Limnological and Social Psychological Studies of Lake Papakeechie and Its Environs

A Product of the Lake Papakeechie Sustainability Initiative (LaPSI)

Anthony S. Serianni, PhD
Department of Chemistry and Biochemistry
University of Notre Dame

PPA Board Meeting
April 12, 2014

Presentation Outline

- Description of LaPSI, Its Work and Its Future Vision
- Results of LaPSI Studies from 2013; Data Interpretation
- Placing LaPSI Data into a Broader Context

LaPSI Mission (fall 2012)

To promote a healthy, vibrant and sustainable ecology at Lake Papakeechie and its environs, including its watershed, through vigilant, up-to-date scientific methods. These methods include, but are not limited to (a) scientific testing to collect, study, archive and communicate scientific data on lake chemical parameters, and on biological and ecological parameters; (b) responsible use and wise application of control, conservation and preservation measures; (c) consistent monitoring and assessment of aquatic and non-aquatic plants and animals; (d) supporting and promoting sustainable behaviors and activities by lake residents with respect to use of the lake as a natural resource and as a source of natural beauty and pleasure; and (e) promoting the private character of the lake.

LaPSI Vision (fall 2012)

To serve as a key information resource and advisory group to the PPA Board over time on the health of the Lake Papakeechie ecosystem/ watershed; to engage with local, state and national individuals and groups on lake management; to witness continuous improvement in the quality of life in and on Lake Papakeechie over the next decade and beyond; to insure that Lake Papakeechie remains a desirable community for future generations of all life on the lake; to respond to, and manage, events of nature (*e.g.,* climate change) in a manner that secures and insures a viable long-term future for the lake and the diverse ecosystems it supports.

Education and Training: Leadership

Indiana Watershed Leadership Academy 2014: Diane Tulloh, Kendall Floyd and Anthony Serianni
Upon successful completion on May 21: Purdue University Professional Certificate in Watershed Management

Participation and/or membership in the Indiana Lakes Management Society (ILMS) (John and Georganna Hart) and the North American Lake Management Society (NALMS)

Education and Training: Student Summer Internships

Summer 2013: Hannah Becker, ND Da Vinci Scholar
Funded by the Notre Dame Institute for Scholarship in the Liberal Arts (ISLA Da Vinci Grant): $4468

Summer 2014: Brian Roddy and Matthew Williams, Notre Dame Da Vinci Scholars
Funded by the Notre Dame Institute for Scholarship in the Liberal Arts (ISLA Da Vinci Grant): $4000

Education and Training: Lake Residents

List of Potential LaPSI Speakers
03/17/14

1. Gary Lamberti – University of Notre Dame - stream/watershed ecology
2. David Lodge – University of Notre Dame - conservation biology
3. Stephen Carpenter – University of Wisconsin Madison - whole ecosystem management – joint LaPSI/WACF speaker
   $400 Honorarium
   $175 Lodging
   $200-600 Travel
4. Melissa Clark – Indiana Clean Lakes
5. Jim Donahoe – Aquatic Weed Control, Syracuse, IN; Sediment Removal Solutions, Goshen, IN (Spoke Saturday, March 15, 2014, 10:00 AM – Syracuse Community Center)
6. Jed Pearson – IDNR, Indiana District 3 fisheries biologist
   1353 South Governors Drive
   Columbia City, IN 46725-9539
   260-244-6805
7. Lyn Crighton – Tippecanoe Watershed Foundation – 574-834-3242
8. Ann Strong - Chautauqua
9. Matt Meersman – St. Joseph County watershed
10. Tim Woodward - Superintendent, Turkey Creek Regional Sewer
11. Nathan Bosch – Center for Lakes and Streams, Grace College

Seminar Program
(Diane Tulloh and Jody Hedges)

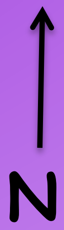
Communication Networks and Public Relations

- Lake Bathymetric Mapping (John Hart)
- Update and Maintain Wikipedia Page (Mark Laurent)
- Update, Maintain and Expand PPA Website (Kendall Floyd)
- Publication in local newspapers (Virginia Surso)
- Publication in scientific journals (Anthony Serianni)
- Presentations at scientific meetings (ND students, LaPSI)

Future Vision: LaPSI

- Establish a fully-equipped research l<u>aboratory</u> in the PPA Building
- Establish the PPA as a <u>leader</u> in lake management in Indiana
- Demonstrate the power of <u>citizen-scientists</u>
- Secure ample external <u>funding</u> for longitudinal work on LP; collaborate with other lake management groups (*e.g.*, WACF)
- Articulate and demonstrate the importance of scientific and social components in effective lake management
- Encourage the formation of a lake "<u>planning commission</u>" to articulate a long-term vision of LP and how it should "develop": How do we maintain and enhance the natural qualities of the lake and its private, non-sports character? How do we preserve the ecosystem services provided by LP?
- <u>Real-time monitoring</u> of lake water quality?

Aerial Photograph of Lake Papakeechie (LP)



LP is a beautiful relatively natural lake ecosystem in which to develop, test and validate effective methods of lake management and preservation.

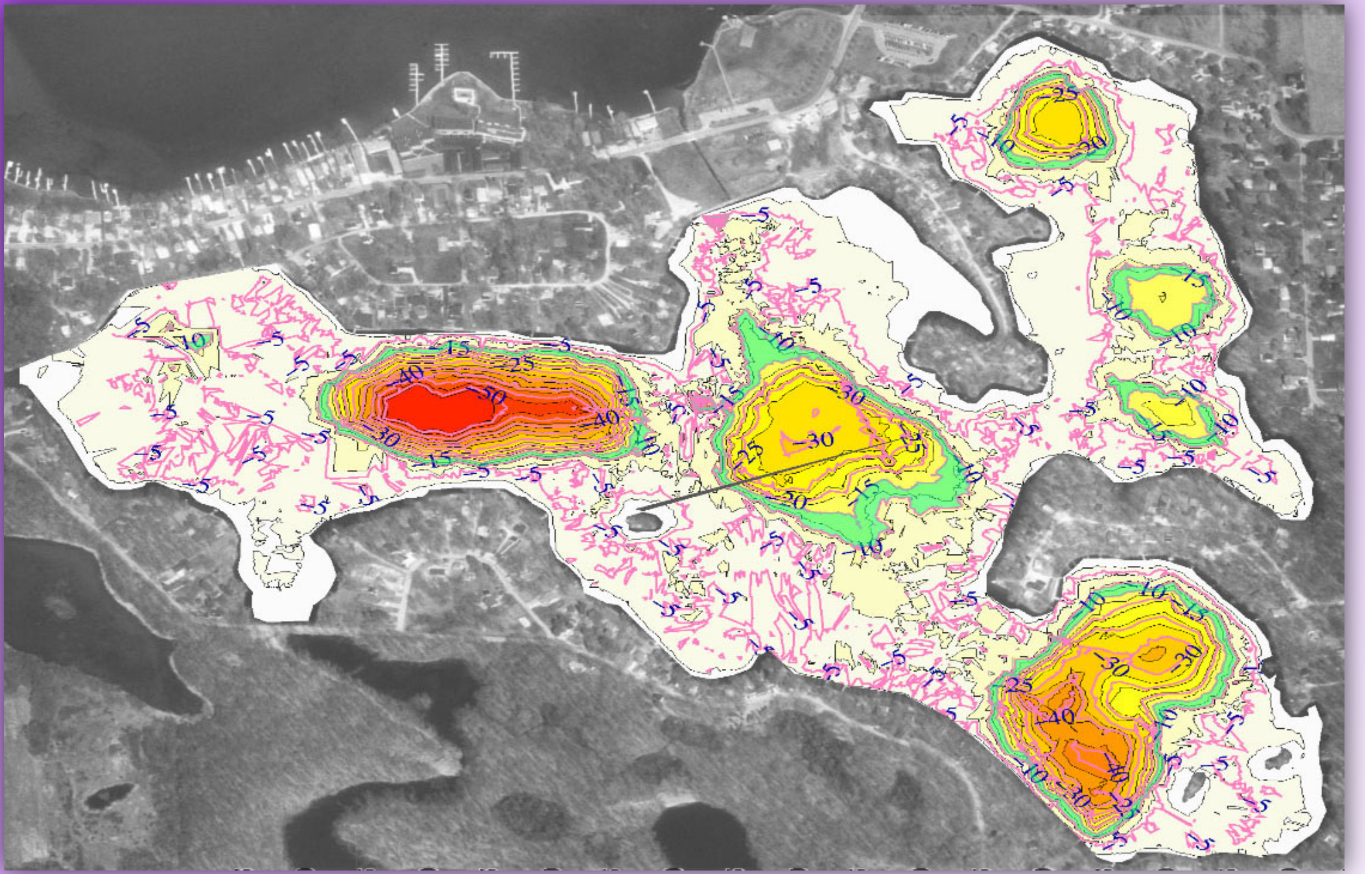
Portion of the Wawasee Subwatershed: Areas South of Lake Papakeechie

LP is part of a larger waterhed; LP impacts, and is impacted by, this watershed.
<u>Consequence</u>: We need to pay attention not only to LP, but also to its environs.

Partitioning of LP into Fifty (50) GPS-Defined Test Sites Distributed in Four (4) Regions – Summer 2013

An Important Milestone: Summer 2013

Bathymetric Map of LP Generated by John Hart and Coworkers



Possibility of Bathymetric Mapping Every 3-5 Years?

Lake Water Testing Profile

Present and Future Plans

- Turbidity (Secchi disc)
- Temperature
- Dissolved oxygen (DO)
- *E. coli* levels
- Dissolved nitrogen (as nitrates): < 0.3 mg/L or < 300 ppb
- Dissolved phosphorus (as inorganic PO_4^{-3}): < 0.03 mg/L or < 30 ppb
- Acidity (pH)
- Chlorophyll a

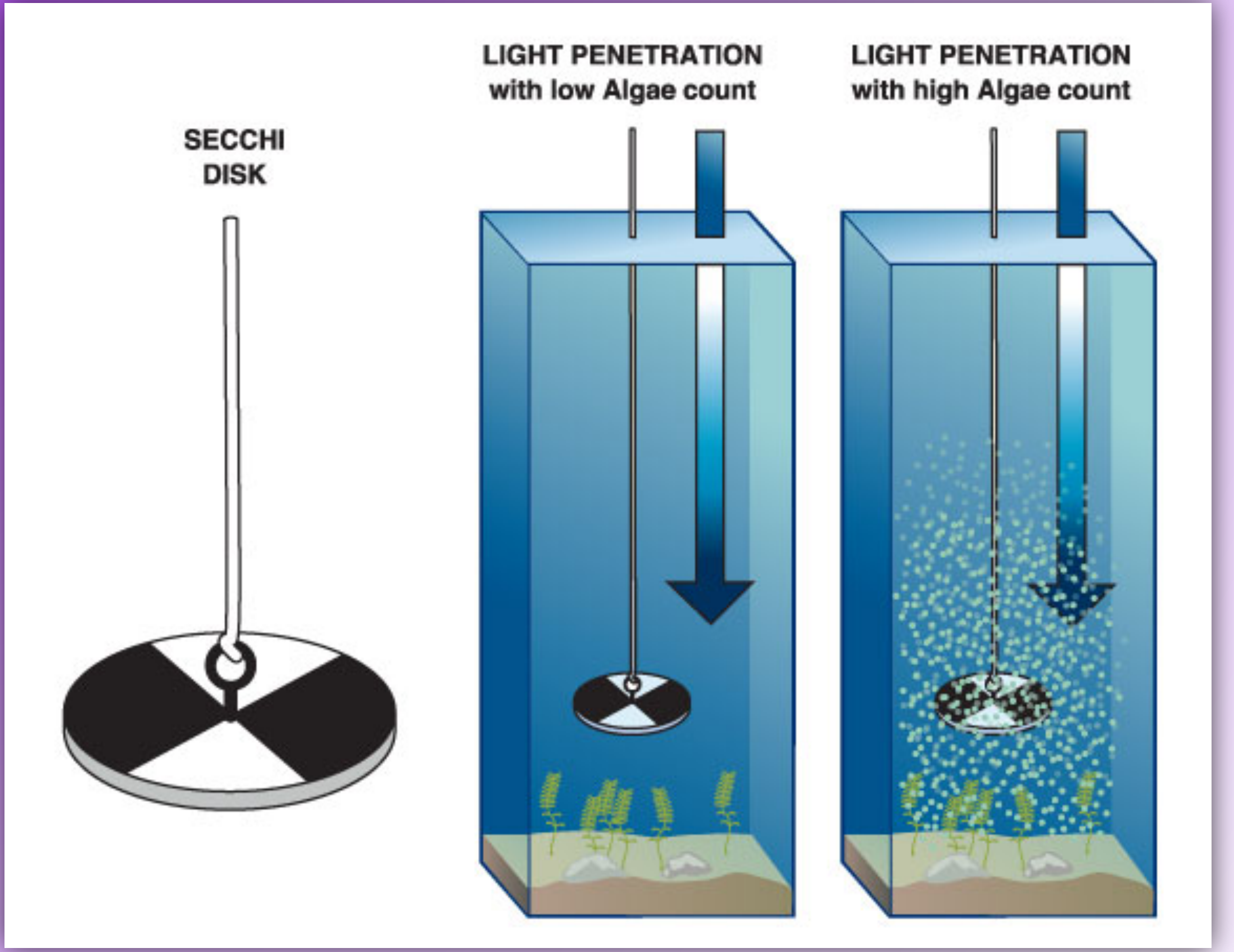
Variables

- **Sample location**
- **Sample density**
- **Sample depth**
- **Time of day (diel fluctuations)**
- **Seasonal fluctuations**

Other factor in Summer 2013: elevated water level on LP – bank erosion, sediment disruption, submersion of plants along shoreline, etc.

Consequence: Water quality data from summer 2013 may be aberrant.

Turbidity Measurements with a Secchi Disc



Dissolved Nitrogen and Phosphorus Measurements
Summer 2014

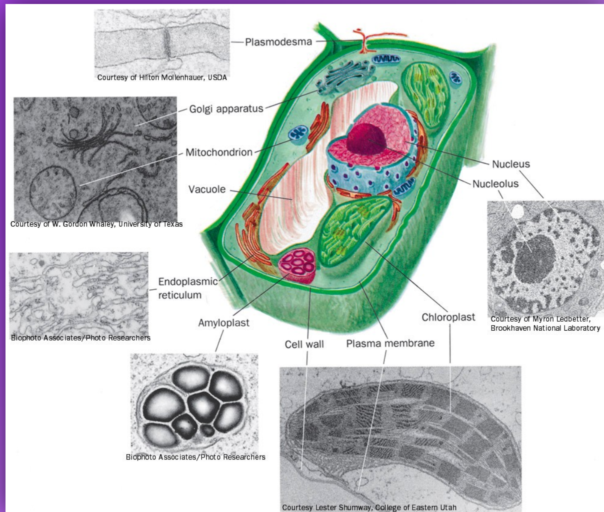
<u>Nitrate (NO_3^-):</u> < 0.3 mg/L or < 300 ppb
HI 96786C Nitrate Ion High Range Selective Meter (Hanna Instruments)
Effective Range = 0-100 mg/liter (or 0-100 ppm)
Resolution = ± 1 mg/L (or ± 1 ppm)

(Low Range meter is also available: 0-30 mg/L range,
0.1 mg/L resolution)

- <u>Phosphorus (PO_4^{-3}) (soluble):</u> < 0.03 mg/L or < 30 ppb

HI 96717C Phosphate High Range Ion Selective Meter (Hanna Instruments)
Effective Range = 0-30 mg/liter (0-30 ppm)
Resolution = ± 0.1 mg/L (± 0.1 ppm)

(Low Range meter is also available: 0-2.5 mg/L range,
0.01 mg/L resolution)



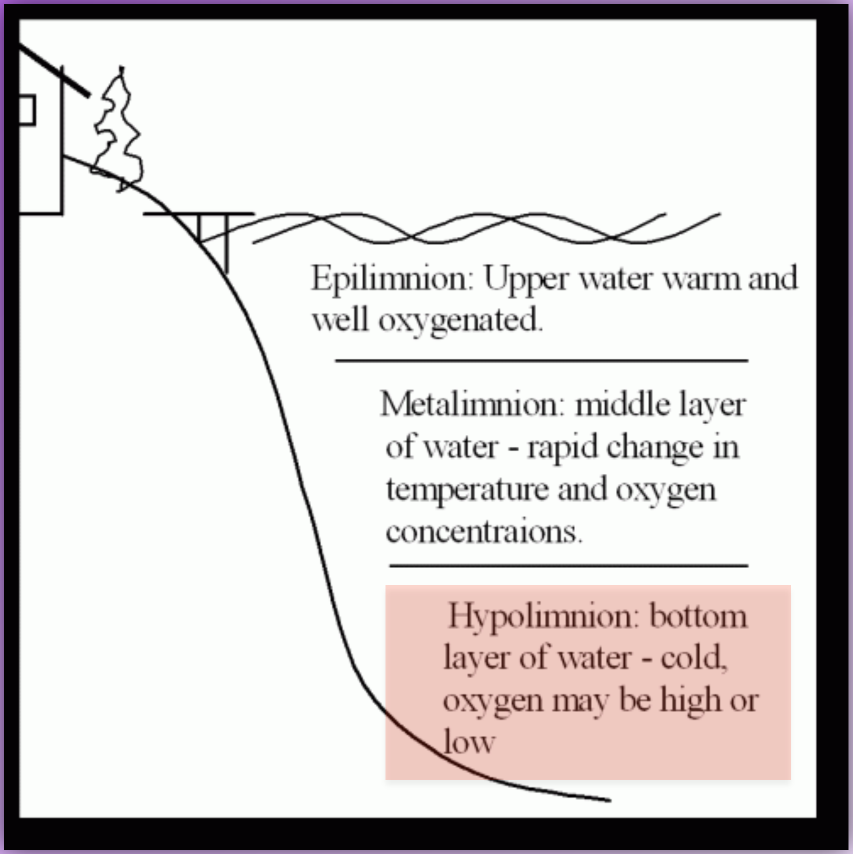
Chlorophyll *a*
Summer 2015

Chlorophyll is the green pigment found in all plants that allows them to use the sun's energy to convert CO_2 and water into oxygen and cellular material (photosynthesis).

