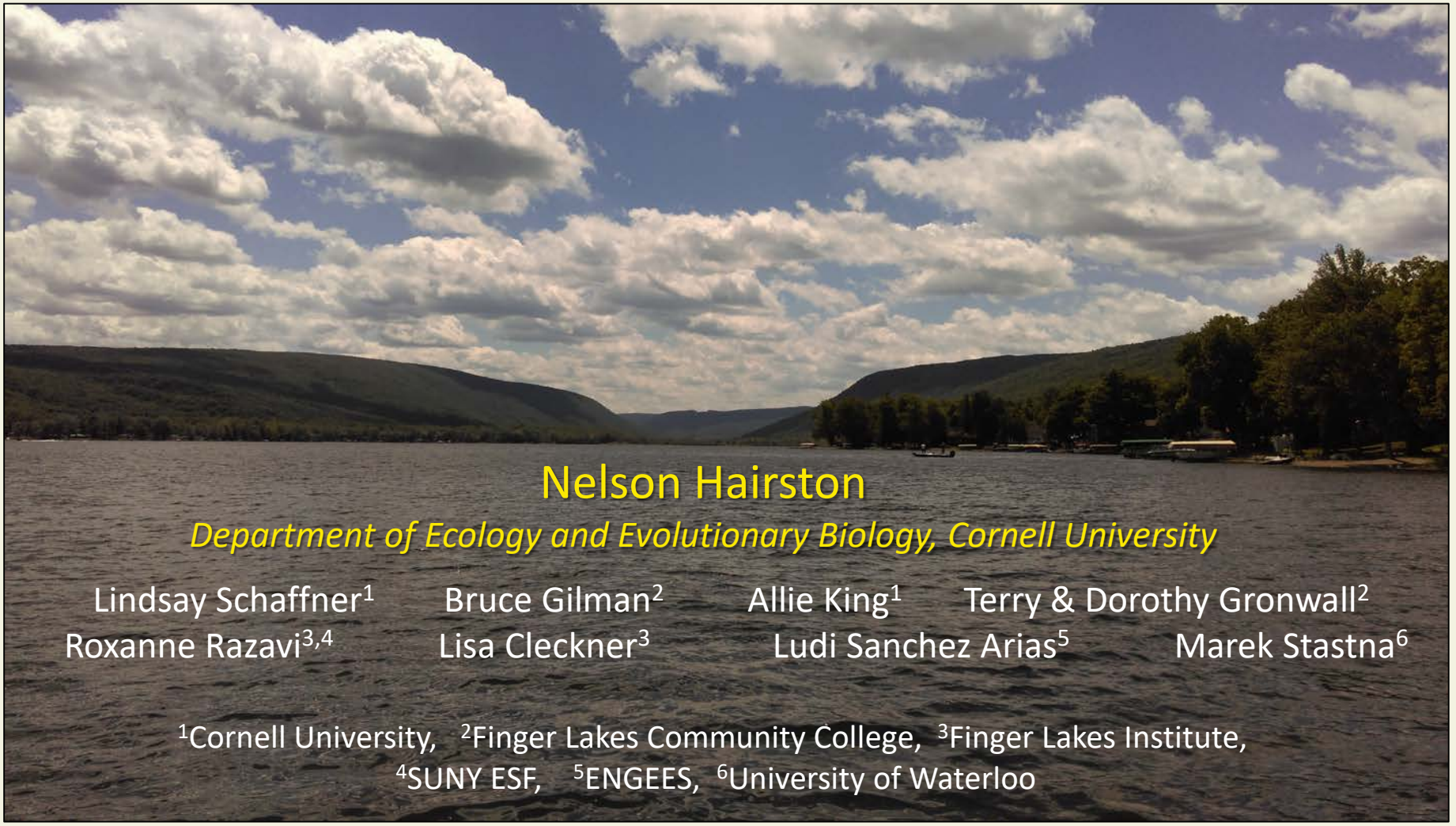
It Comes from the Mud!
Nutrients, Internal Loading, Internal Waves, and Infernal Honeoye HABs



Nelson Hairston

Department of Ecology and Evolutionary Biology, Cornell University

Lindsay Schaffner[1] Bruce Gilman[2] Allie King[1] Terry & Dorothy Gronwall[2]
Roxanne Razavi[3,4] Lisa Cleckner[3] Ludi Sanchez Arias[5] Marek Stastna[6]

[1]Cornell University, [2]Finger Lakes Community College, [3]Finger Lakes Institute,
[4]SUNY ESF, [5]ENGEES, [6]University of Waterloo

Photo: Nelson Hairston

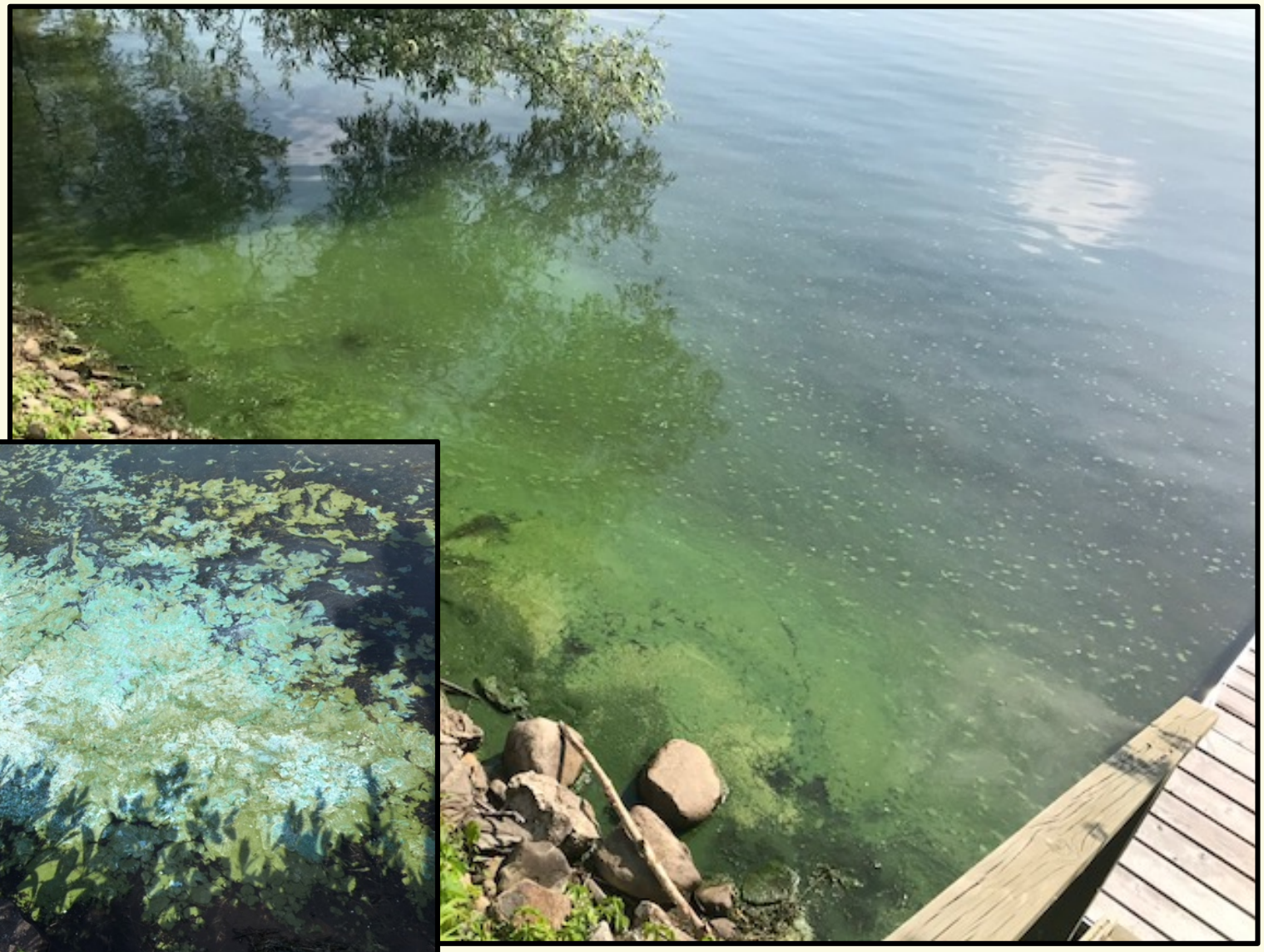
Beautiful Honeoye Lake

Photo: Fred Bertram

Honeoye Lake's continuing Harmful Algal Bloom (HAB) problem

Honeoye Lake cyanobacteria Bloom

Thursday
7 June 2018



Cyanobacterial blooms are “harmful” because they:

Float – blow to shore, die, smell bad

OR

Sink to bottom – die, decompose,
use up dissolved oxygen in bottom water

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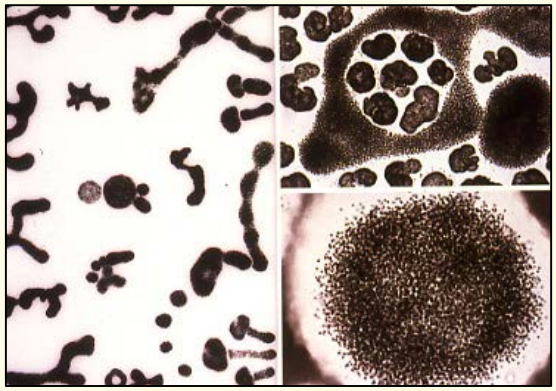

