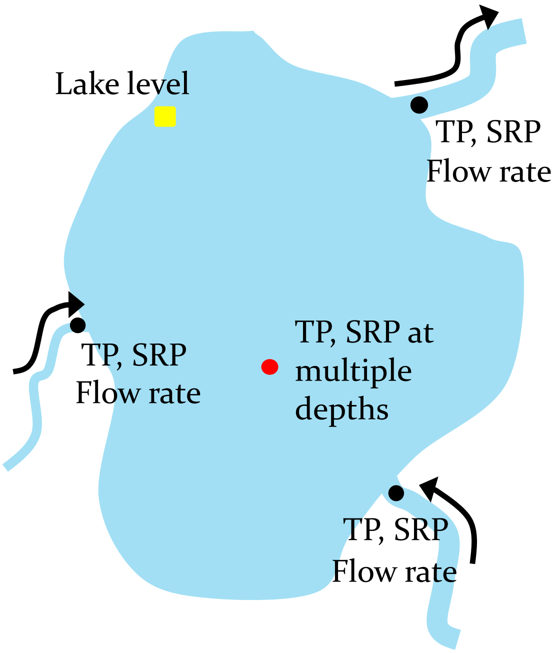



# Water and Nutrient Budgets

- 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



# Water and Nutrient Budgets

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

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

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

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

# 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

# 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

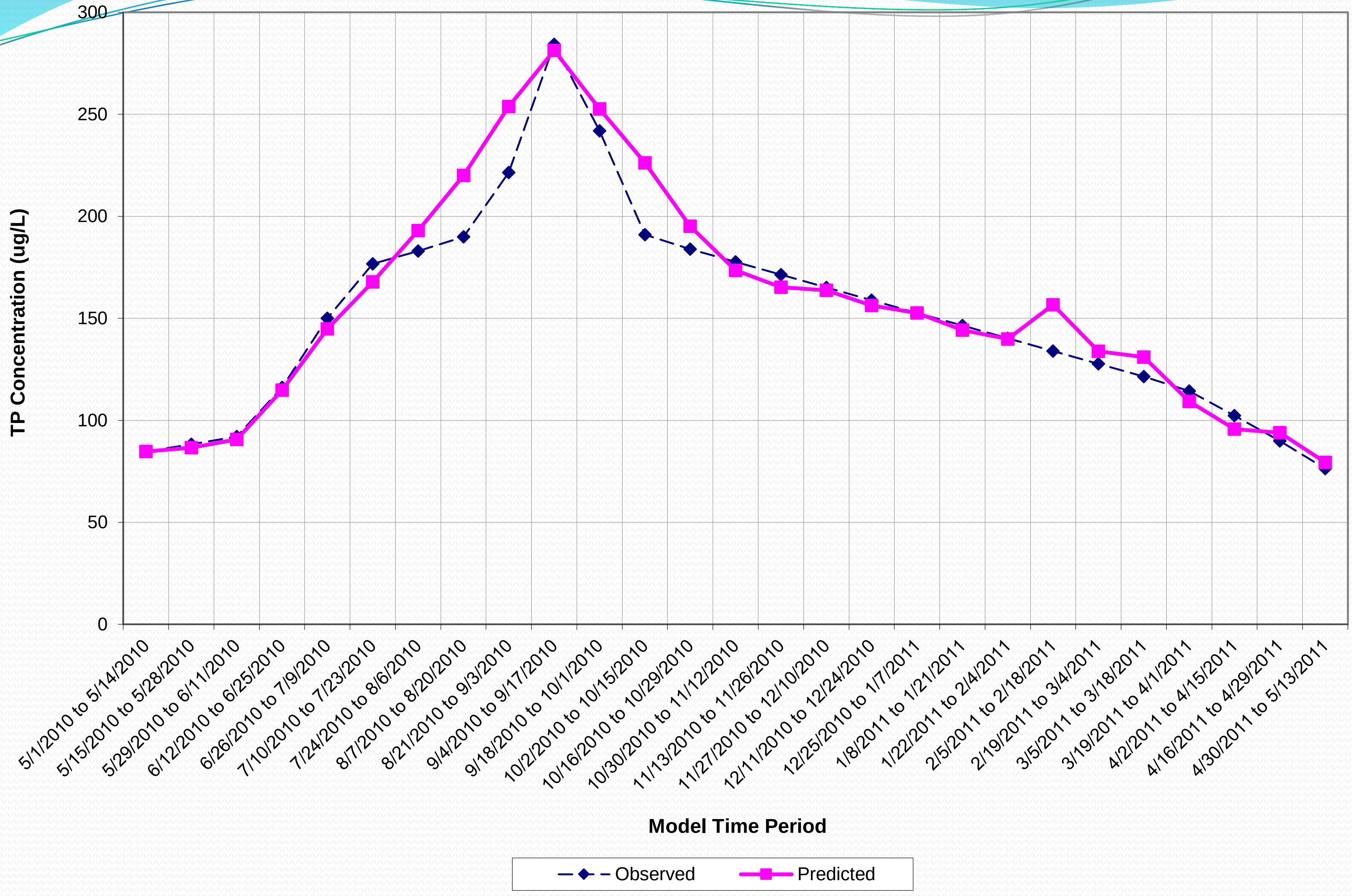
All in mass (kg)

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.

# 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

| 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%** | |


TP Concentration (ug/L)
300
250
200
150
100
50
0
5/1/2010 to 5/14/2010
5/15/2010 to 5/28/2010
5/29/2010 to 6/11/2010
6/12/2010 to 6/25/2010
6/26/2010 to 7/9/2010
7/10/2010 to 7/23/2010
7/24/2010 to 8/6/2010
8/7/2010 to 8/20/2010
8/21/2010 to 9/3/2010
9/4/2010 to 9/17/2010
9/18/2010 to 10/1/2010
10/2/2010 to 10/15/2010
10/16/2010 to 10/29/2010
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1/8/2011 to 1/21/2011
1/22/2011 to 2/4/2011
2/5/2011 to 2/18/2011
2/19/2011 to 3/4/2011
3/5/2011 to 3/18/2011
3/19/2011 to 4/1/2011
4/2/2011 to 4/15/2011
4/16/2011 to 4/29/2011
4/30/2011 to 5/13/2011
Model Time Period
Observed
Predicted

# Questions

# Image Citations

- http://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/
- http://shop.sciencefirst.com/wildco/455-alpha-water-samplers-horizontal
- https://www.flickr.com/photos/22848786@N05/2197591977
- http://www.ecy.wa.gov/programs/eap/fw_riv/DataQuality.html
- http://web.pdx.edu/~sytsmam/limno/Limno09.3_morphology.17.5mb.pdf
- https://en.wikipedia.org/wiki/Cladocera
- http://www.unep.or.jp/ietc/Publications/techpublications/TechPub-11/1-2-1.asp
- http://www.fao.org/docrep/003/T0028E/T0028E03.htm