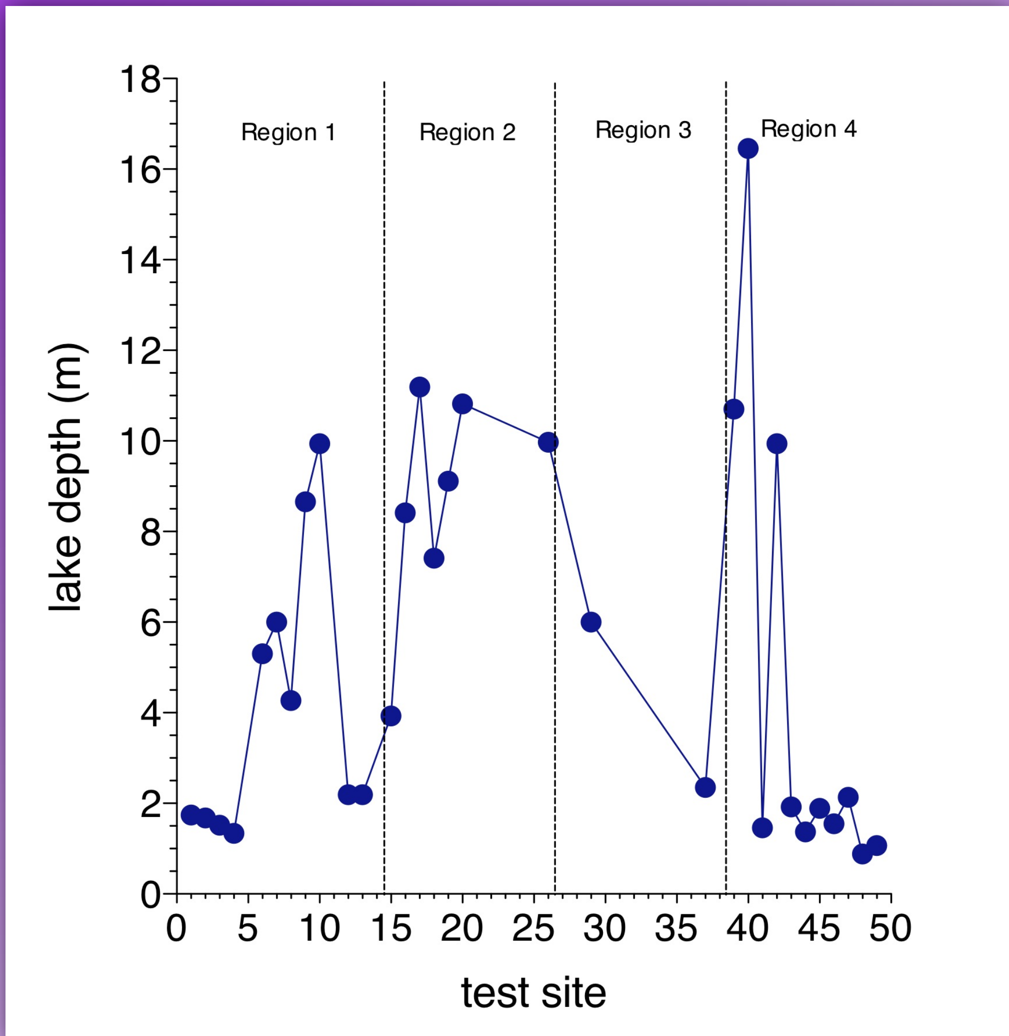
Lake testing for chlorophyll provides an estimate of the amount of algae growing in the lake. Algal growth reflects the level of nutrients in a lake (mainly N and P), but is affected by other factors (*e.g.*, water temperature, water transparency, amount of zooplankton and fish). Water samples for chlorophyll analysis are taken from the upper layer of the lake called the epilimnion.

Chlorophyll measurements are made with a meter (similar to a DO/T meter) equipped with a specific probe.

Some Lake Depth Definitions and Terms

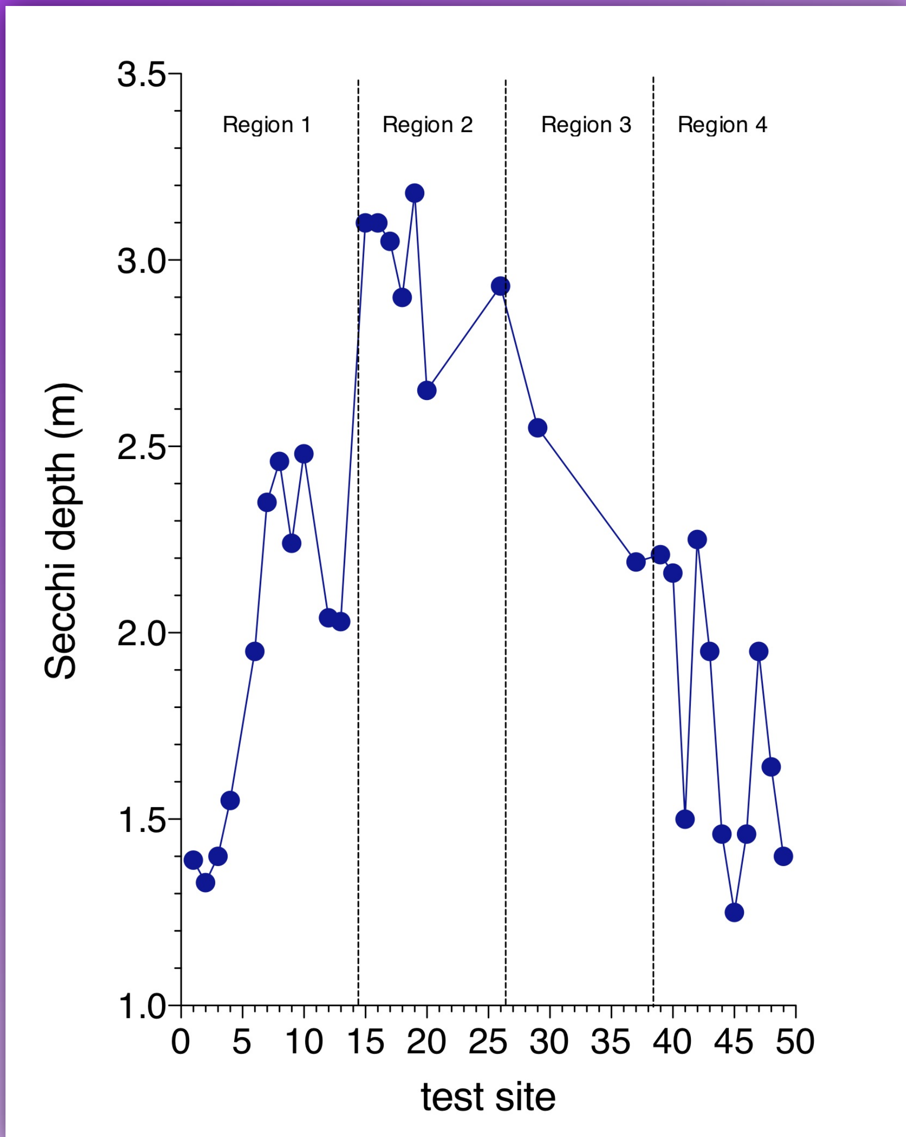


LP Data: Summer 2013



Lake depth varies widely, even within a given Region. The deepest area of the lake resides in Region 4 (near Site 40) (~17 m or ~56 ft) .

LP Data: Summer 2013

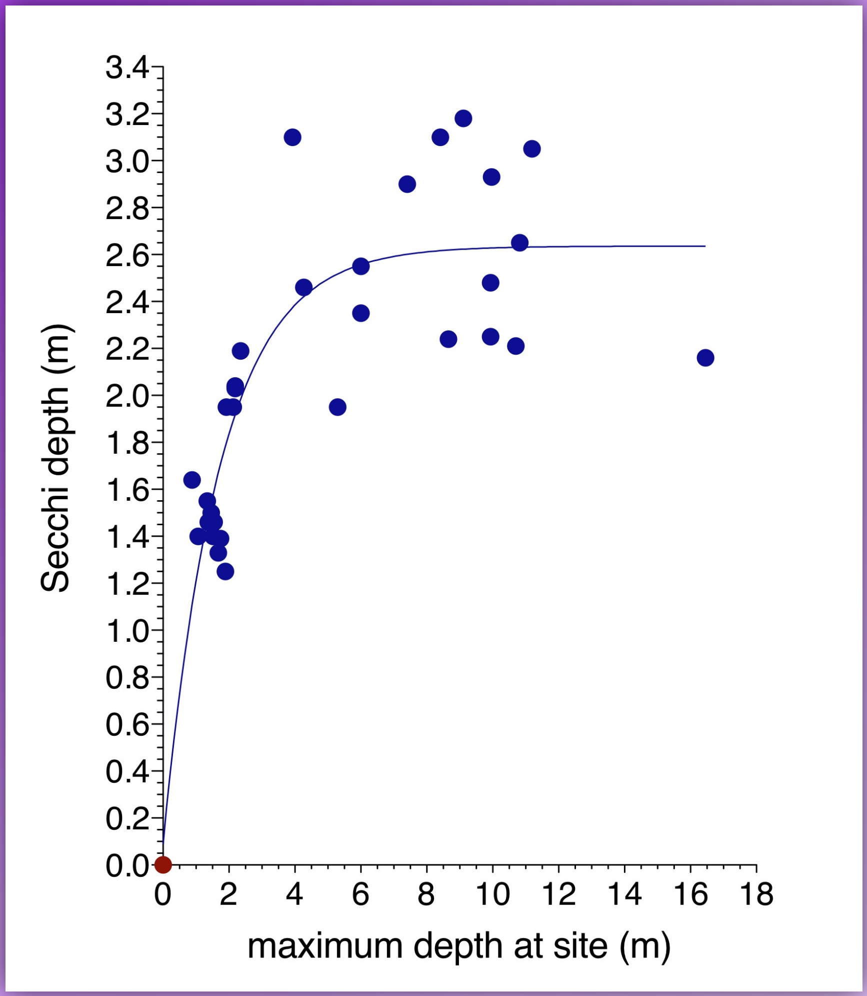


Secchi^{max} = 3.2 m (10.5 ft)

Secchi^{min} = 1.3 m (4.3 ft)

On average, the least turbid region of LP is Region 2.

LP Data: Summer 2013



There is a very weak correlation between maximum lake depth and water clarity – other factors are at work – argues against minimizing the number of data points in lake studies

Using Secchi data:

TSI = 60 – 14.41 ln SD

(SD = Secchi depth in m)

TSI = 60 – 14.41 ln 2.6

TSI = 60 – (14) = <u>46</u>

TSI = 60 – 14.41 ln 1.4

TSI = 60 – (5) = <u>55</u>

Lake Trophic Status

TSI or Trophic State Index (Carlson Index)

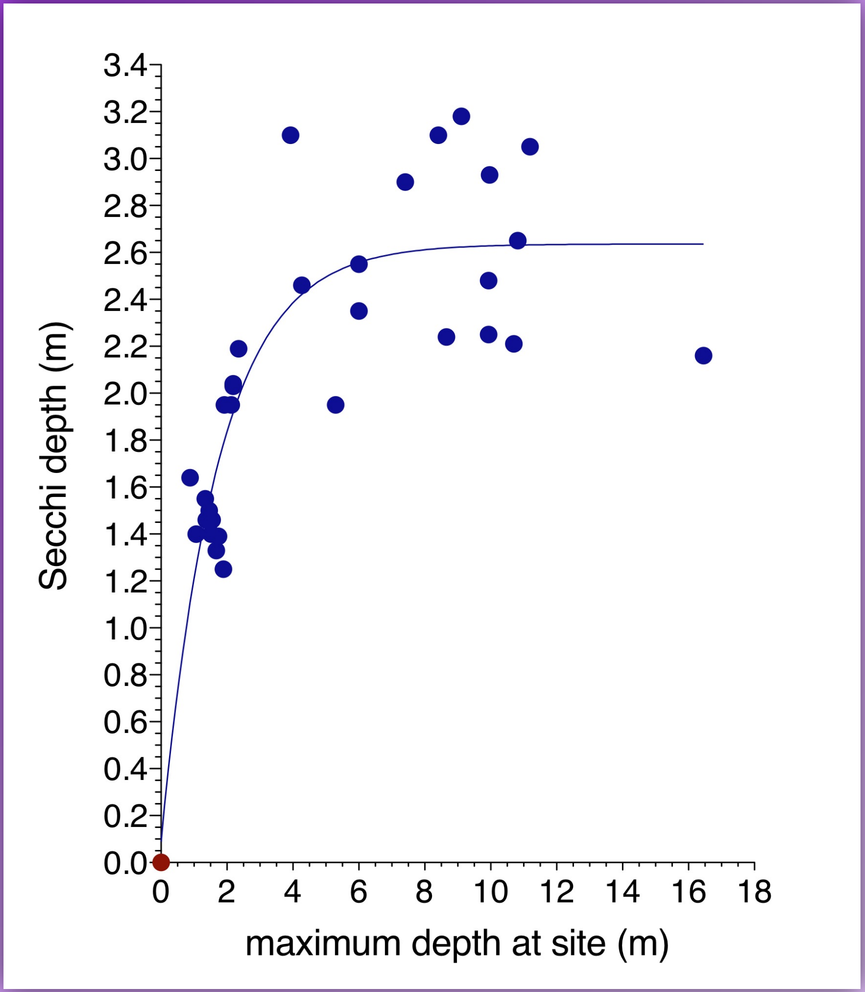
The TSI is a way to rate lakes in terms of their productivity. Its value is calculated in several different ways.