Contain liver-toxins and neuro-toxins

may make people, dogs, cattle sick

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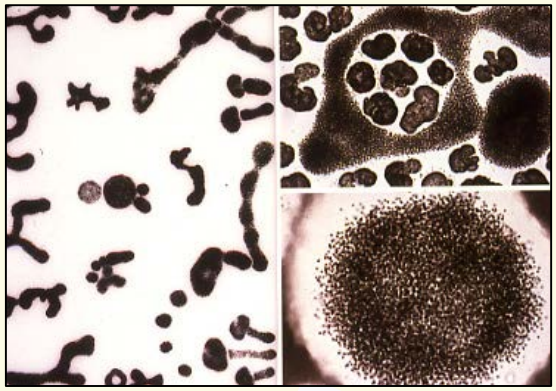
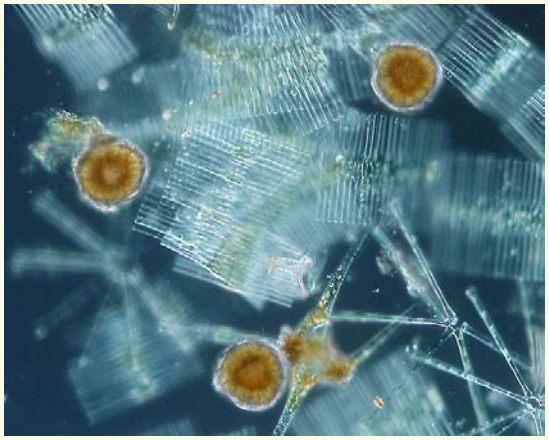


Contain liver-toxins and neuro-toxins may make people, dogs, cattle sick

Daphnia

Also lousy food for the little animals that might eat them:

Toxins & lack essential fatty acids (poor nutritionally)



Phytoplankton – **<u>includes both cyanobacteria and algae</u>: microscopic photosynthetic organisms drifting in the water**

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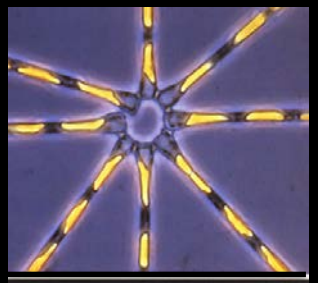
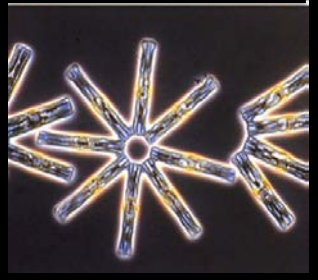
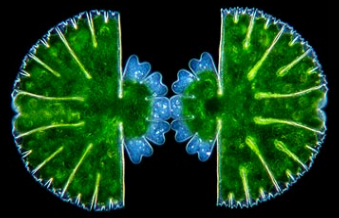
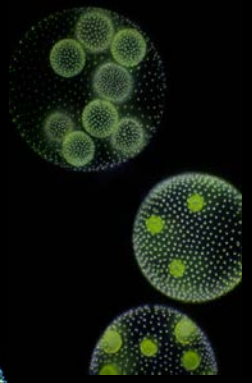
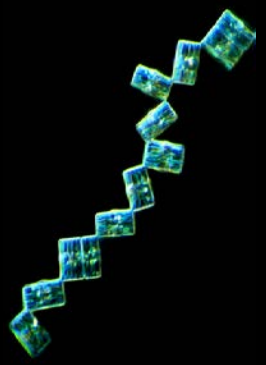
Algae are often beautiful !

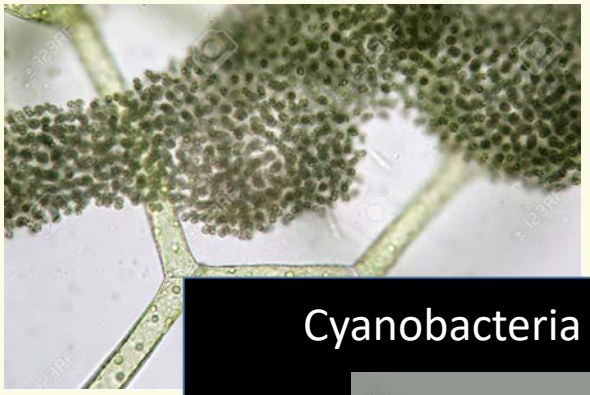












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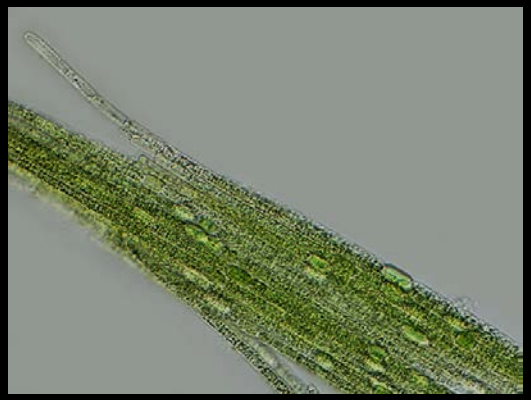
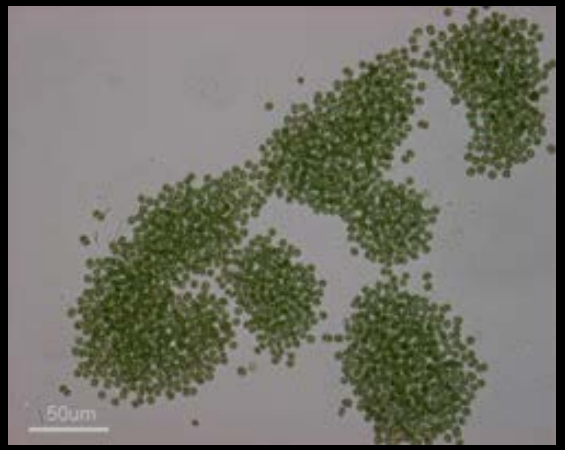
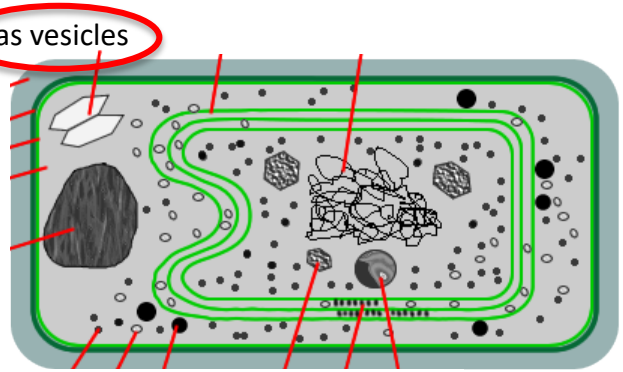
Cyanobacteria … no so much





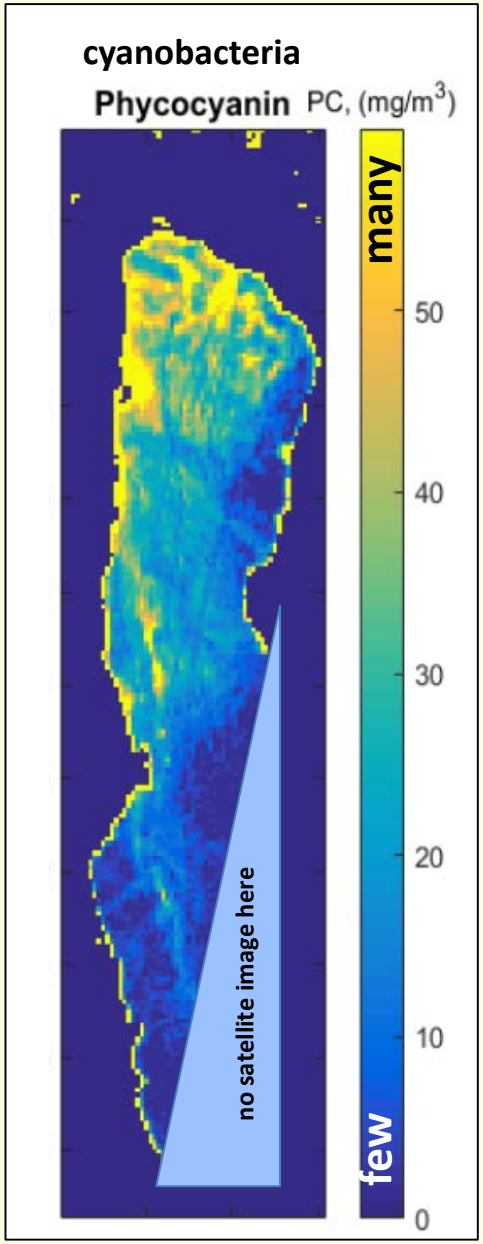
Cyanobacteria



Gas vesicles make cells float

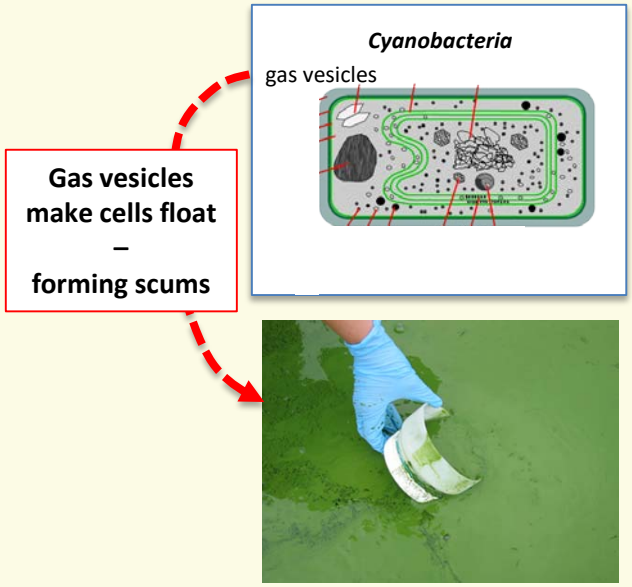
Landsat 8 (satellite) image of Honeoye Lake on September 16, 2015