Using Secchi data:
TSI = 60 – 14.41 ln SD
(SD = Secchi depth in m)

Using total phosphorus:
TSI = 14.42 ln TP + 4.15
(TP = total phosphorus concentration in surface water in μg/L)

Using chlorophyll a:
TSI = 9.81 ln Chl a + 30.6
(Chl a = chlorophyll a concentration in μg/L)

LP Data: Summer 2013



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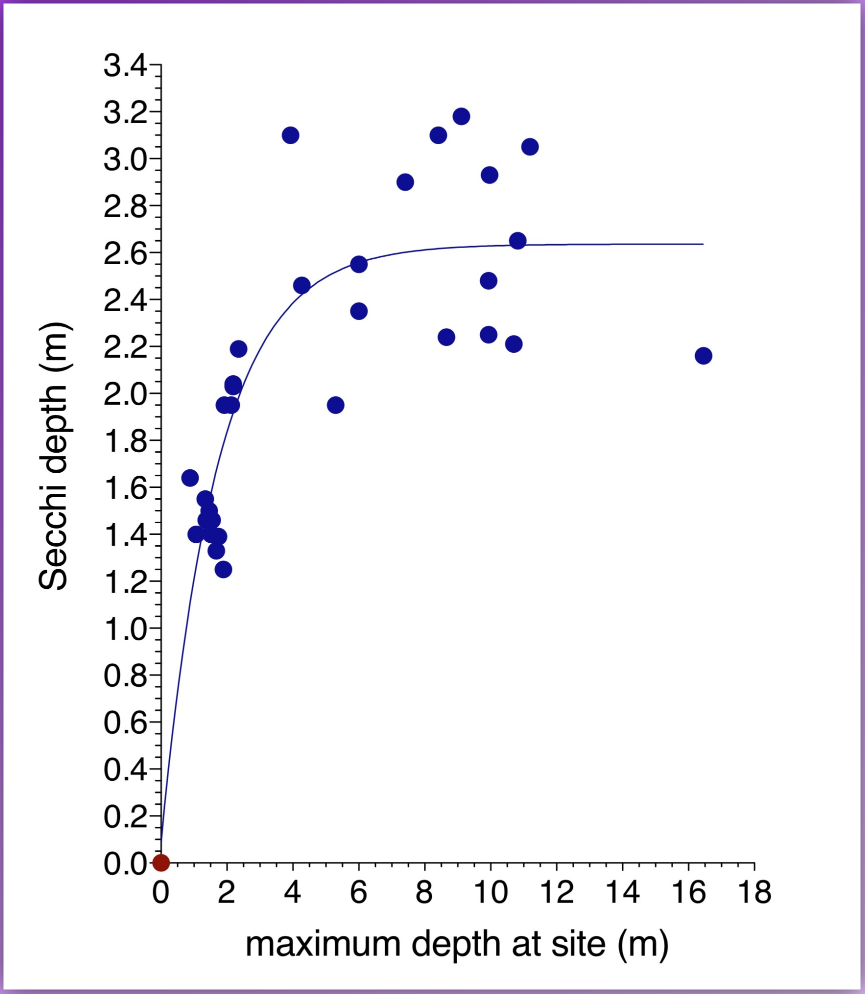
TSI = 60 – (5) = <u>55</u>

Interpretation of TSI Values

- Data need to be collected for many years to establish trends.
- It is best to calculate TSI values more than one way for comparison.
- In general, chlorophyll a is the best indicator to use for measurements in the summer, and TP is the best indicator for the remainder of the year.

TSI 0-40: oligotrophic lakes
TSI 40-60: mesotrophic lakes
TSI 60-100: eutrophic lakes

LP Data: Summer 2013



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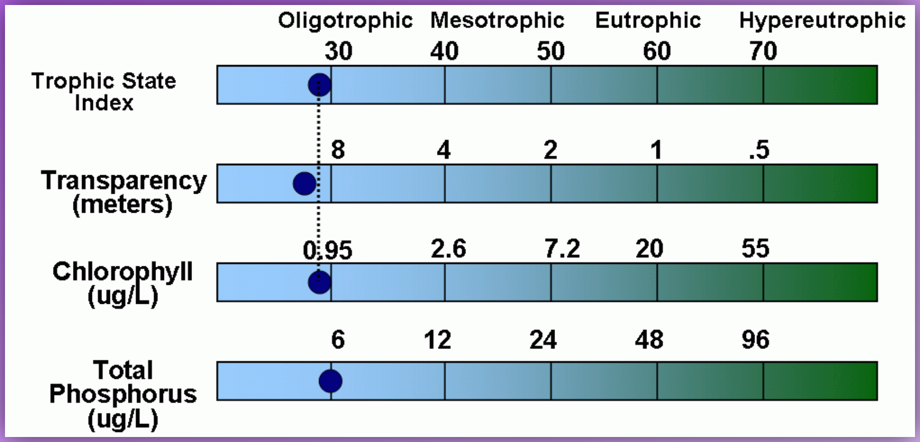
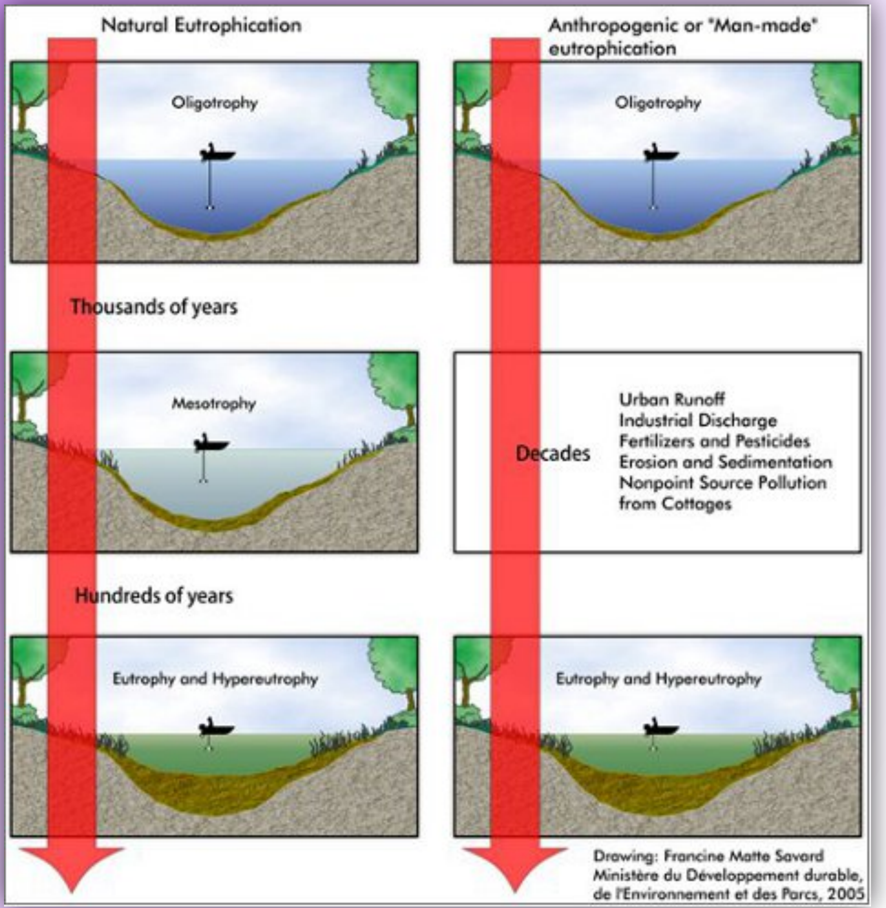
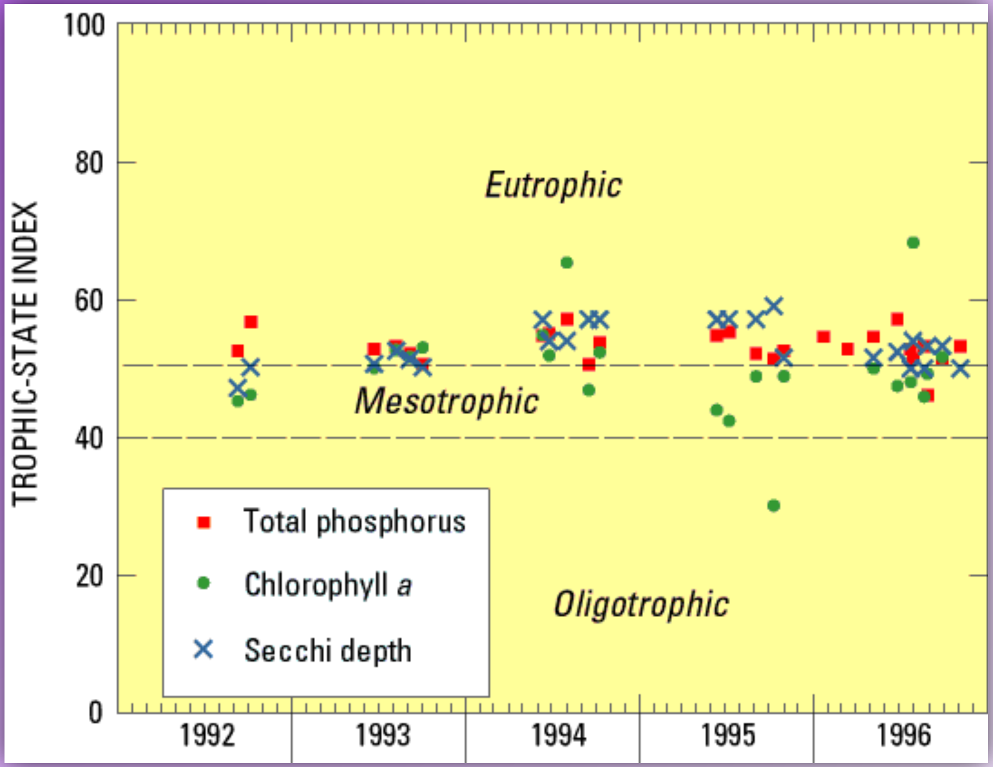
$\mathrm{TSI} = 60 - (5) = \underline{55}$

Correlations Between Water Transparency, Chlorophyll, TP and TSI: Anthropogenic Eutrophication

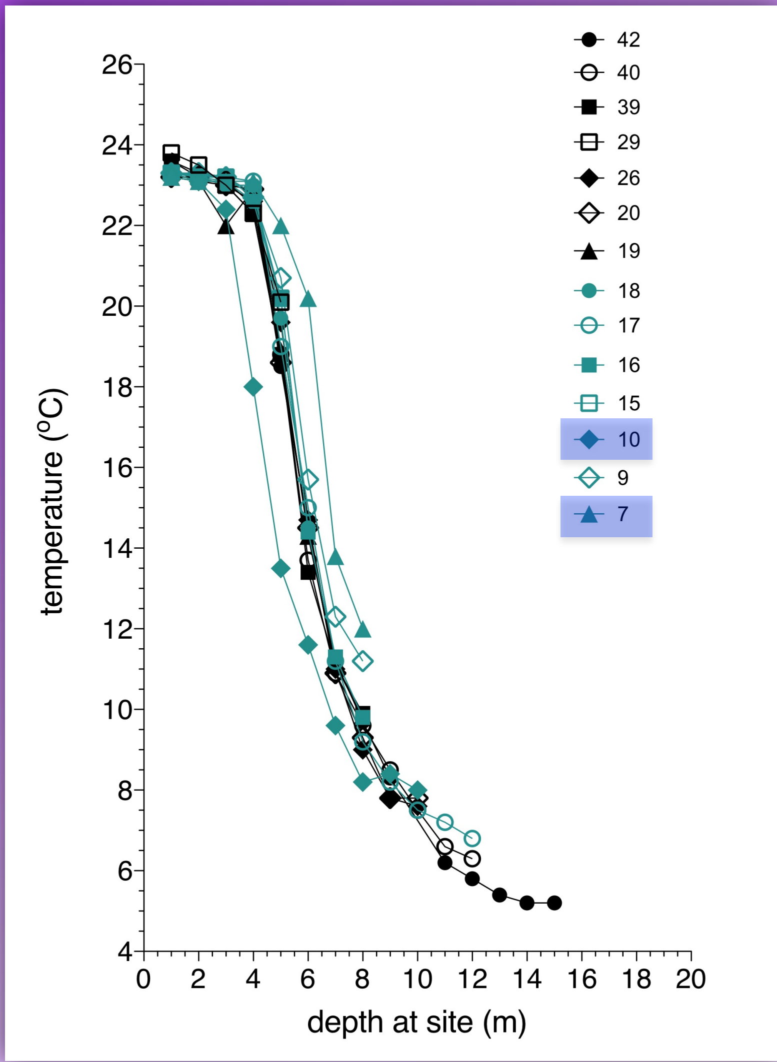




Calculating TSI From Different Lake Parameters:
The Importance of Longitudinal Study



T *vs* depth curves are essentially independent of test site with two exceptions.

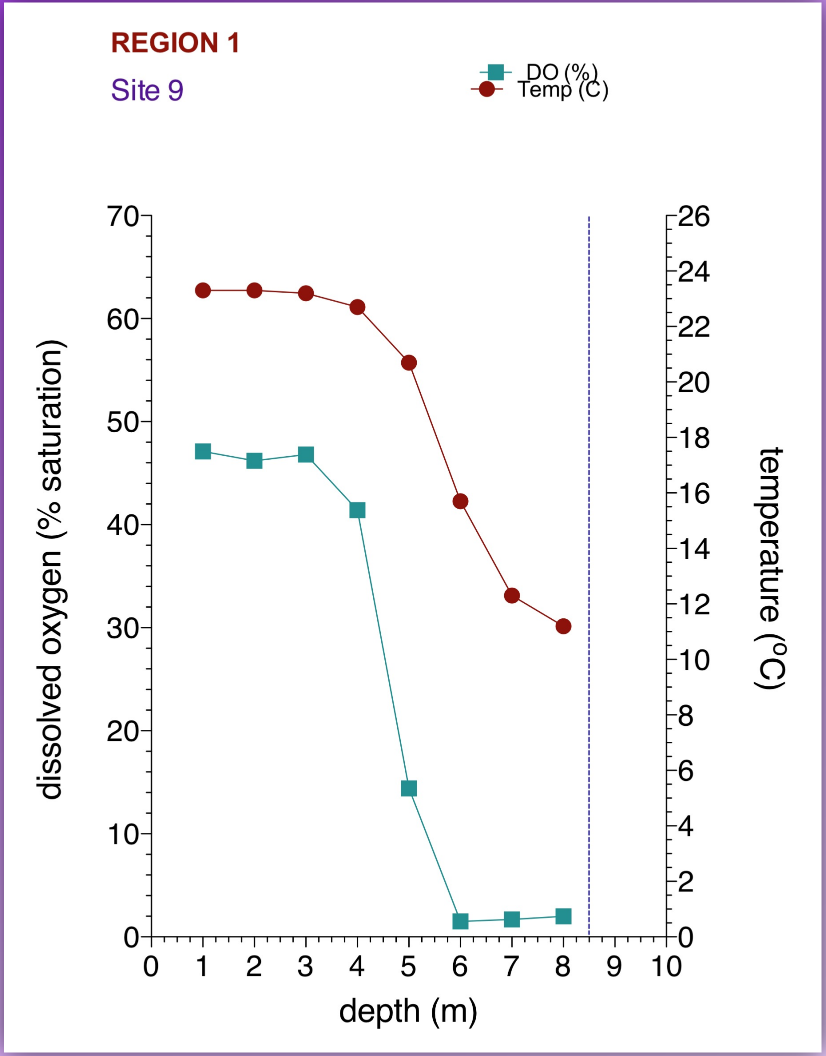


LP Data: Summer 2013

Epilimnion: 0-4 m
Thermocline: ~ 6 m
Hypolimnion: ~ >10 m

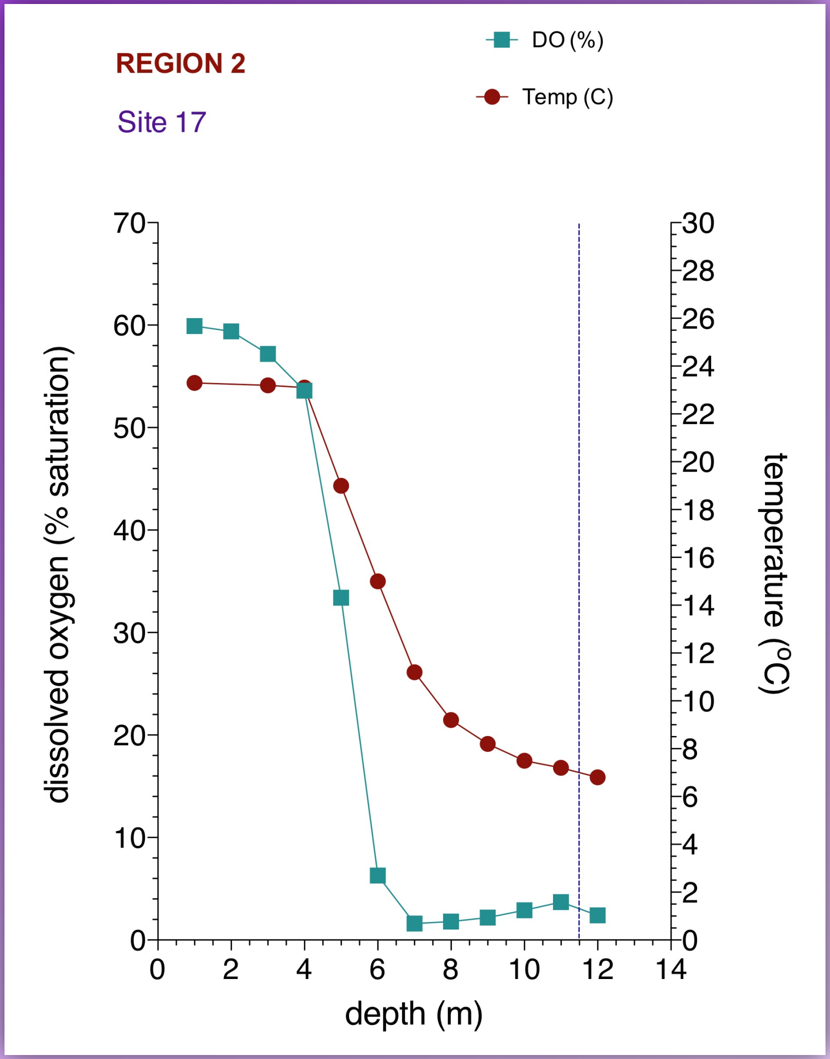
LP Data: Summer 2013

DO as a function of lake depth



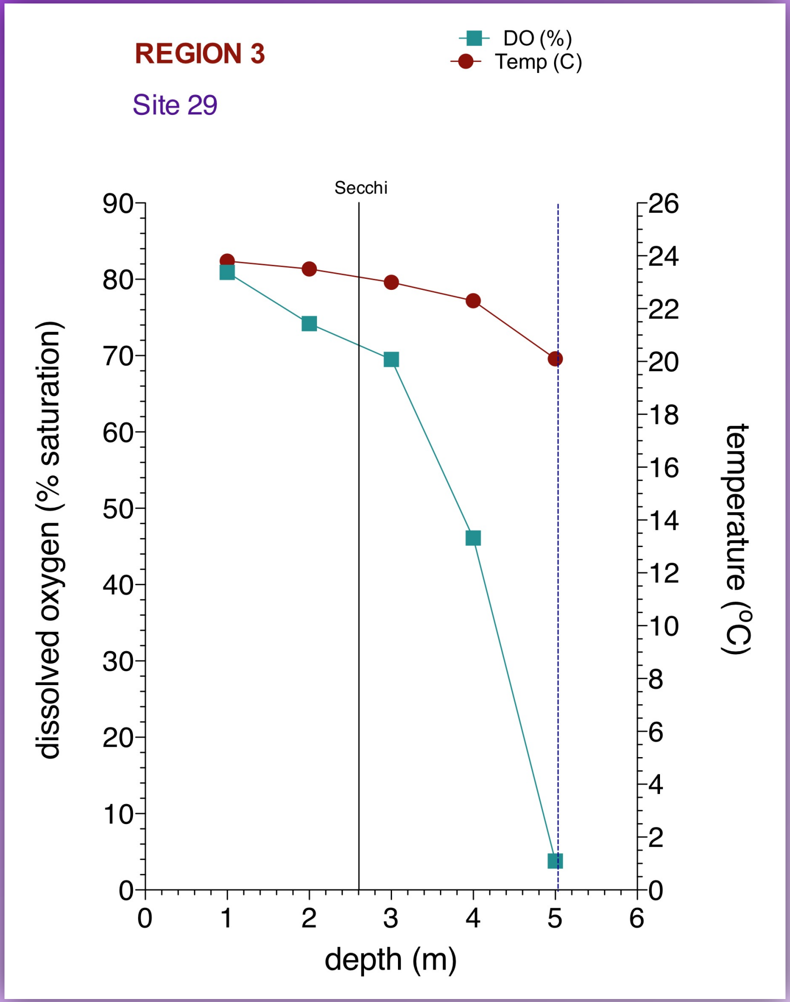
- DO drops off rapidly below ~4 m.
- Hypolimnion essentially anoxic at ~6 m.