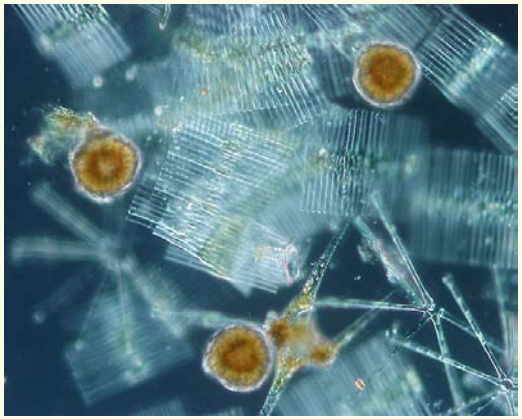
Anthony Vodacek and Ryan Ford, RIT



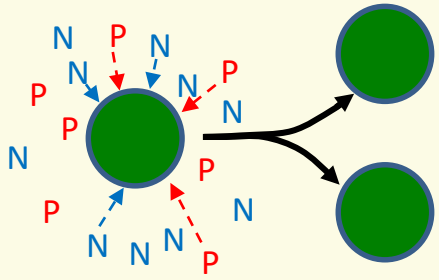
When they float, cyanobacteria cells, blow with the wind and accumulate at down-wind areas.

This one reason why the come and go along the shore from day to day.





Phytoplankton (both cyanobacteria and algae) require Nitrogen and Phosphorus to multiply



Nutrient pollution

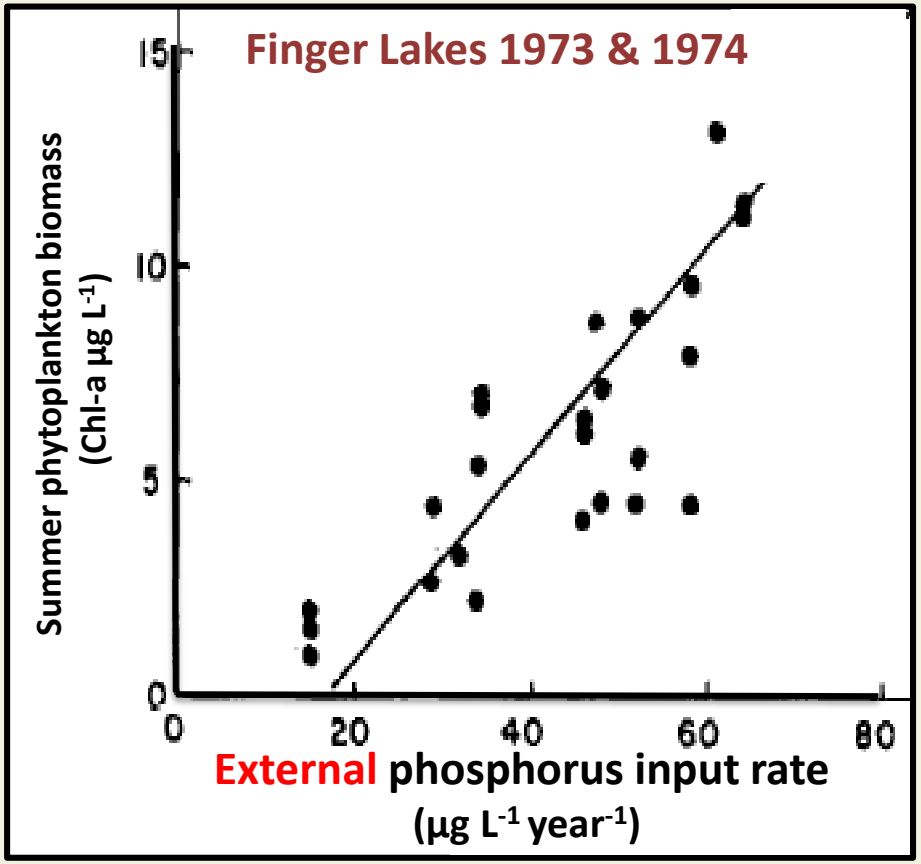
N and P

		N:P
From:	* city wastewater treatment facilities	10:1
	* home septic systems	5:1
	* agricultural runoff	50:1

<u>P is scarcer</u>, so it tends to be limiting for phytoplankton growth

External Loading –
P from outside the lake

Evidence for "External Loading" driving phytoplankton growth in the Finger Lakes:



Oglesby & Schaffner (1978 L&O)

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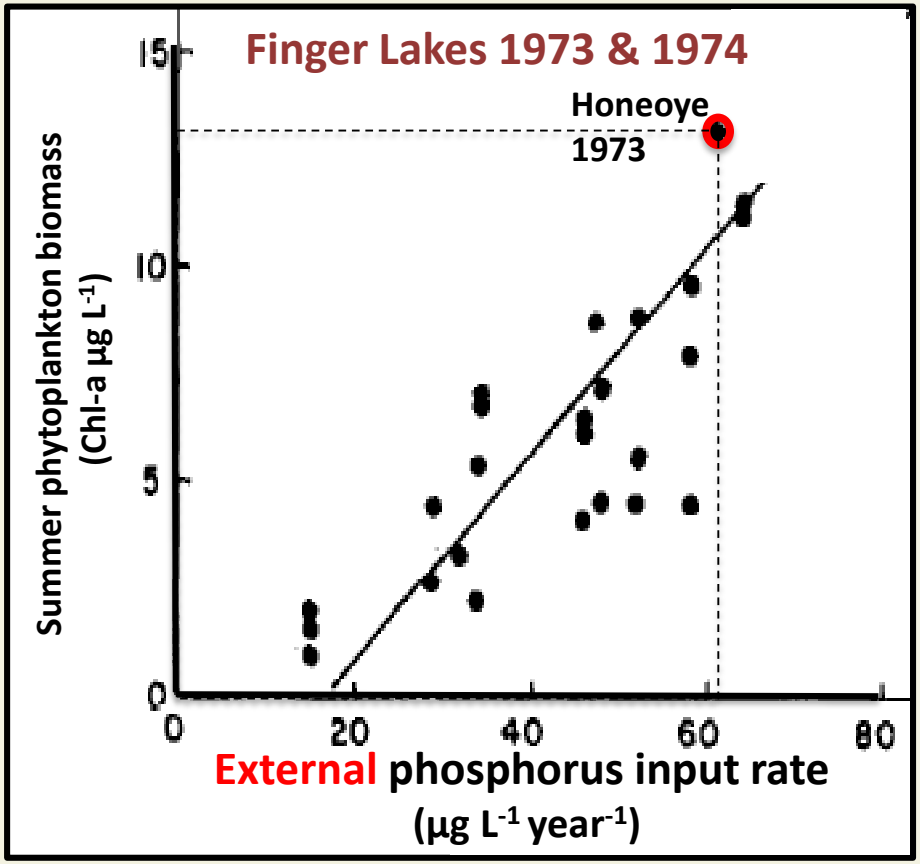