DO as a function of lake depth



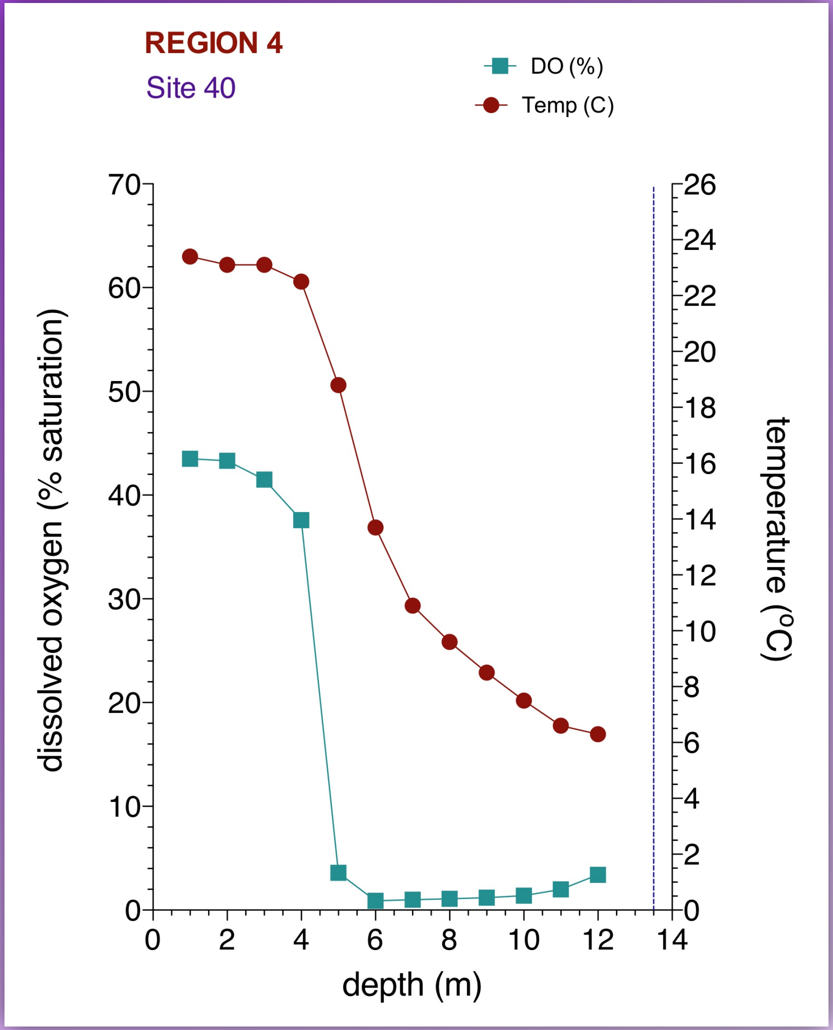
LP Data: Summer 2013

DO as a function of lake depth



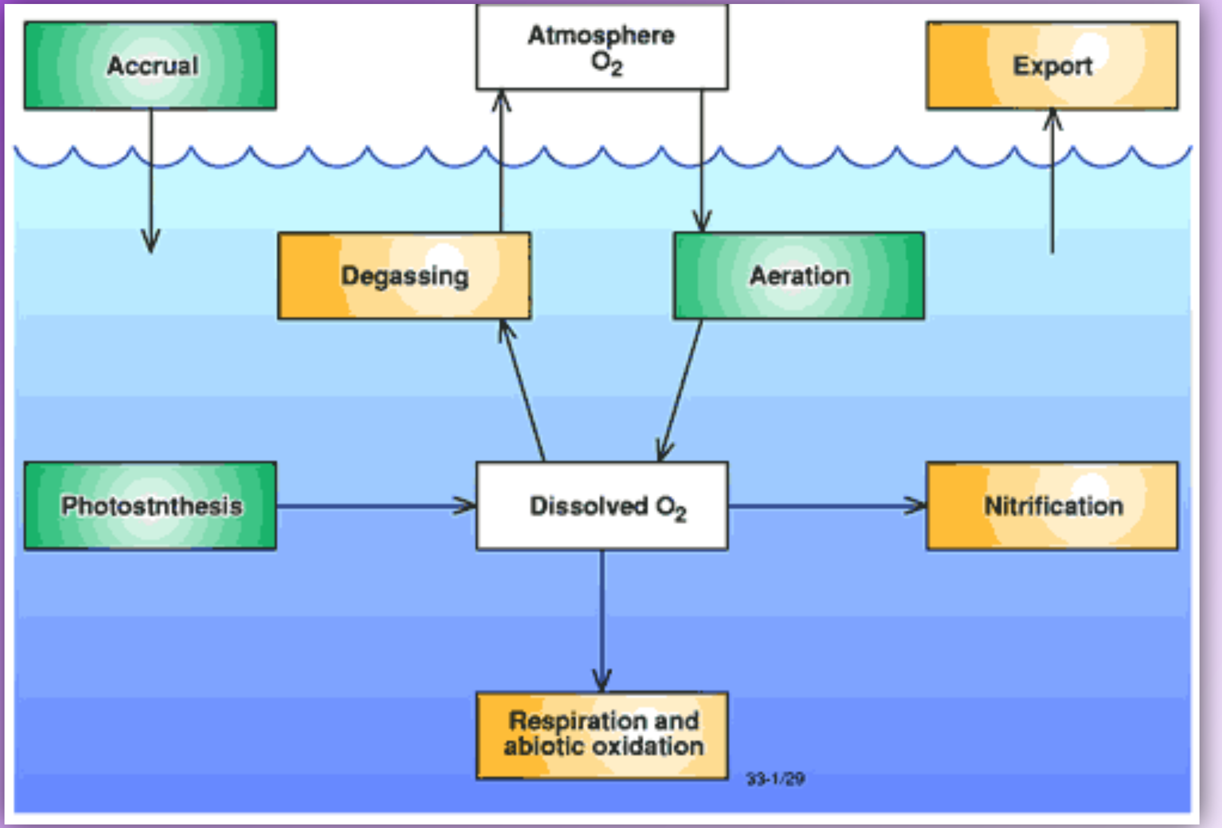
LP Data: Summer 2013

DO as a function of lake depth

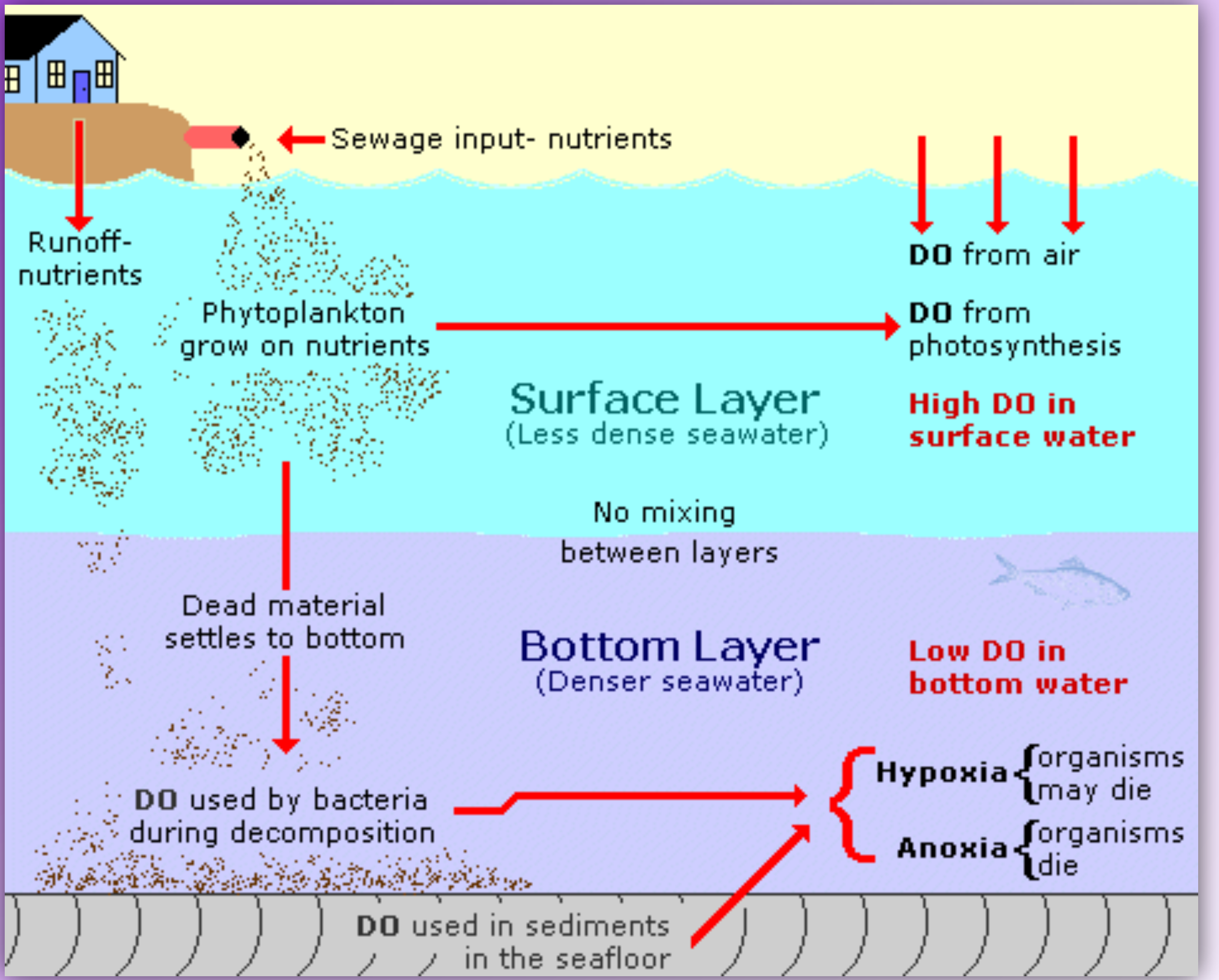


LP Data: Summer 2013

Sources and Sinks of Dissolved Oxygen

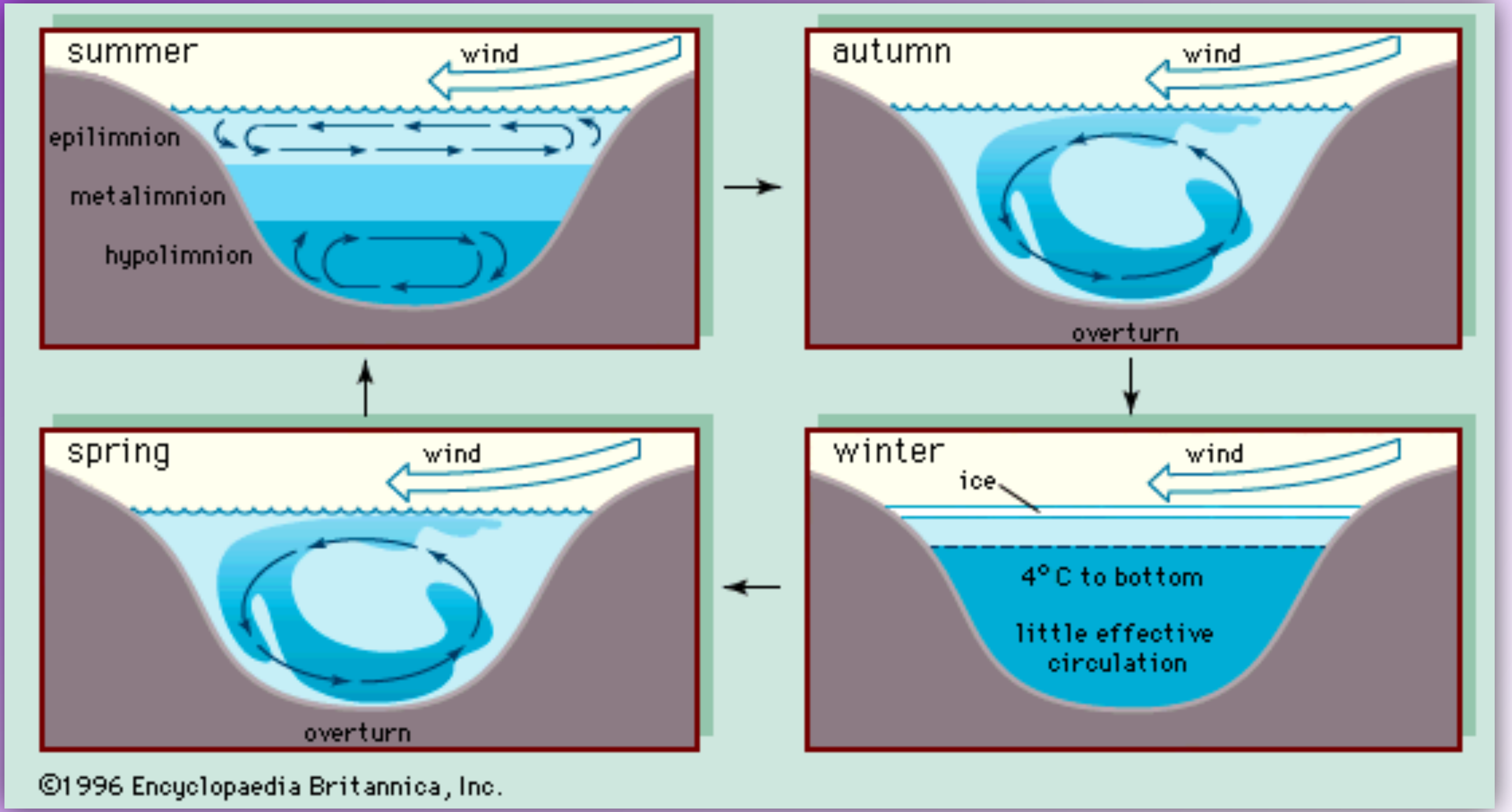


Chemical and Biological Factors Affecting DO in Water Bodies

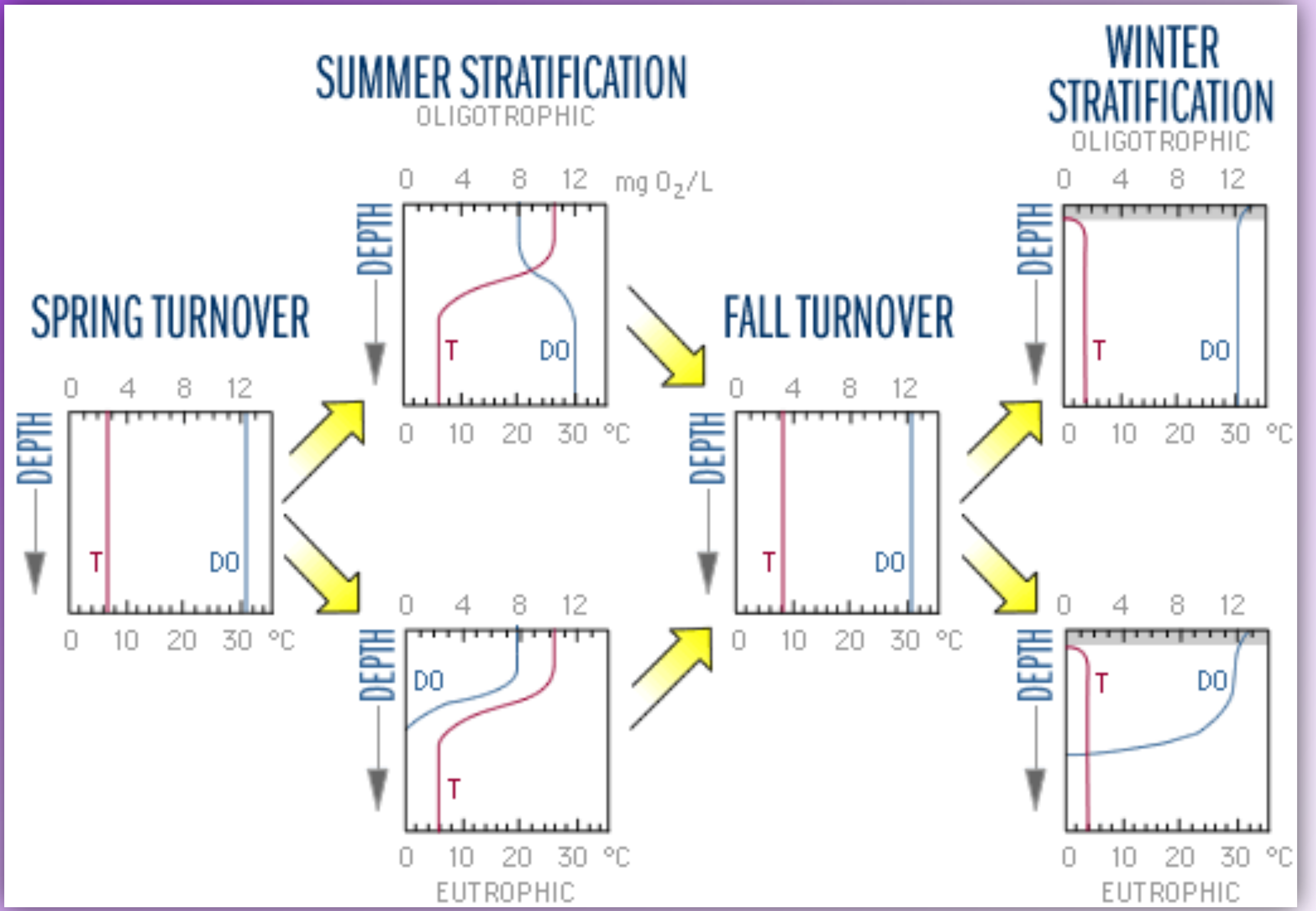


Dimictic Lakes - Natural Annual Cycle

Seasonal heating and cooling
Wind-induced turbulence

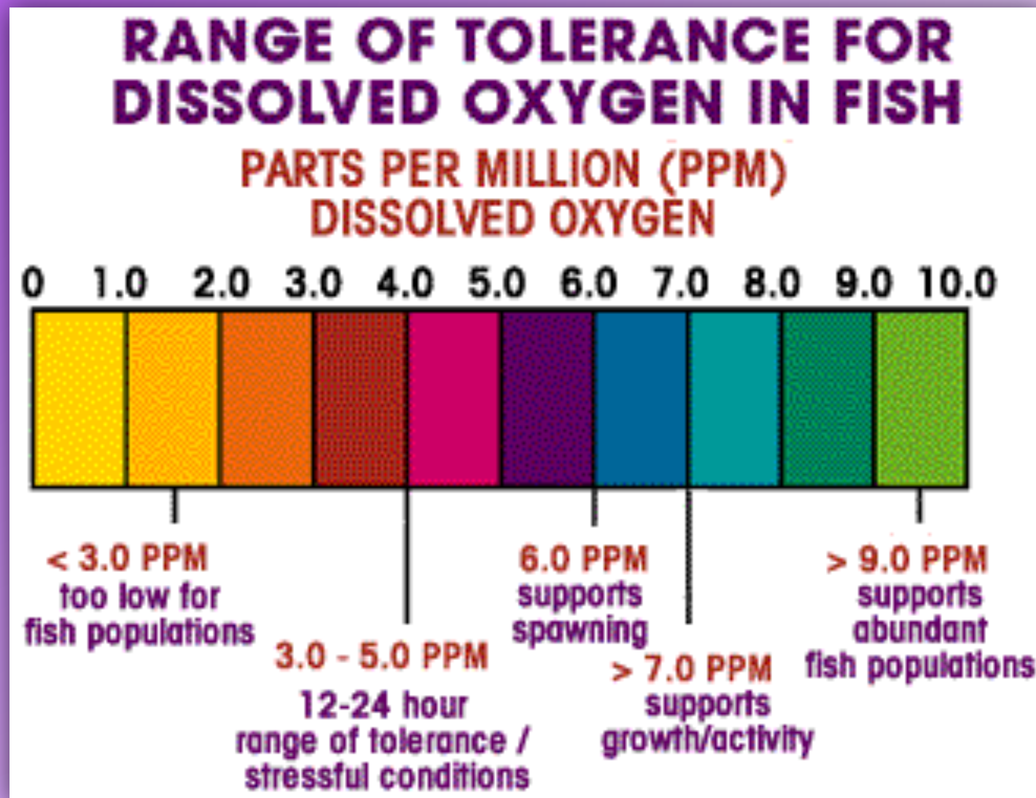


Lake Temperature Seasonal Temperature and DO Stratification



Stratification Affects Lake Chemistry and Biology

- During stratification, the hypolimnion is cut off from the oxygen in the air.
- If the lake is productive, there will be organic matter from the epilimnion settling into the hypolimnion.
- This organic matter will be broken down by microbial respiration resulting in a decrease in dissolved oxygen.
- This may leave the hypolimnion critically deficient in dissolved oxygen so that it cannot support many animals like fish.

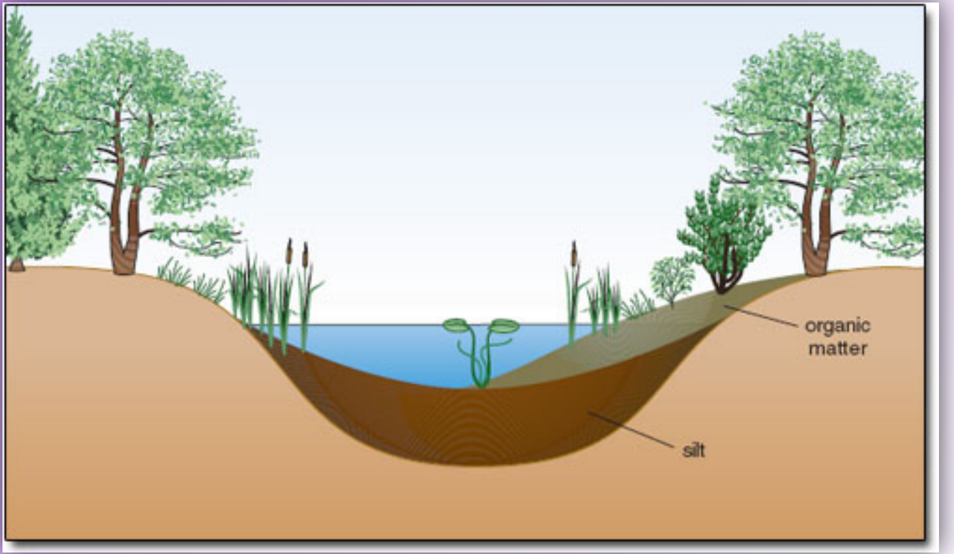

RANGE OF TOLERANCE FOR DISSOLVED OXYGEN IN FISH
PARTS PER MILLION (PPM) DISSOLVED OXYGEN
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
< 3.0 PPM too low for fish populations
3.0 - 5.0 PPM 12-24 hour range of tolerance / stressful conditions
6.0 PPM supports spawning
> 7.0 PPM supports growth/activity
> 9.0 PPM supports abundant fish populations

Lake Trophic Status

- **Oligotrophic**
  - Low productivity, clear water, life more sparse
- **Eutrophic**
  - High productivity, murkier water, but more life

Excess Nutrients: N and P
Natural Eutrophication

- Productivity of lakes is determined by a number of factors:
  - Geology and soils of watershed
  - Water residence time
  - Lake morphometry
  - Water mixing regime
- Over thousands of years these factors gradually change resulting in lakes becoming more productive.



Cultural (Anthropogenic) Eutrophication

- Human activities can alter the balance of these factors, esp. when excess nutrients (P in freshwater) are introduced.
- Untreated sewage for example has a TP conc of 5-15 mg/L.
- Even conventionally treated sewage has about ½ that.
- Compare that with in-lake concentrations of 0.03 mg/L that can cause eutrophic conditions.
- So, small amounts of sewage can cause problems

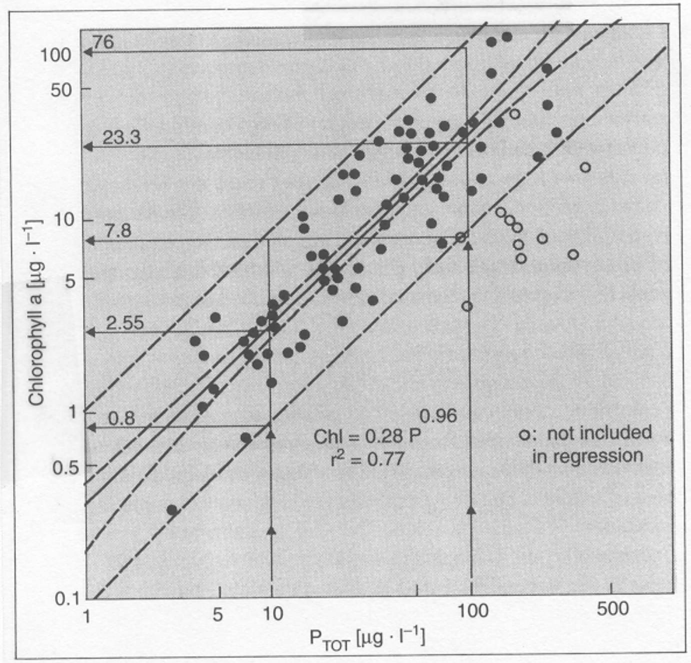


Figure 8.11 The phosphorus–chlorophyll model of the OECD eutrophication study (from Vollenweider and Kerekes 1982). Each data point represents one lake. Log-log regression of chlorophyll (yearly average in the euphotic zone) and total phosphorus (yearly average for the entire water column). Inner dashed line: 95% confidence interval around the regression line; outer dashed line: 95% confidence limit for the dependent variables; thin lines with arrows: predicted chlorophyll values for lakes with 10 and 100 μg P_{tot}/l.

Cultural (Anthropogenic) Eutrophication

Problems associated with cultural eutrophication include:

- Anoxic hypolimnion
  - Part of lake removed as habitat
  - Some fish species eliminated
  - Chemical release from sediments
- Toxic and undesirable phytoplankton
  - Blooms of toxic cyanobacteria
  - Phytoplankton dominated by cyanobacteria and other algae that are poor food for consumers
- Fewer macrophytes
  - Elimination of habitat for invertebrates and fish
- Esthetics

BOX 8.1 SOME CHARACTERISTICS OF OLIGOTROPHIC AND EUTROPHIC LAKES

	Oligotrophic	Eutrophic
Morphometry	deep	shallow
Volume ratio epi/hypolimnion	<1*	>1*
Primary production	low (50–300 mg C m^{-2} d^{-1})	high (>1000 mg C m^{-2} d^{-1})
Algal biomass	small 0.02–0.1 mg C/l 0.3–3 μg Chl a/l	large >0.3 mg C/l 10–500 μg Chl a/l
Nutrients	low P_{tot} after complete circulation < 10 μg/l	plentiful P_{tot} after complete circulation > 30 μg/l
Massive development of cyanobacteria	absent	present
O_2 depletion in the hypolimnion	little, >50%	strong, may be anoxic
O_2 profile	orthograde	clinograde
Profundal zoobenthos	diverse, O_2 requiring	species poor, tolerate low O_2
Chironomid larvae	*Tanytarsus* group	*Chironomus* group
Fish fauna	deep-water salmonids, coregonids (cold stenotherms)	cyprinids, centrarchids (sunfish) ("warm-water" fish)

* exceptions possible.