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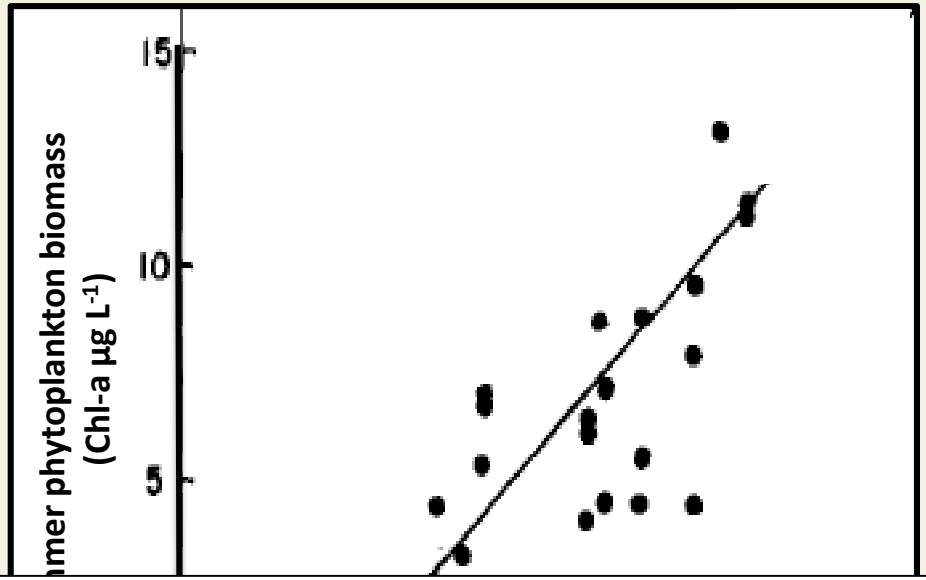
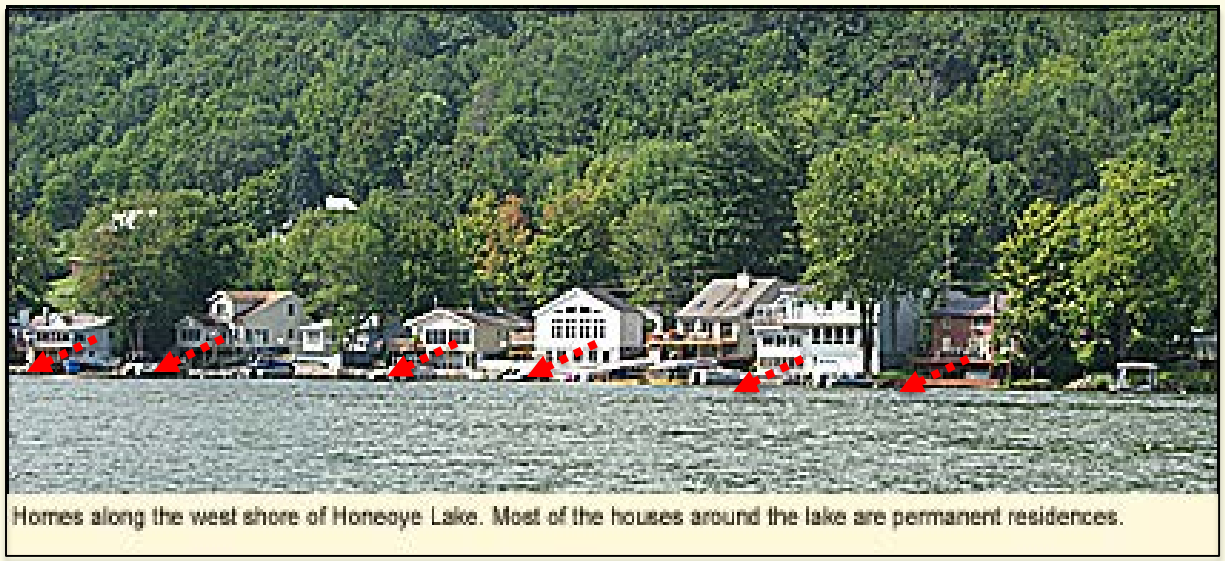
External P Load: Foundation for managing HABs in lakes



Nitrogen may also be a significant driver of HABs.
Here I use Phosphorus, but N may also be important.

Nitrogen dynamics in Honeoye Lake are being studied by:
Mark McCarthy & Silvia Newell (Wright State University)
Lisa Cleckner & Roxanne Razavi (FLI & SUNY ESF)

External loading

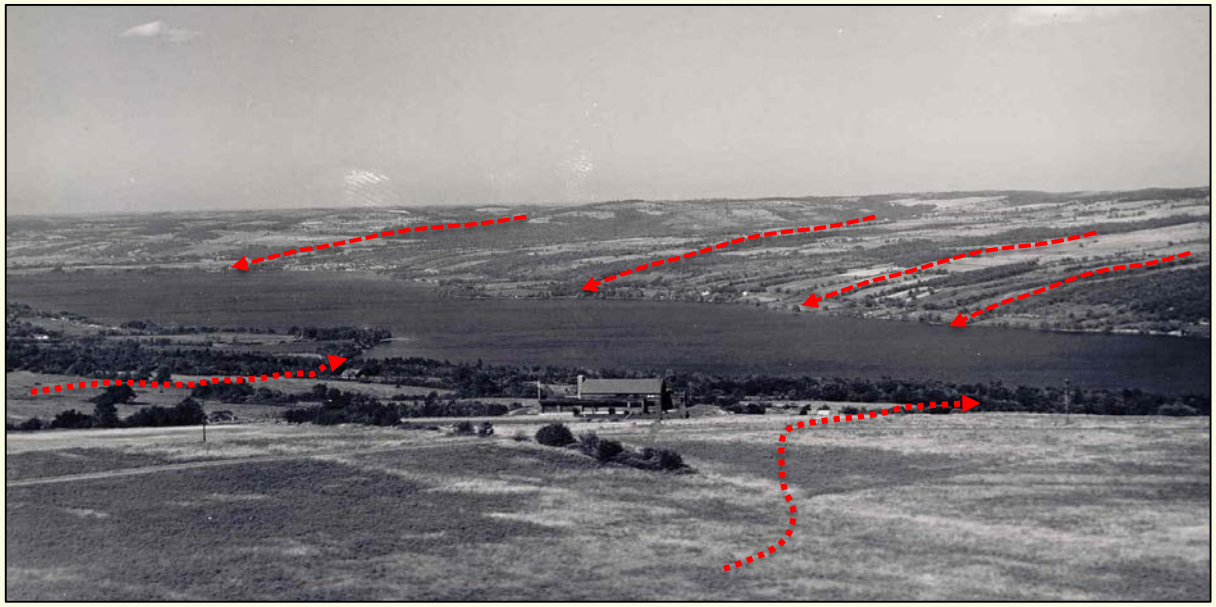


Homes along the west shore of Honeoye Lake. Most of the houses around the lake are permanent residences.

http://www.ilovethefingerlakes.com/lakes/Honeoye.htm

Before 1980

Houses and cottages had septic systems – of varying quality – that leached into the lake

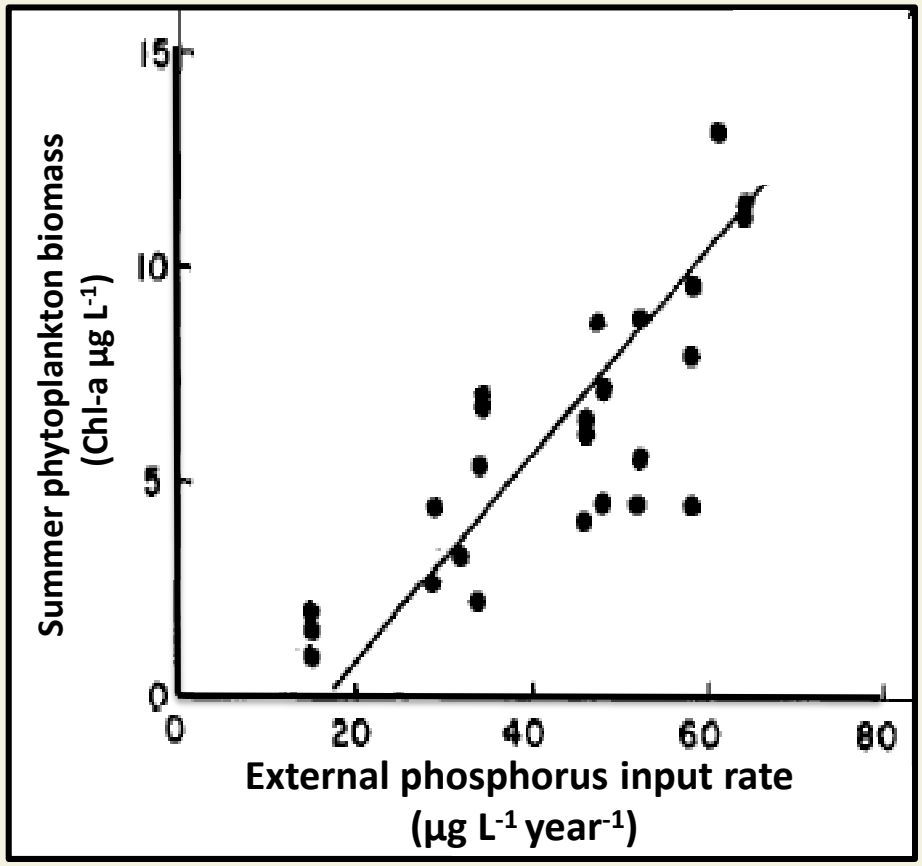


http://www.wemett.net/pics/bott_photos/canadice/mcintee_pics/honeoye_lake_from_6139_canadice_hill_rd.jpg

Watershed *used to* have lots of land in agriculture. Nutrients runoff to lake.

Evidence for "External P Loading" driving phytoplankton growth:

Foundation for managing HABs in lakes

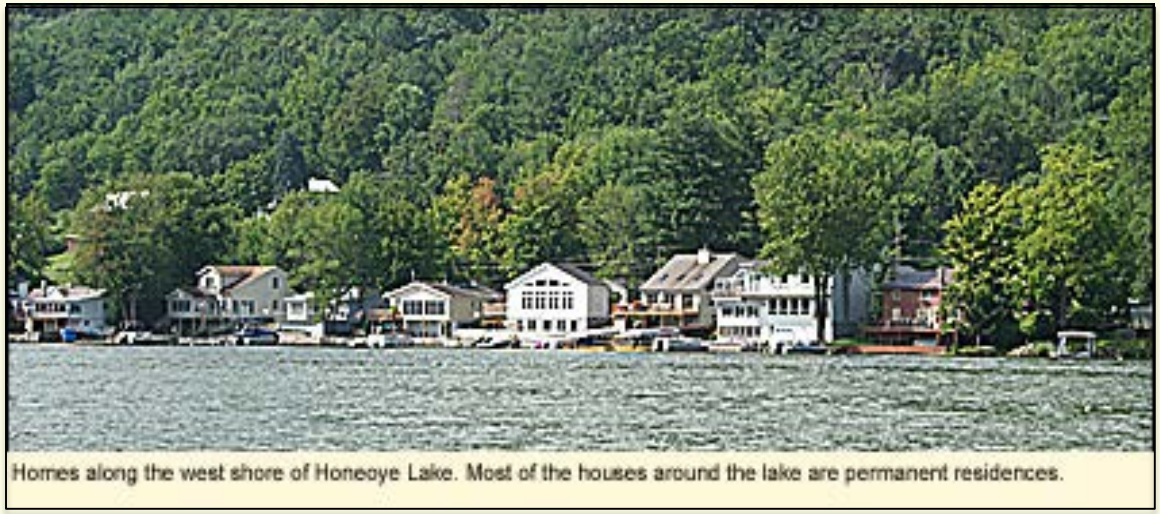


Oglesby & Schaffner (1978 L&O)

Restrict nutrient inputs:

1) **Point sources**
   (wastewater treatment plants)
2) **Household septic systems**
3) **Agricultural runoff**

Managing external loading at Honeoye Lake:



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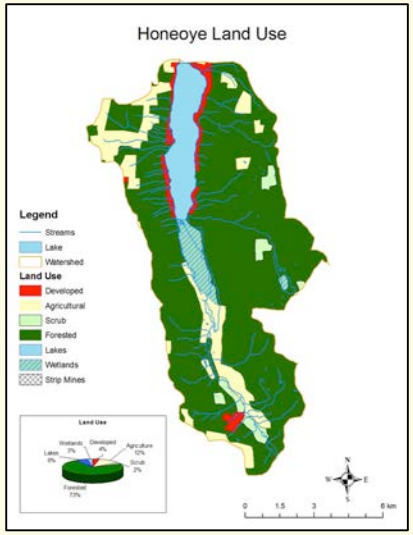
All houses and cottages tied to sewer system in 1980

Wastewater treatment plant does not discharge to the lake

http://www.iloveusny.com/2015/08/15/3-lakes-in-4-days/

Watershed now almost entirely forested, only 12% Ag (horse farms)



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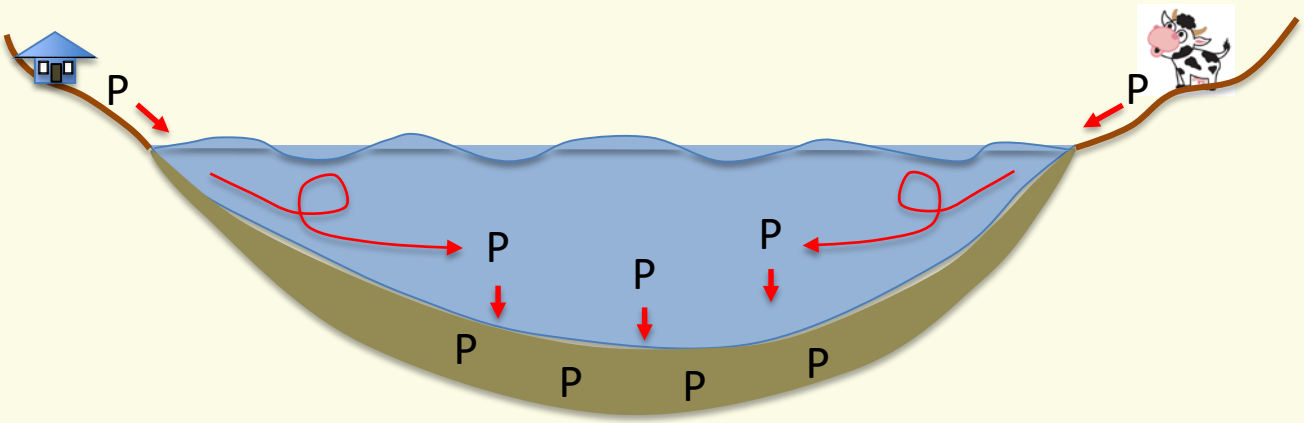
Not much left to regulate


But still the lake looks like this in late summer
(2016)
Photo: T Gronwall

Legacy phosphorus

… deposited in lake sediments



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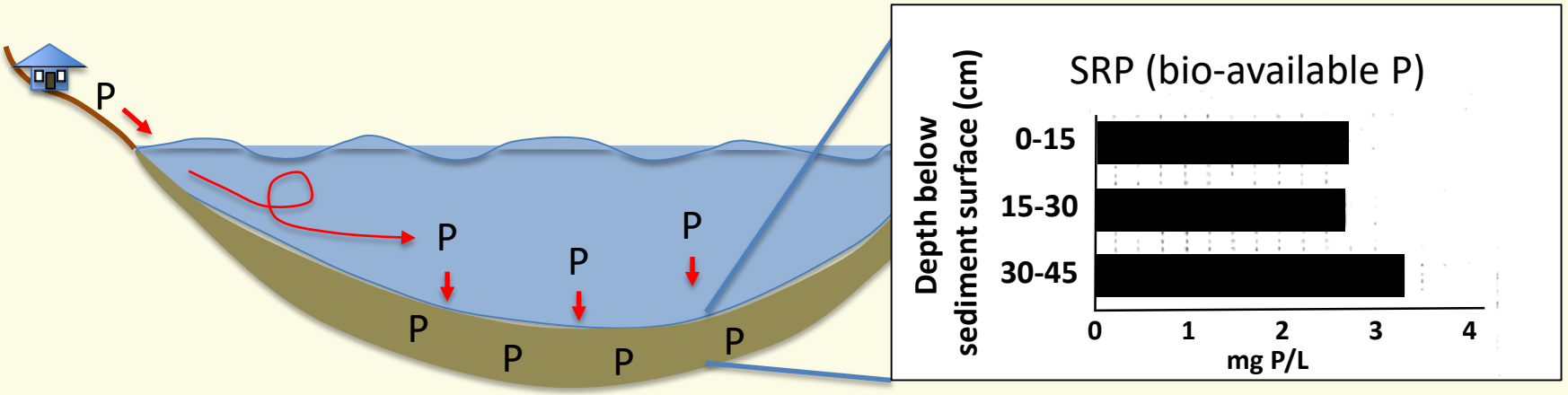
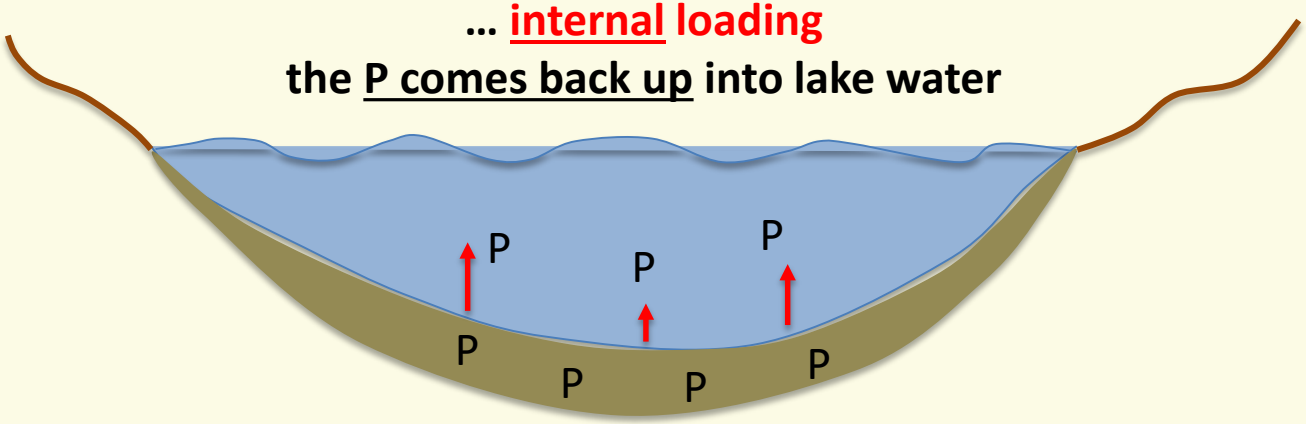


Bruce Gilman (2001)