Cultural (Anthrpogenic) Eutrophication
A Case Study

- Lake Washington
  - Following WWII, population increases in the Seattle area resulted in increases in sewage discharge to Lake Washington
  - Secchi depth decreased from about 4 m to 1-2 m as algae bloomed from sewage P
  - Diversion system was built and effluent was diverted to Puget Sound in mid-1960's
  - Algae subsided and water clarity increase
  - Daphnia reestablished itself and further clarified the lake

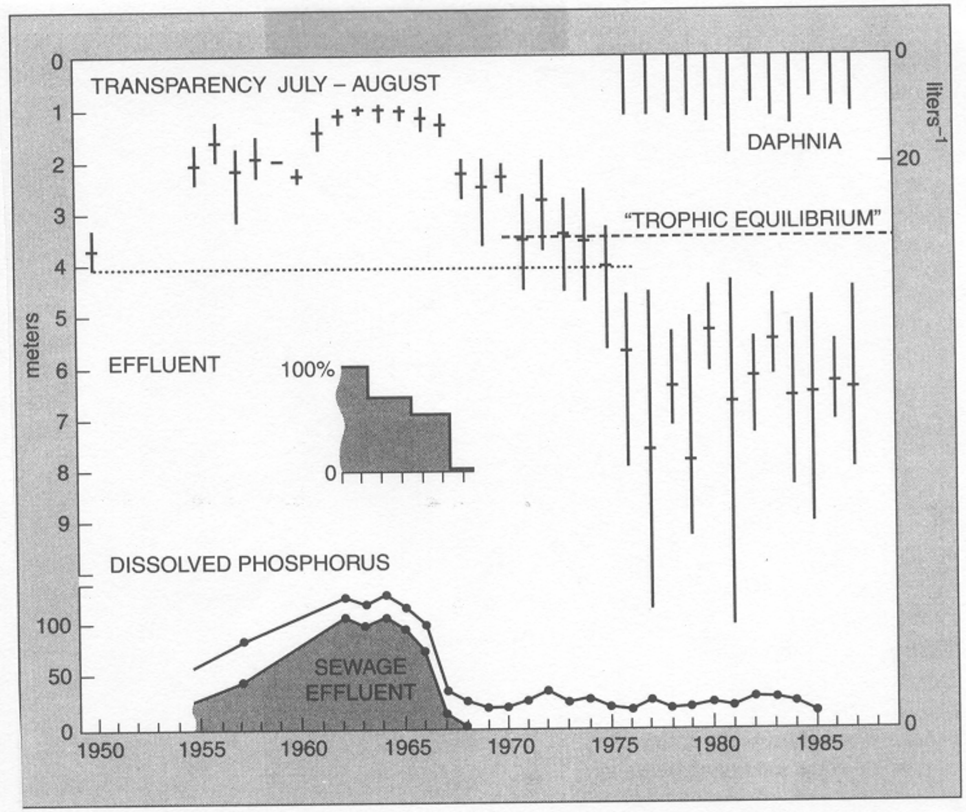
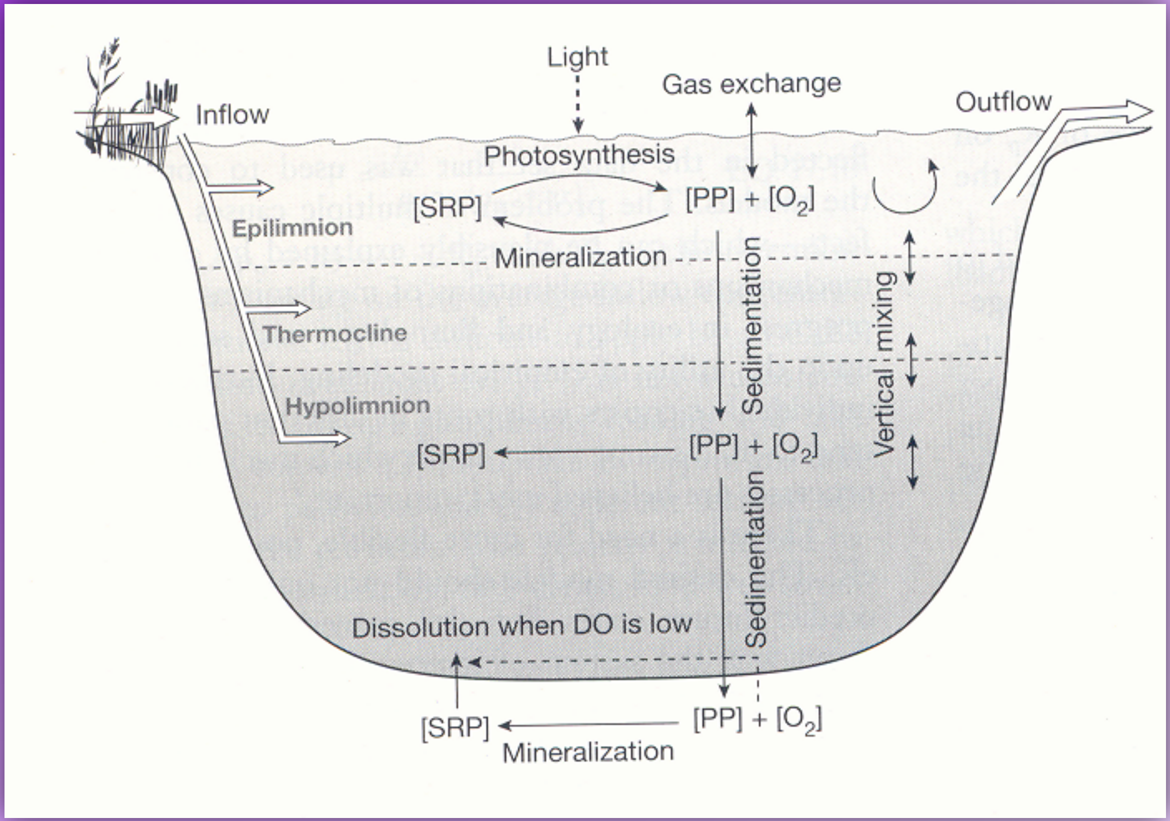


Figure 8.14 Summary of changes in Lake Washington (U.S.) in response to the diversion of sewage from the lake (after Edmondson 1991).

Lake Chemistry - Phosphorus

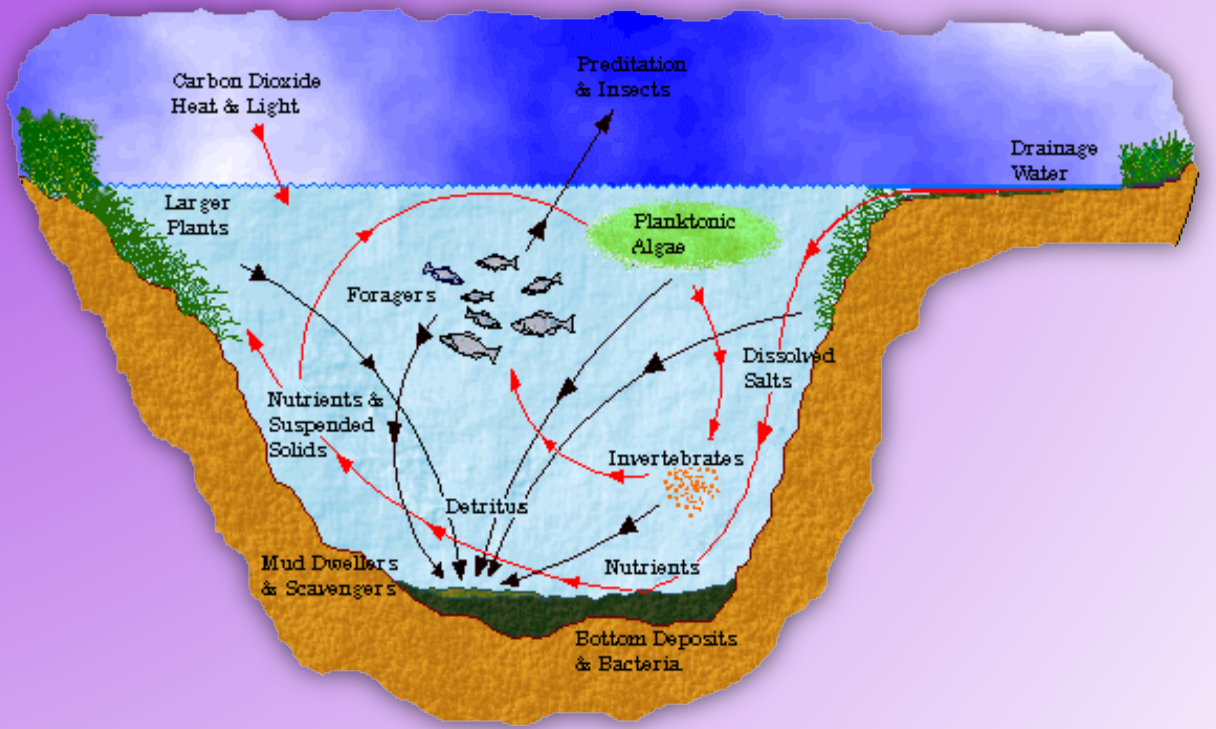


PP = particulate phosphorus (insoluble)

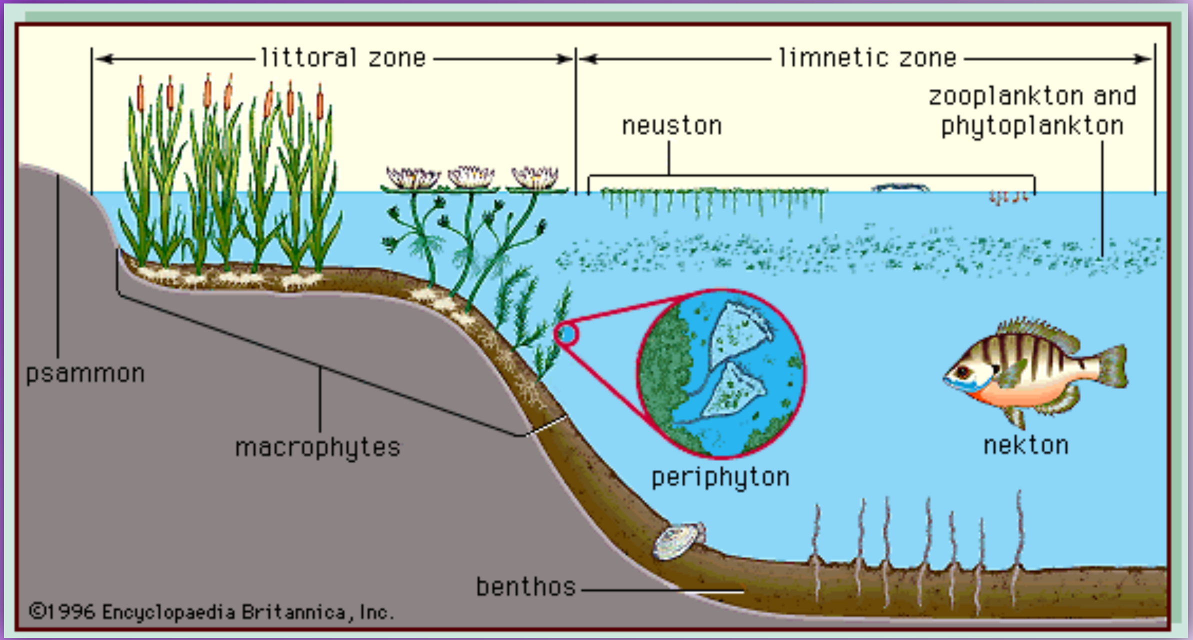
SRP = water soluble reactive phosphorus

- **P limits biological production in lakes**
- **P cycles in lakes**
- **P accumulates in the sediments**

Overview of the Lake Food Web

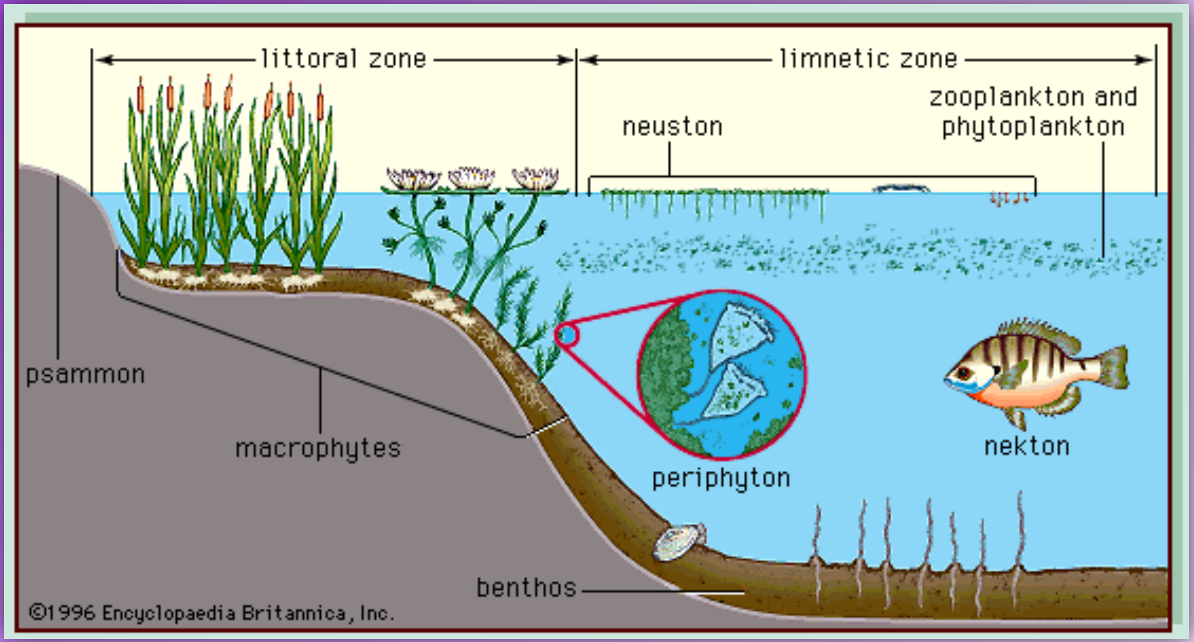


Zonation of Biota in Lakes



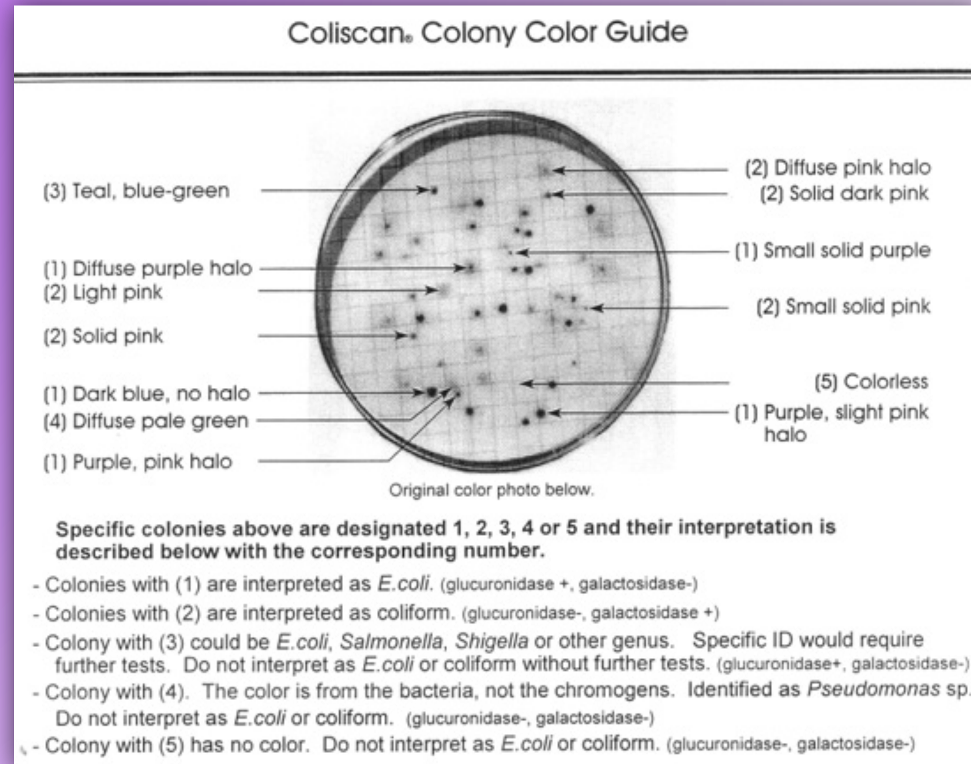
- Biological zonation is strongly influenced by light availability.
- The **littoral zone** is the region of the lake that has sufficient light for photosynthesis to the lake bottom.
- The **limnetic zone** is the open water area in which sufficient light for primary producers is only available in the top layer of the water column.
- The dark portion of the open water is sometimes called the **profundal zone.**

Types of Lake Organisms: Biological Monitoring



- **Macrophytes**: large leafy plants with attached microscopic periphyton
- **Plankton**: Suspended small organisms controlled by currents
- **Benthos**: Bottom dwellers
- **Nekton**: Larger, mobile organisms
- Note which zone each is found in

LP Data: Summer 2013
Coliscan *E. coli* Test



For lake water to meet recreational standards, the geometric mean of 5 samples over a 30-day period is required to be less than 125 CFU/100 mL, with no sample testing higher than 235 CFU/100 mL.

LP *E. coli* Results: Summer-Fall 2013

Sites with Positive Tests:

Summer 2013:
Site 21: ~50 CFU/100 mL

Fall 2013:
Site 5: ~33 CFU/100 mL
Site 31: ~33 CFU/100 mL
Site 36: ~33 CFU/100 mL
Site 46: ~33 CFU/100 mL

Reference Data

Clean Lakes Program (Indiana)

Data from 456 lakes collected in July-August 1998-2004

	Secchi Disk (ft)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	Chl *a* (µg/L)	Plankton (NU/L)
Median	6.9	0.275	0.818	1.66	0.12	0.17	12.9	35570
Max.	32.8	9.4	22.5	27.05	2.84	2.81	380.4	753170
Min.	0.3	0.013	0.018	0.230	0.01	0.01	0.013	39

The data are means of epilimnetic and hypolimnetic samples.