Legacy phosphorus

… internal loading

the P comes back up into lake water

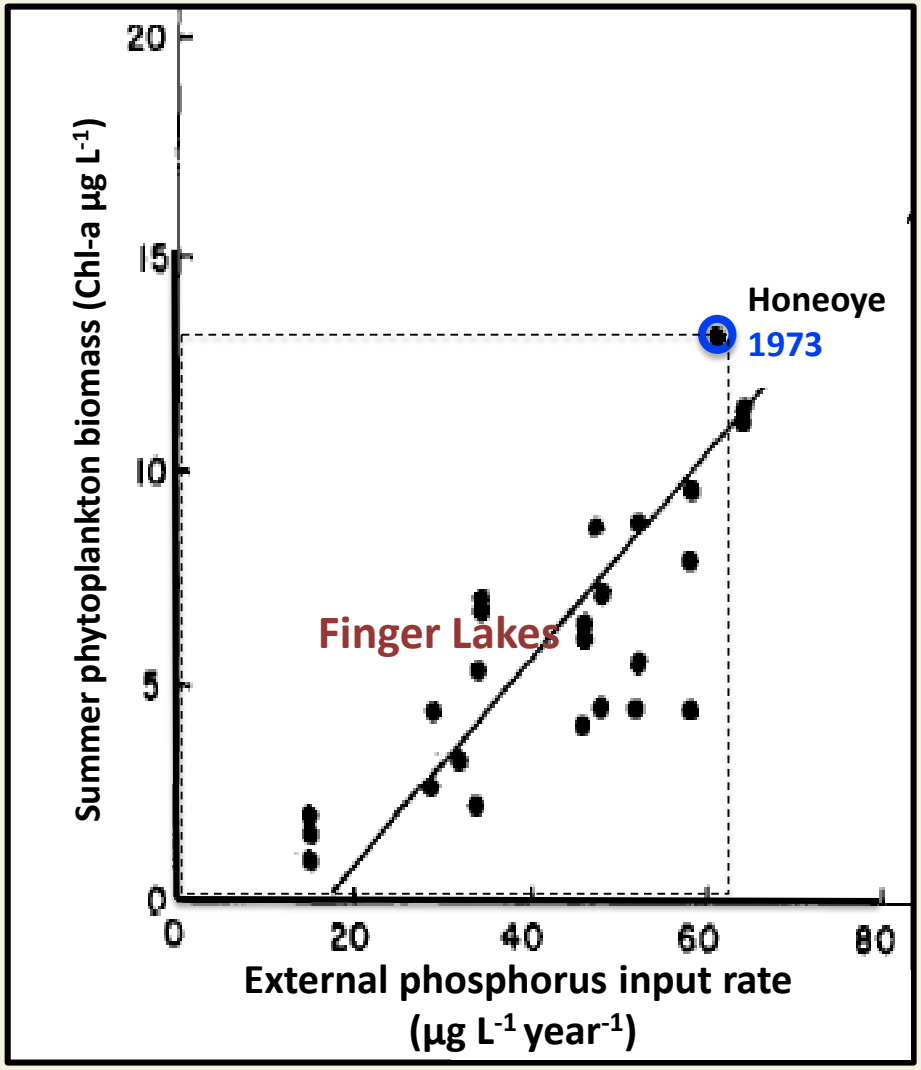


By: 1) decomposition of dead plankton and other organisms on bottom

2) chemical reduction of Iron-P compounds

3) excretion by benthic consumers (e.g. zebra mussels)

Evidence for *Internal Loading* driving phytoplankton growth:



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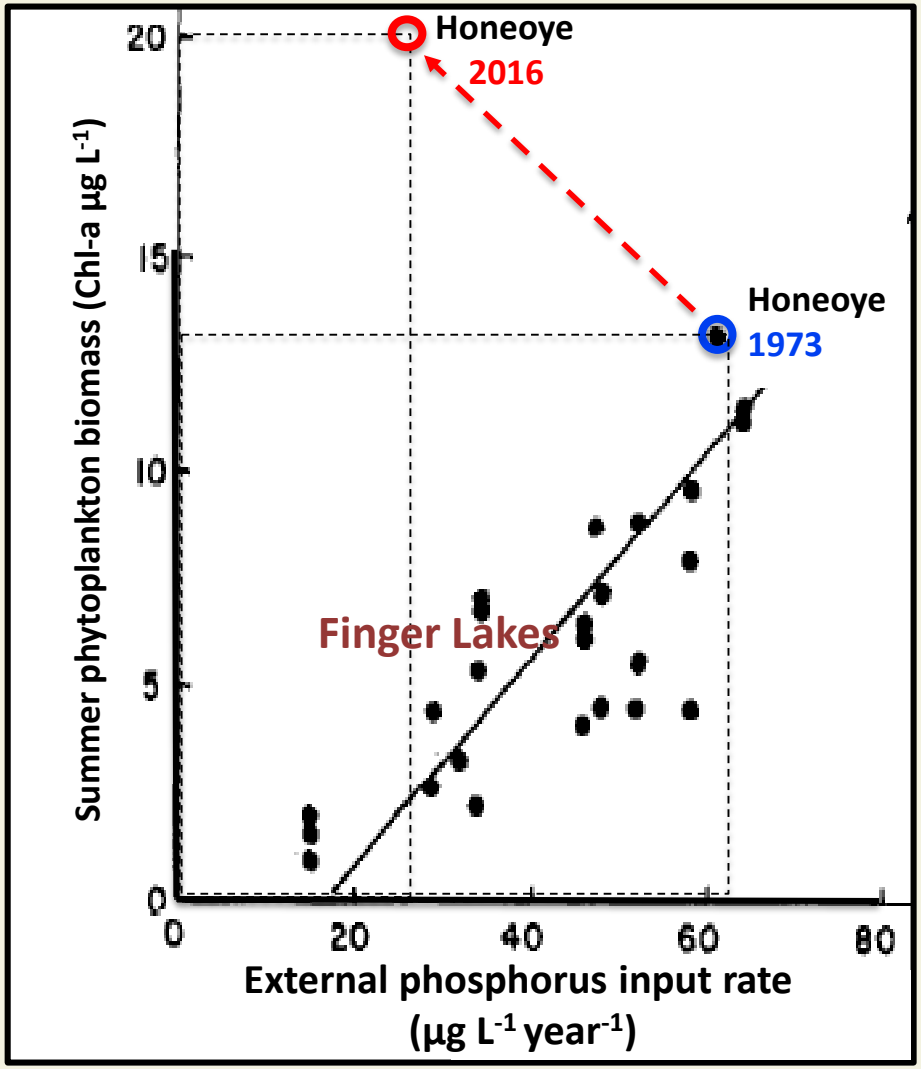

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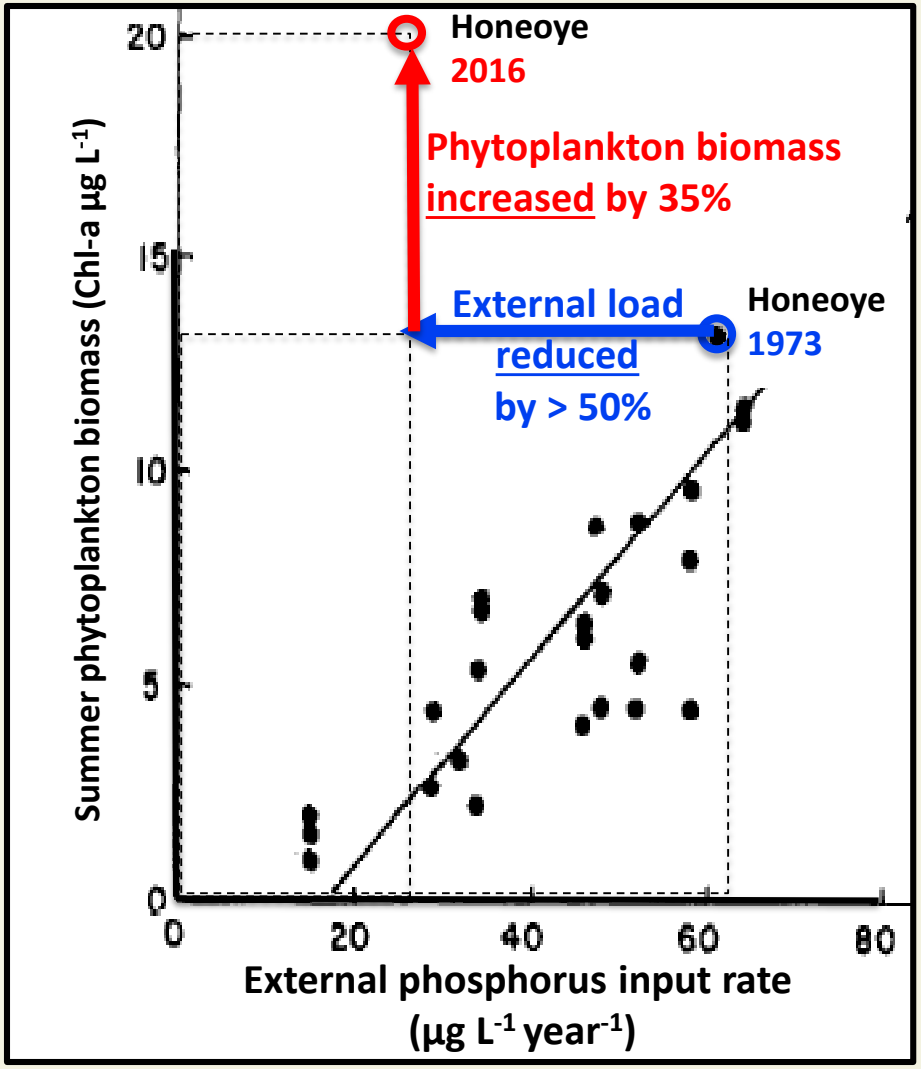
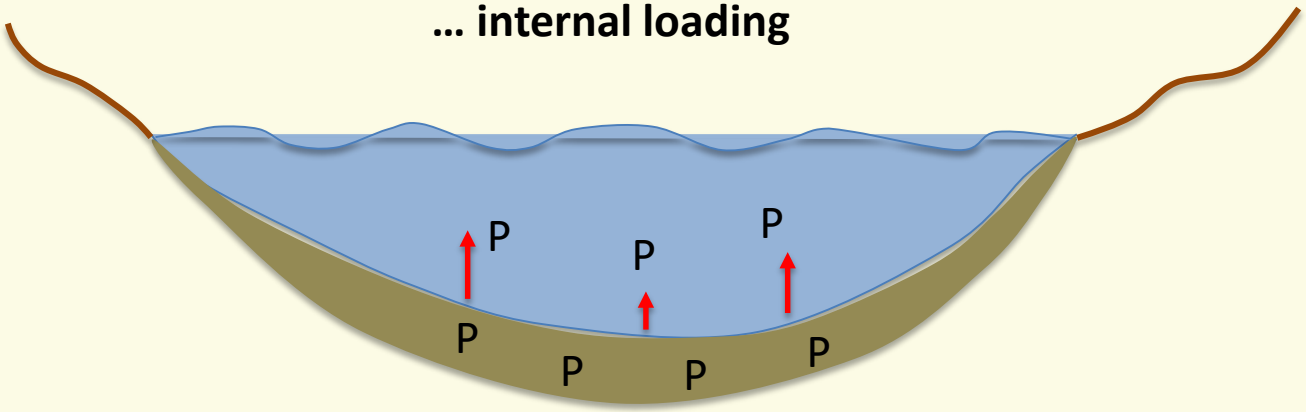
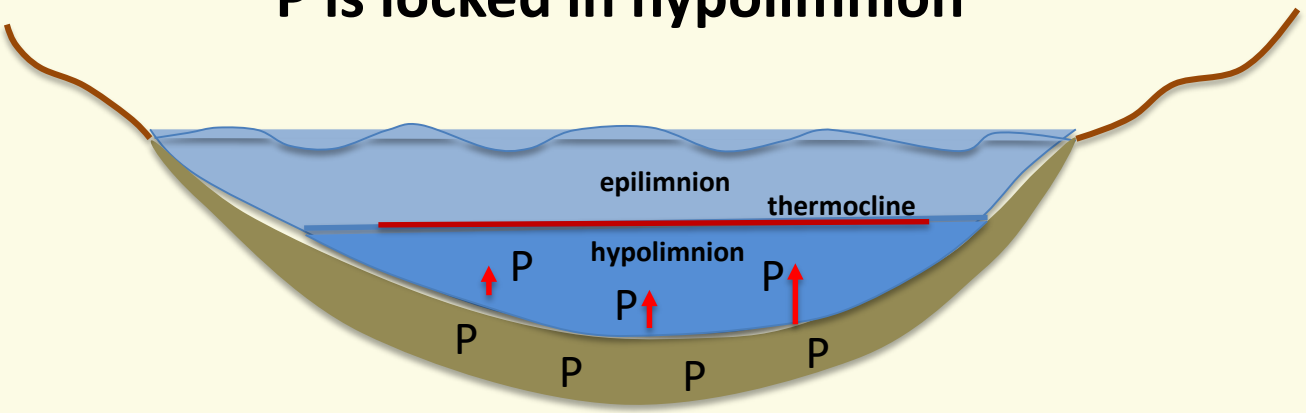


Legacy phosphorus

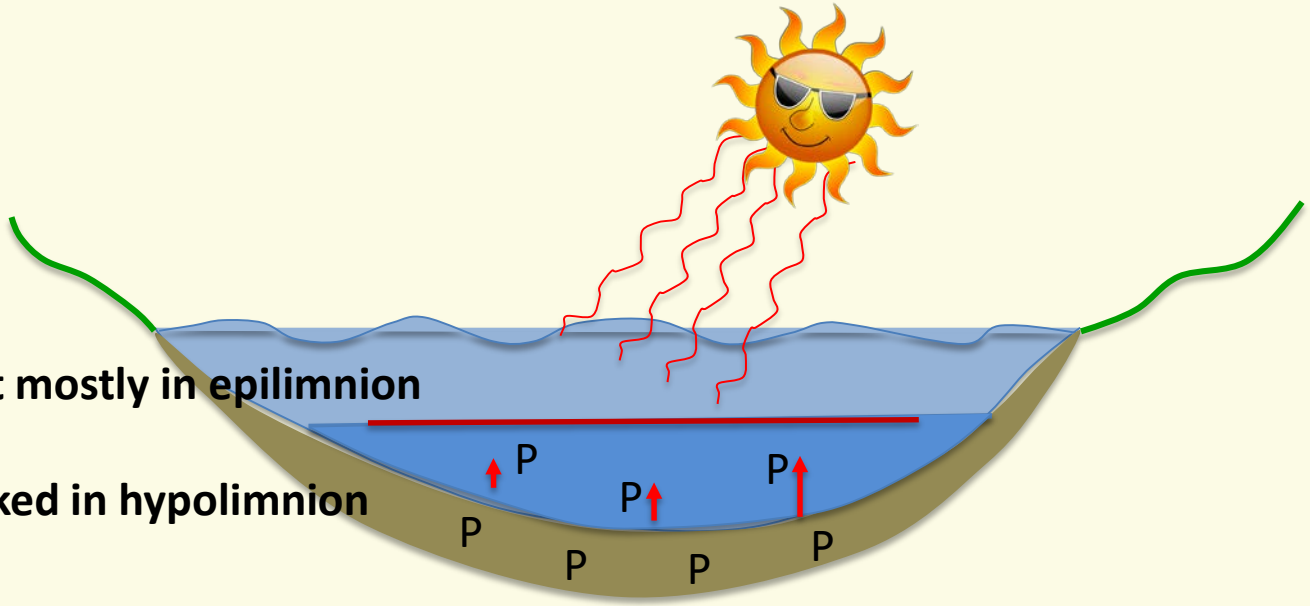
… internal loading



BUT during summer thermal stratification,
P is locked in hypolimnion



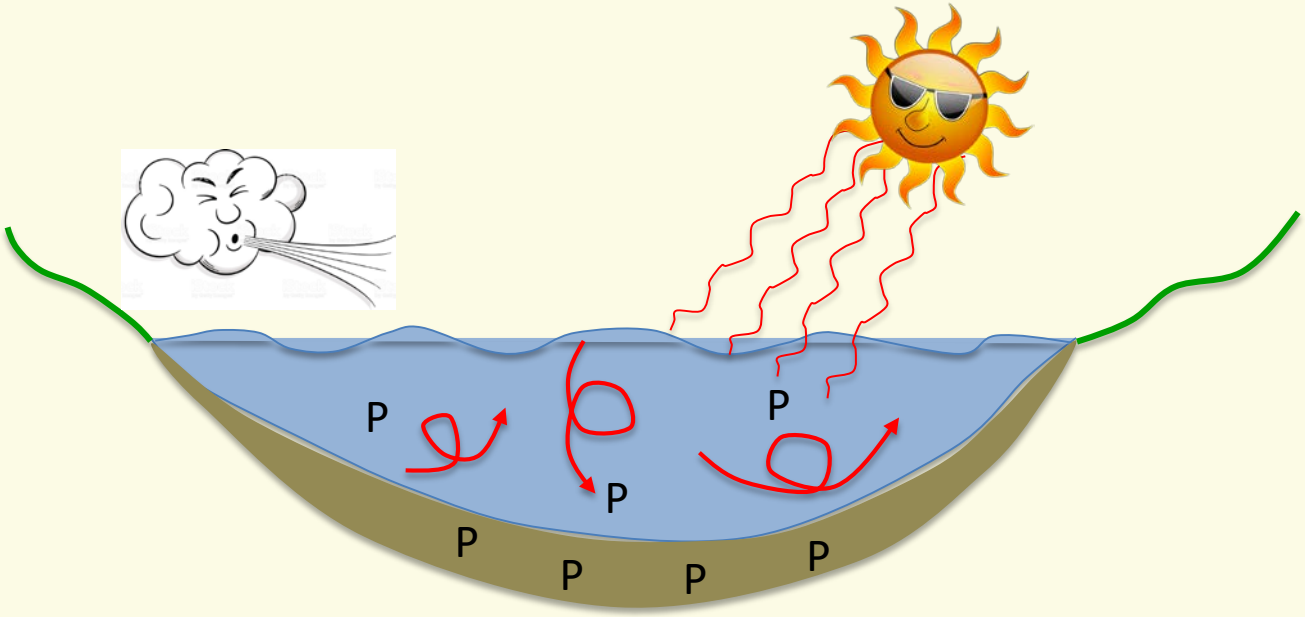
Legacy phosphorus



Phytoplankton growth restricted because light and nutrients are separated by depth