Grace College Study: Summer 2007

June 27, July 16, August 7 (5-6 weeks)

Sampling Locations on Lake Papakeechie

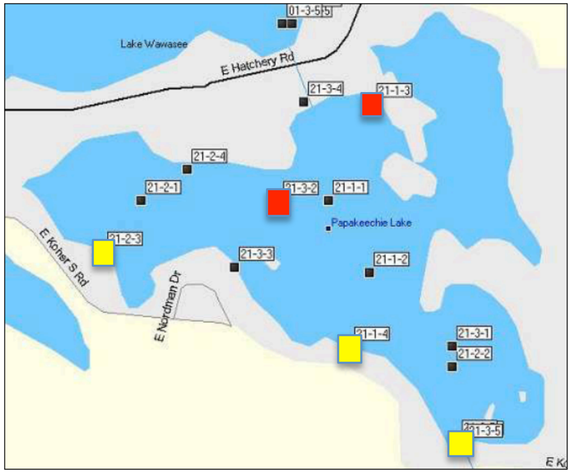
14 test sites

Grace College Study: Summer 2007

Lake Papakeechie

Site	GPS Location	Date	Time	Time (hr)	Current Weather	Past Weather	E. Coli (col/100 mL)	Total Phosphorus (mg/L)
21-1-1	N41 22.394 W85 40.184	6/27/2007	19:27	19.45	overcast	showers	3	0.03
21-1-2	N41 22.286 W85 40.103	6/27/2007	19:34	19.5667	overcast	showers	4.1	
21-1-3	N41 22.537 W85 40.098	6/27/2007	19:13	19.2167	overcast	showers	648.8	0.03
21-1-4	N41 22.176 W85 40.141	6/27/2007	20:00	20	overcast	showers	42.6	
21-1-5	N41 22.037 W85 39.917	6/27/2007	19:50	19.8333	overcast	showers	56.5	<0.03
21-2-1	N41 22.393 W85 40.553	7/16/2007	12:11	12.1833	clear/sunny	clear/sunny	8.3	0.06
21-2-2	N41 22.147 W85 39.940	7/16/2007	12:54	12.9	clear/sunny	clear/sunny	0	
21-2-3	N41 22.317 W85 40.629	7/16/2007	12:17	12.2833	clear/sunny	clear/sunny	62	0.06
21-2-4	N41 22.440 W85 40.462	7/16/2007	12:01	12.0167	clear/sunny	clear/sunny	4.1	
21-2-5	N41 22.038 W85 39.930	7/16/2007	12:42	12.7	clear/sunny	clear/sunny	1	0.09
21-3-1	N41 22.178 W85 39.941	8/7/2007	14:01	14.0167	clear/sunny	storm	1	0.55
21-3-2	N41 22.392 W85 40.281	8/7/2007	13:44	13.7333	clear/sunny	storm	524	
21-3-3	N41 22.295 W85 40.369	8/7/2007	13:50	13.8333	clear/sunny	storm	14	0.53
21-3-4	N41 22.540 W85 40.233	8/7/2007	13:34	13.5667	clear/sunny	storm	22	
21-3-5	N41 22.034 W85 39.919	8/7/2007	14:09	14.15	clear/sunny	storm	17	0.33

Sampling Locations on Lake Papakeechie



***E. coli* > 40 CFU/100 mL at five (5) sites**

Grace College Study: Summer 2007

Lake Papakeechie

Site	Nitrates (mg/L)	Turbidity (NTU_s)	Total Flourescence	pH	Depth (m)	D.O. % sat. (~1m)	D.O. % sat (~3m)	D.O. % sat. (~5m)
21-1-1	<0.1	2.084	100.7	8.75	8	118.7	103.4	38.5
21-1-2		1.619	101.4	8.73	3.3	117	99.3	
21-1-3	<0.1	2.244	100.4	8.83	0.7	139.8		
21-1-4		0.744	107.2	8.63	1.8	118.5		
21-1-5	<0.1	1.158	90.82	8.66	0.9	124.6		
21-2-1	<0.1	1.866	67.82	8.51	2.4	98.7		
21-2-2		1.609	59.8	8.48	9	94.5	87.1	118.8
21-2-3	<0.1	2.299	77.8	8.77	0.6	159.7		
21-2-4		1.382	53.52	8.62	1.3	100.5		
21-2-5	<0.1	1.134	53.94	8.43	0.7	133		
21-3-1	<0.1	1.044	67.98	8.5	10	92.4	94.6	96.2
21-3-2		1.059	78.46	8.54	2.6	103.3		
21-3-3	<0.1	1.305	85.59	8.51	0.7	93.6		
21-3-4		1.956	84.98	8.55	0.5	104.6		
21-3-5	<0.1	1.172	74.47	8.55	0.7	110		

Nitrates: < 0.1 mg/L (WQS <0.3 mg/L)
pH: 8.4 – 8.8 (slightly alkaline)
Test Site Depths: 0.5 – 10 m (1.6 ft – 33 ft)
DO (~1 m, ~3 m and ~5 m), only three sites

Grace College Study: Summer 2007
Lake Papakeechie

Site	Temp. C (~1m)	Temp. C (~3m)	Temp. C (~5m)	Secchi down (ft)	Secchi up (ft)	Secchi Avg (ft)	Secchi hit	Air Temp. C
21-1-1	27.8	25.1	17.7	6.1	5.9	6		
21-1-2	27.7	25.2		8.1	7.8	7.95		
21-1-3	28.9						x	
21-1-4	27.7						x	
21-1-5	28.1						x	
21-2-1	25.5			6.4	6	6.2		28
21-2-2	25.7	25.3	16					28
21-2-3	26.2						x	29.5
21-2-4	25.6						x	27.2
21-2-5	26.2						x	28.1
21-3-1	29	28	26.6	6.7	6.6	6.65		32.5
21-3-2	28.7			5.1	5	5.05		34.2
21-3-3	29.4						x	32.8
21-3-4	29.8						x	34.6
21-3-5	29.2						x	31.5

Temperature: (~1 m, ~3 m, ~5 m): only three sites

Secchi: 5-8 ft (only five sites)

Grace College Study: Summer 2007
June 27, July 16, August 7 (5-6 weeks)
Lake Wawasee

Site_1	GPS Location	Date	Time	Time (hr)	Current Weather	Past Weather	E. Coli (col/100 mL)	Total Phosphorus (mg/L)
01-1-1	N41 23.238 W85 40.933	6/27/2007	18:01	18.0167	overcast	storm	0	0.05
01-1-2	N41 23.567 W85 40.965	6/27/2007	18:10	18.1667	overcast	storm	0	
01-1-3	N41 24.044 W85 41.190	6/27/2007	18:20	18.3333	overcast	storm	6.3	0.03
01-1-4	N41 23.029 W85 41.126	6/27/2007	16:47	16.7833	overcast	showers	7.3	
01-1-5	N41 22.654 W85 40.255	6/27/2007	16:35	16.5833	overcast	showers	3.1	0.05
01-2-1	N41 23.946 W85 41.770	7/16/2007	11:00	11	overcast	clear/sunny	0	0.04
01-2-2	N41 24.122 W85 42.066	7/16/2007	11:05	11.0833	overcast	clear/sunny	0	
01-2-3	N41 24.764 W85 42.070	7/16/2007	11:13	11.2167	overcast	clear/sunny	1	0.06
01-2-4	N41 24.140 W85 43.269	7/16/2007	11:20	11.3333	overcast	clear/sunny	1	
01-2-5	N41 22.671 W85 40.235	7/16/2007	10:20	10.3333	overcast	clear/sunny	7.4	0.05
01-3-1	N41 24.275 W85 42.939	8/7/2007	12:42	12.7	clear/sunny	storm	0	0.58
01-3-2	N41 23.986 W85 41.878	8/7/2007	12:23	12.3833	clear/sunny	storm	0	
01-3-3	N41 24.258 W85 41.573	8/7/2007	12:28	12.4667	clear/sunny	storm	2	0.13
01-3-4	N41 24.021 W85 42.834	8/7/2007	12:37	12.6167	clear/sunny	storm	0	
01-3-5	N41 22.655 W85 40.274	8/7/2007	12:16	12.2667	clear/sunny	storm	36	0.47

All test sites show *E. coli* < 40 CFU/100 mL.

Grace College Study: Summer 2007
Lake Wawasee

Site_1	Temp. C (~1m)	Temp. C (~3m)	Temp. C (~5m)	Secchi down (ft)	Secchi up (ft)	Secchi Avg (ft)	Secchi hit	Air Temp. C
01-1-1	25.9	25.2	23.4	3.8	3.2	3.5		
01-1-2	26.5	26.2	24.8	3.3	3.1	3.2		
01-1-3	26.9						X	
01-1-4	26.8						X	27.5
01-1-5	27.1						X	31.7
01-2-1	24.5	24.4	24.3	6.8	6.7	6.75		28.3
01-2-2	24.2	24.2	24.1	6.4	6.2	6.3		28.7
01-2-3	23.9							29.2
01-2-4	24.2						x	28.6
01-2-5	24.3						x	26.8
01-3-1	27.1	27.3	27.3	5.5	5.2	5.35		35.7
01-3-2	27.4	27.3	27.3	6.4	6.2	6.3		30.6
01-3-3	28						x	34.2
01-3-4	27.7							36.1
01-3-5	27.7						x	29

Temperature: (~1 m, ~3 m, ~5 m): only five sites

Secchi: 5-7 ft (only six sites)

Grace College Study: Summer 2007
Lake Wawasee

Site_1	Nitrates (mg/L)	Turbidity (NTU_s)	Total Flourescence	pH	Depth (m)	D.O. % sat. (~1m)	D.O. % sat (~3m)	D.O. % sat. (~5m)
01-1-1	<0.1	5.708	83.36	8.65	13	117.2	111.6	89.5
01-1-2		5.3	58.89	8.59	11	122.2	119.5	106
01-1-3	<0.1	4.592	65.16	8.55	0.8	113.7		
01-1-4		4.096	69.68	8.61	0.9	147.7		
01-1-5	<0.1	1.483	62.46	8.39	1	143.1		
01-2-1	<0.1	1.393	57.99	8.41	11.9	96.1	95	93
01-2-2		1.327	57.82	8.45	19.8	95.5	96.3	95.4
01-2-3	<0.1	1.548	50.75	8.41	1.7	95.7		
01-2-4		2.318	40.49	8.28	0.8	90.1		
01-2-5	<0.1	2.868	58.58	8.14	0.9	81.7		
01-3-1	<0.1	1.028	52.46	8.42	15.2	90.8	93.7	94.2
01-3-2		1.33	53.49	8.35	8.7	89.8	90.8	92.3
01-3-3	<0.1	1.656	55.05	8.4	0.85	94.4		
01-3-4		0.561	45.85	8.44	1.3	93.6		
01-3-5	<0.1	1.376	93.84	8	0.76	77.8		

Nitrates: < 0.1 mg/L (WQS <0.3 mg/L)
pH: 8.0 – 8.7 (slightly alkaline)
Test Site Depths: 0.8 m – 19 m (2.6 ft – 62 ft)
DO (~1 m, ~3 m and ~5 m) at only six sites

Wawasee Area Watershed Management Plan

Elkhart, Kosciusko, and Noble Counties, Indiana

April 13, 2007

Prepared for:

Wawasee Area Conservancy Foundation

P.O. Box 584

Syracuse, Indiana 46567

Prepared by:

JFNew

c/o Sara Peel

708 Roosevelt Road

Walkerton, Indiana 46574

(574) 586-3400

JFNew 2007

Lake Papakeechie

The dam creating Lake Papakeechie was completed in 1913 by impounding what was formerly known as Jarrett's Creek. Lake Papakeechie possesses a surface area of 178 acres (72 ha) and a volume of 890 acre-feet (11,814,107 m^3; Table 9). The lake's maximum depth is 40 feet (12.2 m) and the average depth is 5 feet (1.5 m; Table 10). The shoreline development ratio is a measure of the development potential of a lake. A perfectly circular lake with the same area as Lake Papakeechie (178 acres or 40 ha) would have a circumference of 9,870 ft (3,008.4 m). Dividing Lake Papakeechie's shoreline length (18,270 feet (5,568.7 m) by 9,870 feet yields a ratio of 1.8:1. This ratio is fairly low compared to the shoreline development ratios observed on many other developed, northern Indiana lakes. Like Syracuse Lake, Lake Papakeechie lacks a number of shoreline channels observed on other popular Indiana lakes.

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Table 9. Morphological characteristics of Lake Papakeechie.

Lake Papakeechie	
Surface Area	178 acres (72 ha)
Volume	890 acre-feet (11,814,107 m^3)
Maximum Depth	40 feet (12.2 m)
Mean Depth	5 feet (1.5 m)
Shoreline Length	18,270 feet (5,568.7 m)
Shoreline Development Ratio	1.8:1
Residence Time	0.22 years (80.3 days)

Surface water drains to Lake Papakeechie by two primary routes (Figure 3). These routes include drainage from the Tri-Lakes Fish and Wildlife Area through Spear Lake and direct drainage to the lake (Table 10). The Spear Lake tributary drains 2915 acres (1180 ha) from the Tri-County Fish and Wildlife Area lakes. The remaining 386 acres (156 ha) flows directly to Lake Papakeechie. The watershed area to lake area ratio for Lake Papakeechie (19.5:1) is relatively normal for glacial lakes and is much lower than typical ratios for reservoirs (100:1 to 300:1; Vant, 1987).

Table 10. Watershed and subwatershed sizes for the Lake Papakeechie watershed.

Subwatershed/Lake	Area (acres)	Area (hectares)	Percent of Watershed
Unnamed tributary (Spear Lake)	2,915	1,180	83.7%
Direct to lake	386	156	11.1%
Watershed Draining to Lake	**3,301**	**1,335.9**	**94.9%**
Lake Papakeechie	178	40	5.1%
Total Watershed	**3,479**	**1,409**	**100.0%**
Watershed to Lake Area Ratio	19.5:1		

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Wawasee Area Watershed Management Plan
Elkhart, Kosciusko, and Noble Counties, Indiana

April 13, 2007

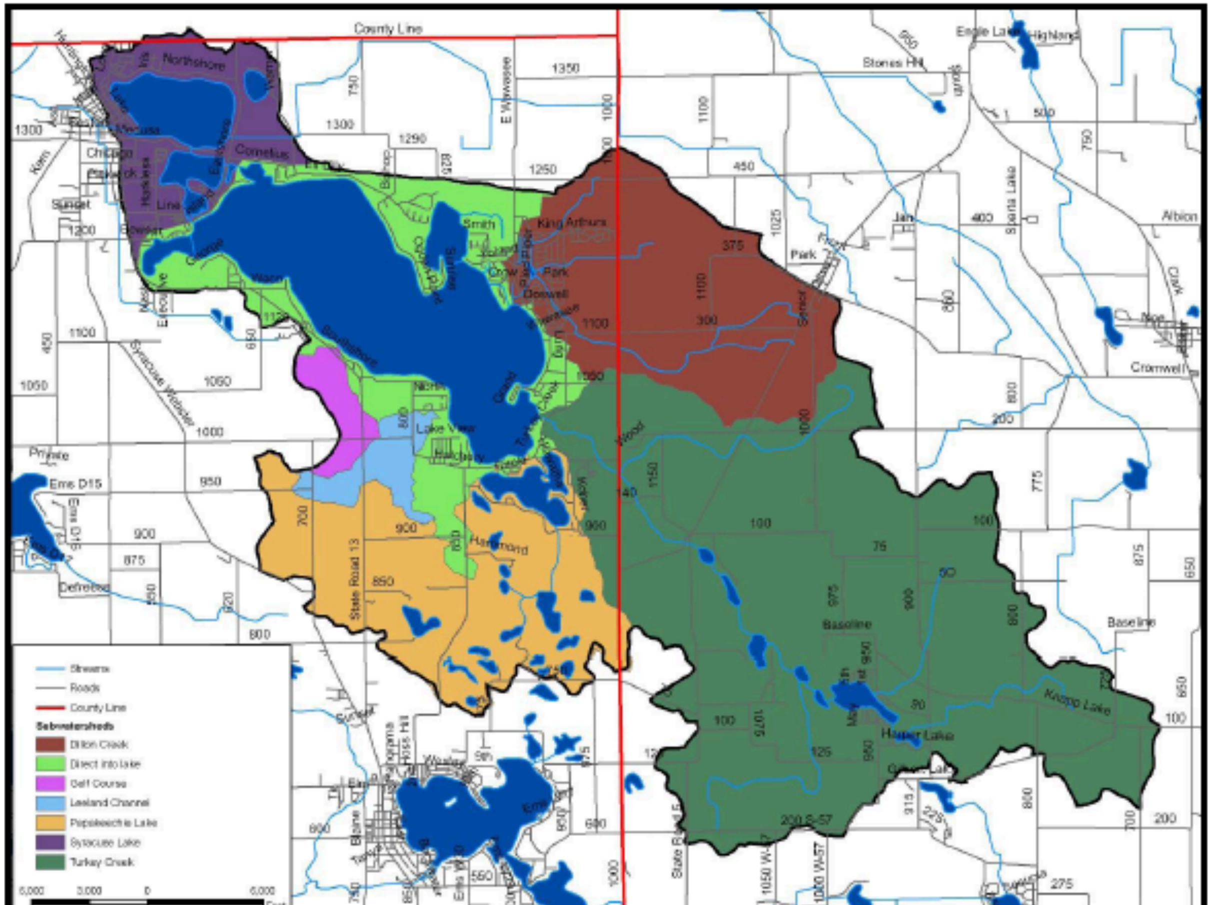

Figure 3. Lake Wawasee subwatersheds.

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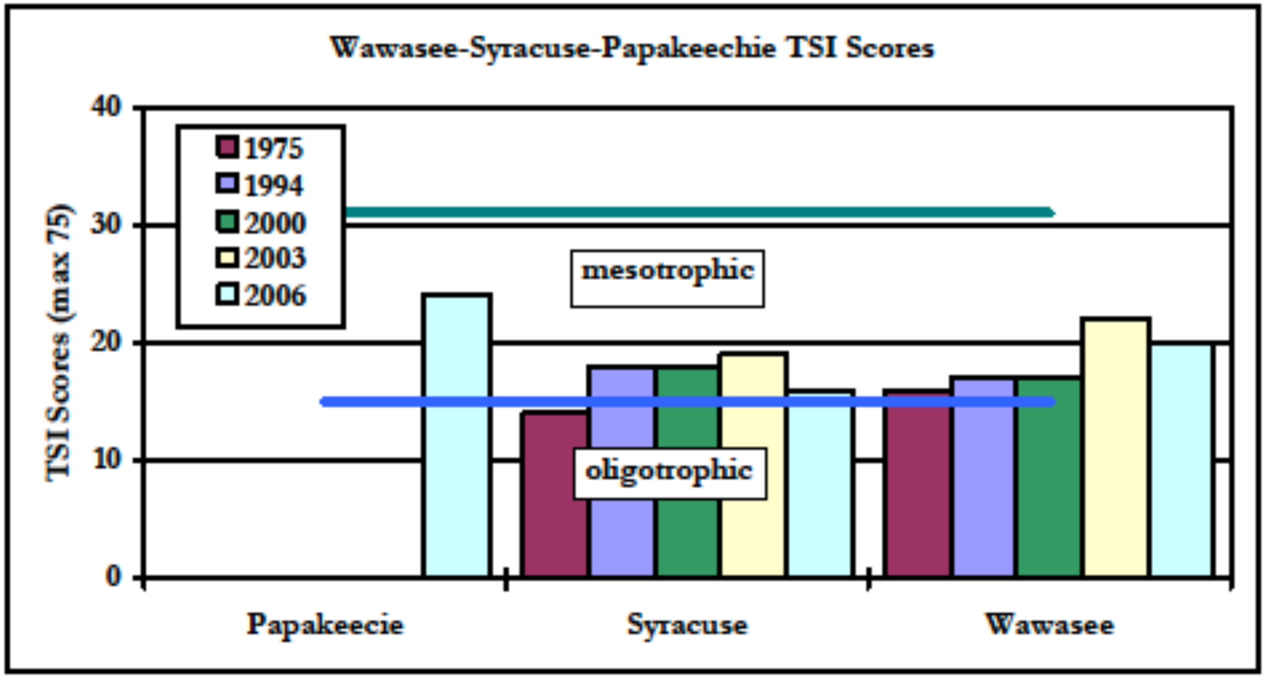

Figure 25. Variation in ITSI scores in Lake Papakeechie, Syracuse Lake, and Lake Wawasee, 1975 to 2006.

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Current Trophic Status (based on last assessment):

Syracuse (2006)	mesotrophic
Wawasee (2006)	mesotrophic
Papakeechie (2006)	mesotrophic

Allen (2003)	eutrophic	Indian Village (2003)	eutrophic
Barrel and ½ (2003)	hypereutrophic	Duely (2003)	oligotrophic
Hammond (2003)	eutrophic	Rider (2003)	mesotrophic
Long (1995)	mesotrophic	Gordy (2003)	mesotrophic
Price (1995)	mesotrophic	Hindman (2003)	hypereutrophic
Rothenberger (2003)	hypereutrophic	Moss (2003)	eutrophic
Shock (2003)	eutrophic	Harper (2003)	eutrophic
Spear (2000)	eutrophic	Knapp (2003)	hypereutrophic
Wyland (2000)	mesotrophic	Little Bause (2003)	mesotrophic
		Little Knapp (2003)	oligotrophic

JFNew 2007

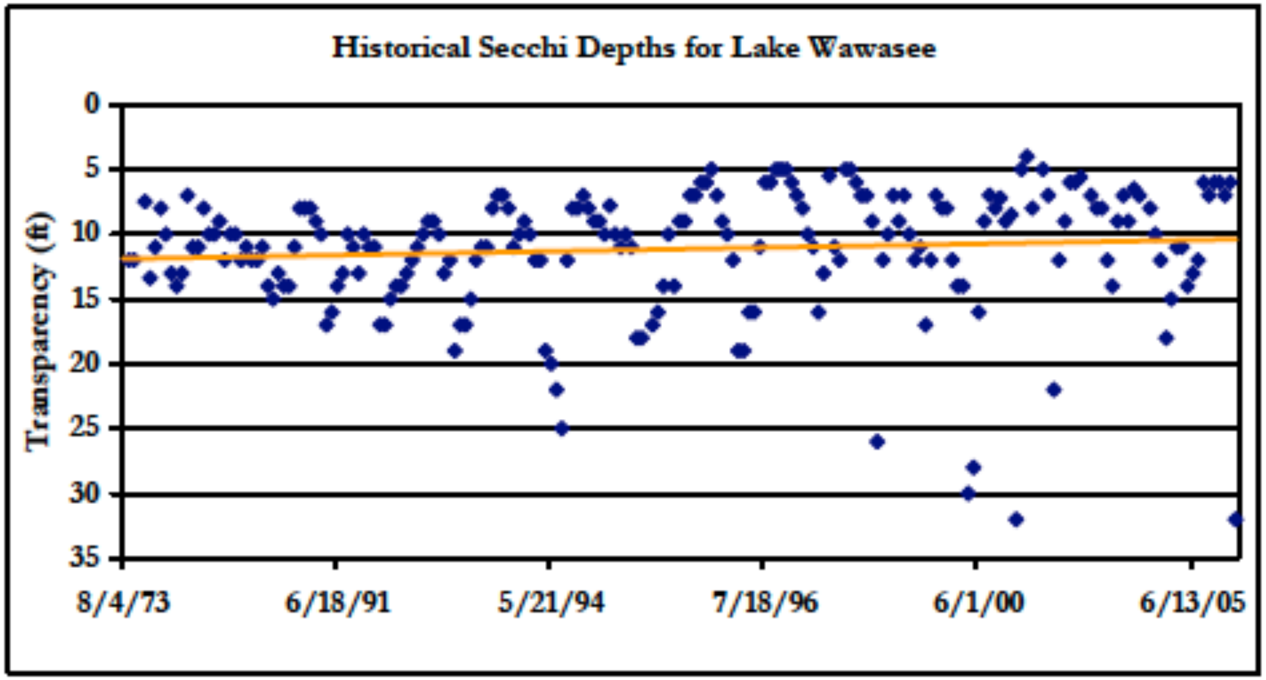


Figure 20. Secchi disk transparencies measured in Lake Wawasee, 1973 to 2005.

JFNew 2007

Table 39. Water quality characteristics of Lake Wawasee, July 12, 2006.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.6	7.6	-
Alkalinity	115 mg/L	115 mg/L	-
Conductivity	338.2 µmhos	314.3 µmhos	-
Secchi Depth Transparency	8.2 feet	-	0
Light Transmission @ 3 ft.	29%	-	4
1% Light Level	24.6 feet	-	-
Total Phosphorus	0.058 mg/L	0.044 mg/L	2
Soluble Reactive Phosphorus	0.010 mg/L*	0.010 mg/L*	0
Nitrate-Nitrogen	0.015 mg/L*	0.015 mg/L*	0
Ammonia-Nitrogen	0.018 mg/L*	0.516 mg/L	0
Organic Nitrogen	0.537 mg/L	1.096 mg/L	1
Total Suspended Solids	2.00 mg/L	2.20 mg/L	-
Oxygen Saturation @ 5ft.	100.6%	-	0
% Water Column Oxic	32%	-	3
Plankton Density	1,594/L	-	0
Blue-Green Dominance	55.9%	-	10
Chlorophyll *a*	0.02 µg/L	-	-
		TSI Score	20

*Method detection limit

JFNew 2007

Table 41. Water quality characteristics of Lake Papakeechie, July 12, 2006.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.5	7.7	-
Alkalinity	133 mg/L	198 mg/L	-
Conductivity	313.3 μmhos	300.3 μmhos	-
Secchi Depth Transparency	4.3 feet	-	6
Light Transmission @ 3 ft.	11.3%	-	4
1% Light Level	11.1 feet	-	-
Total Phosphorus	0.038 mg/L	0.219 mg/L	3
Soluble Reactive Phosphorus	0.013 mg/L	0.040 mg/L	0
Nitrate-Nitrogen	0.019 mg/L	0.018 mg/L*	0
Ammonia-Nitrogen	0.018 mg/L*	2.047 mg/L	4
Organic Nitrogen	0.706 mg/L	0.727 mg/L	2
Total Suspended Solids	2.890 mg/L	8.500 mg/L	-
Oxygen Saturation @ 5ft.	92.6%	-	0
% Water Column Oxic	33%	-	3
Plankton Density	6,189/L	-	2
Blue-Green Dominance	37.1%	-	0
Chlorophyll *a*	0.98 μg/L	-	-
		TSI Score	24

*Method detection limit

JFNew 2007

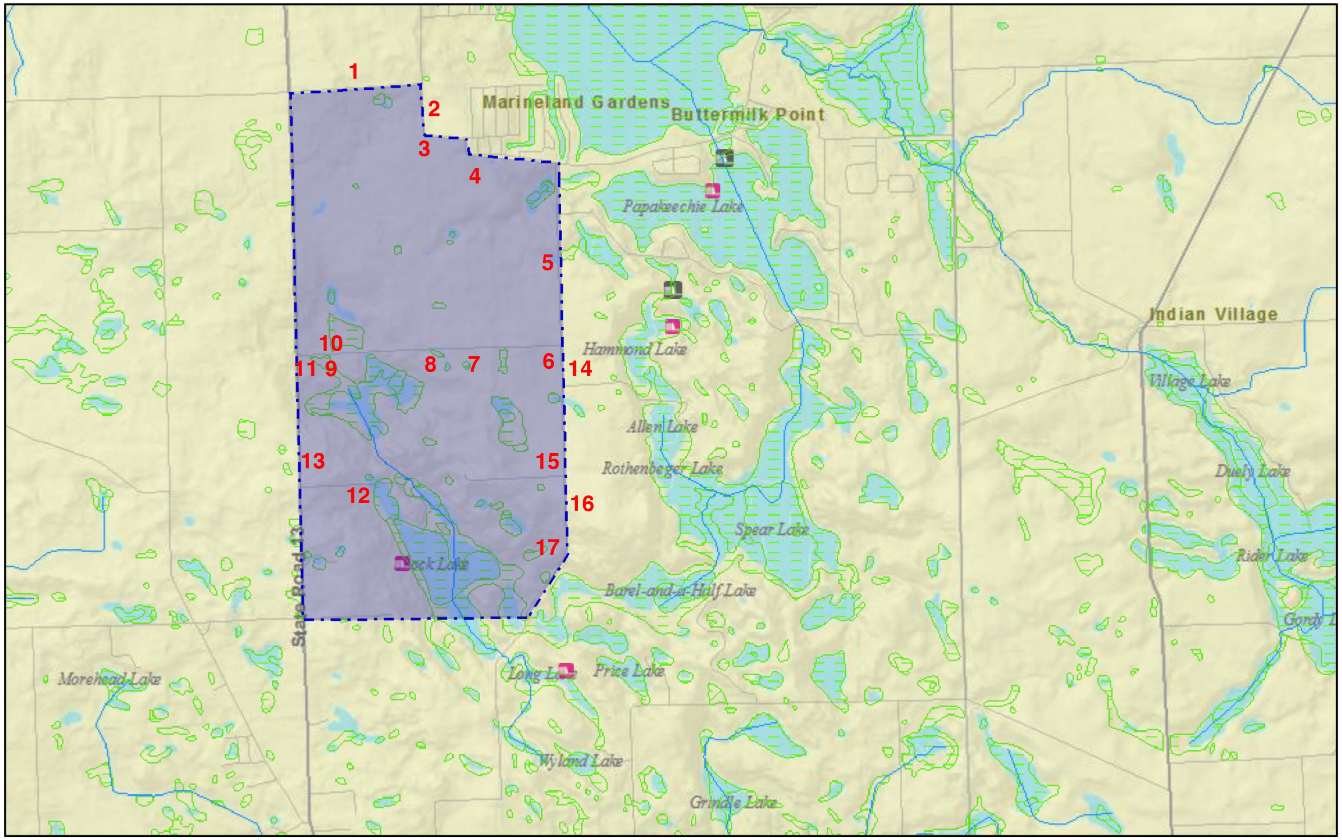
3.2.3 Lake Papakeechie

Like Lake Wawasee and Syracuse Lake, Lake Papakeechie would best be described as a mesotrophic lake (Table 41). Lake Papakeechie possessed higher nutrient concentrations (specifically soluble reactive and total phosphorus and ammonia-nitrogen) than either Lake Wawasee or Syracuse Lake. Lake Papakeechie's total phosphorus concentration exceeds the concentration for Vollenweider's eutrophic lakes, but is not as high as concentrations found in his hypereutrophic lakes. Epilimnetic soluble reactive and total phosphorus concentrations were lower than concentrations present in the hypolimnion suggesting that phosphorus is being released from the lake's sediment. The phosphorus release factor (hypolimnetic SRP concentrations/epilimnetic SRP concentration) indicates that this is occurring. Likewise, Lake Papakeechie's hypolimnetic ammonia-nitrogen concentration is more than two orders of magnitude higher than the lake's epilimnetic concentration. This suggests that organic matter is accumulating in the lake's hypolimnion. The low percentage of the water column containing sufficient dissolved oxygen further supports this premise.

Lake Papakeechie's water clarity was the poorest of the three lakes (4.2 feet) and is also poorer than most lakes in Indiana. Poor water clarity is further supported by the lake's 1% light level or the depth at which point only 1% of the available light is transmitted. Only 1% of available light is transmitted to 11 feet in Lake Papakeechie; this is less than one-quarter of the lake's water column. Additionally, only one-third of the water column contains sufficient dissolved oxygen to support aquatic biota. Nonetheless, the lake is not utilizing all of its available nutrients. Low chlorophyll *a* concentrations and limited plankton density further support the premise that Lake Papakeechie is not fully utilizing nutrients available in its water column. All of this translates to Lake Papakeechie's ITSI score indicating that the lake falls in the mesotrophic category.

End

DNR and EPA Dams On, or Near, LP



February 24, 2014

Streams (NHD) Dams (IDNR)

Wetlands

Dams 1996 (EPA)

1:32,000

0 0.275 0.55 1.1 mi

0 0.425 0.85 1.7 km

U.S. Geological Survey
Indiana Department of Natural Resources