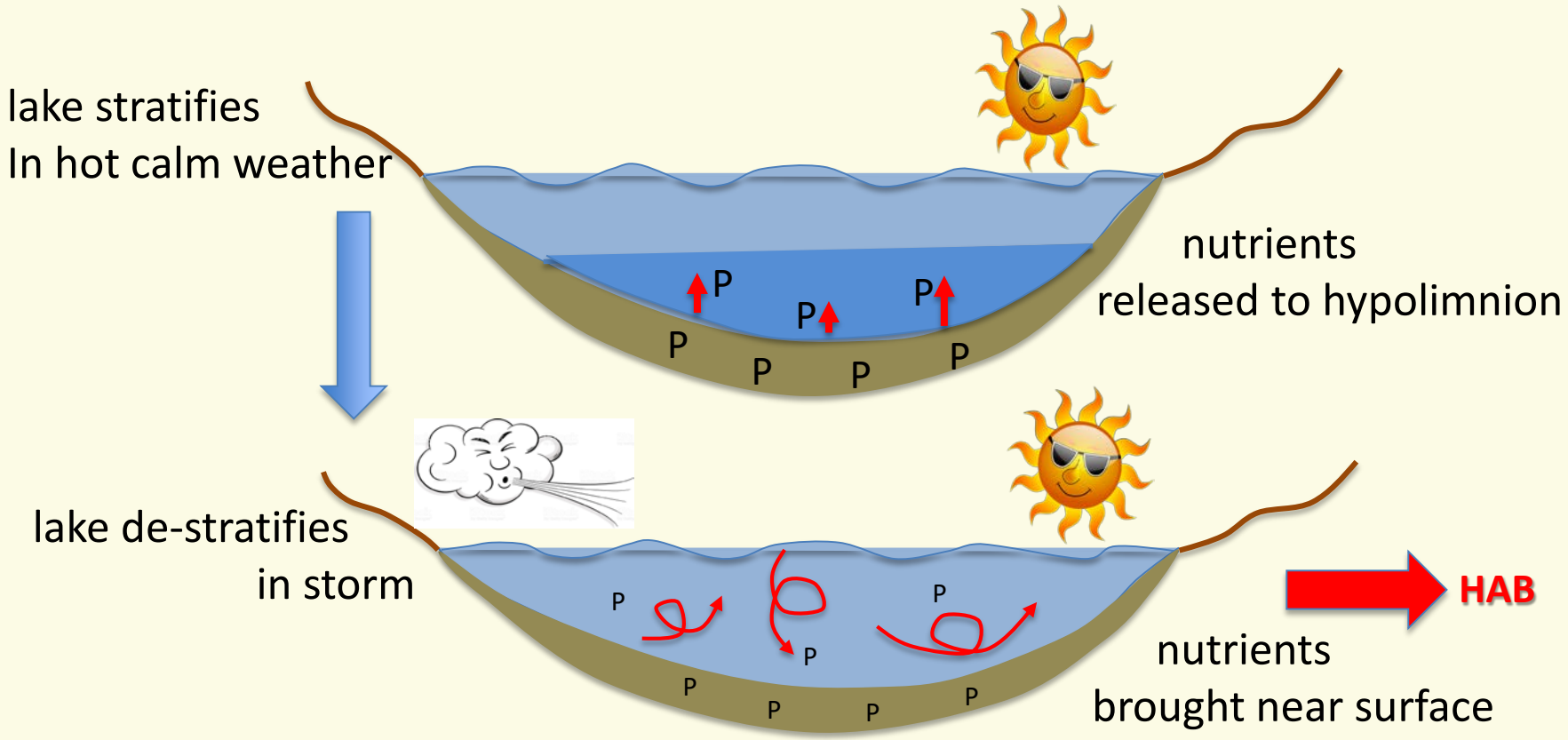
Legacy phosphorus

Unless strong storm mixes water column



<u>Phytoplankton blooms</u> because light and nutrients are both available near surface

Honeoye Lake z_{max} = 9 m: deep enough to stratify: shallow enough to mix.



Phosphorus pumping hypothesis for Honeoye Lake … maintains HAB.

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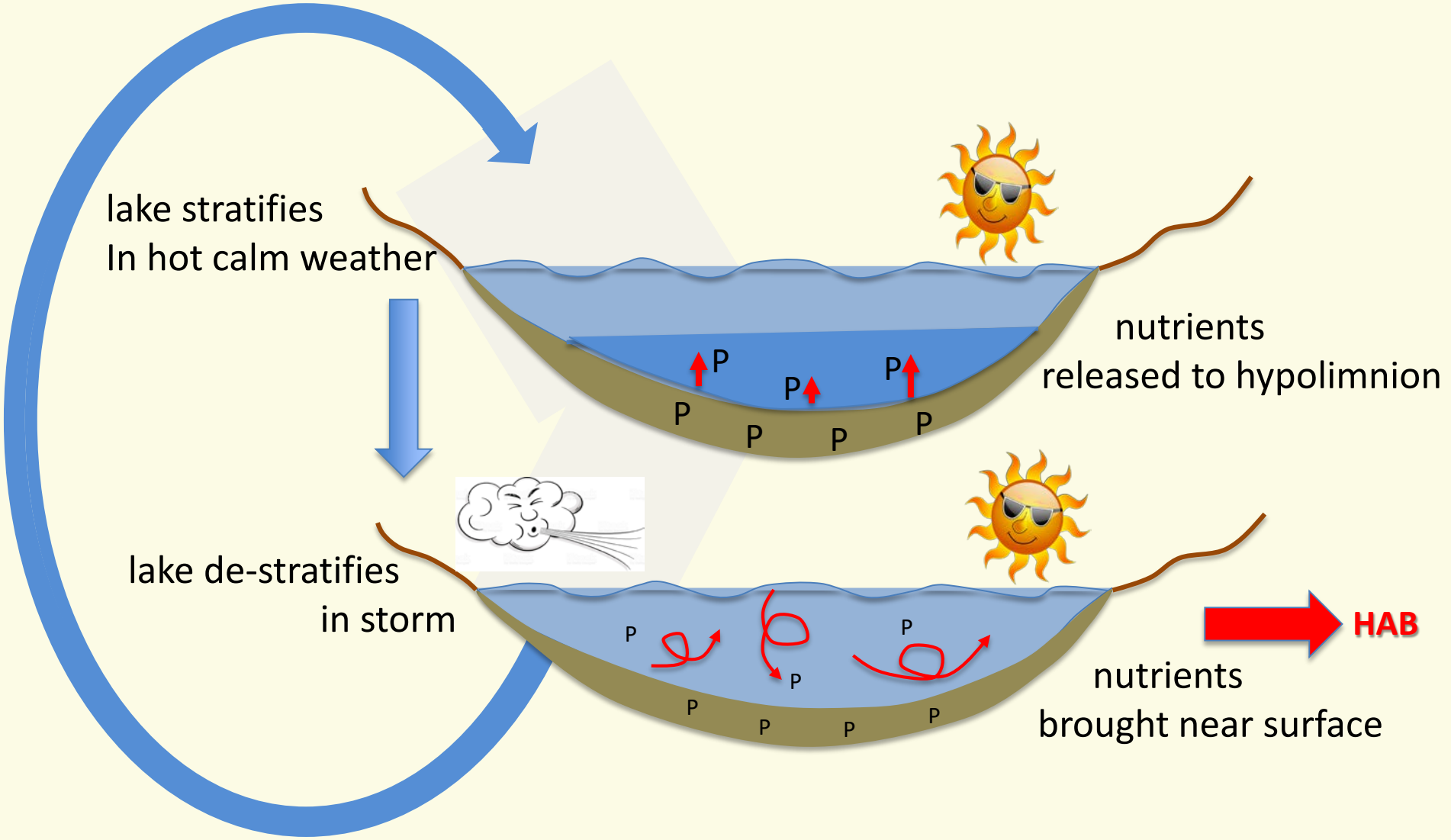


Approach:

1) **Document seasonal changes in thermal stratification:**
   Measure temperature vs depth throughout summer

2) **Explore causes of mixing events by measuring wind speed/direction, precipitation, and other meteorological parameters**

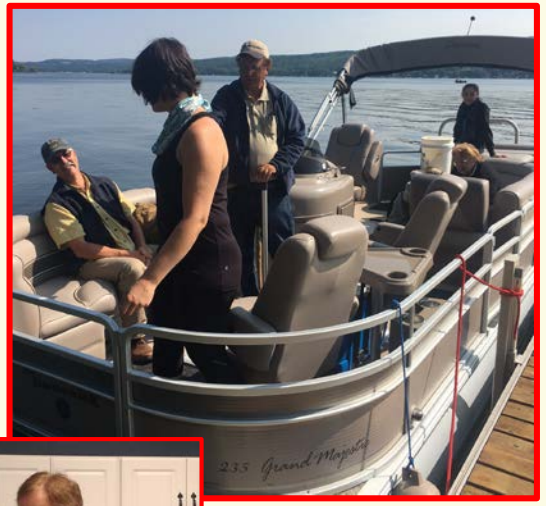
3) **Measure phosphorus, chlorophyll (and other parameters as a function of depth)**

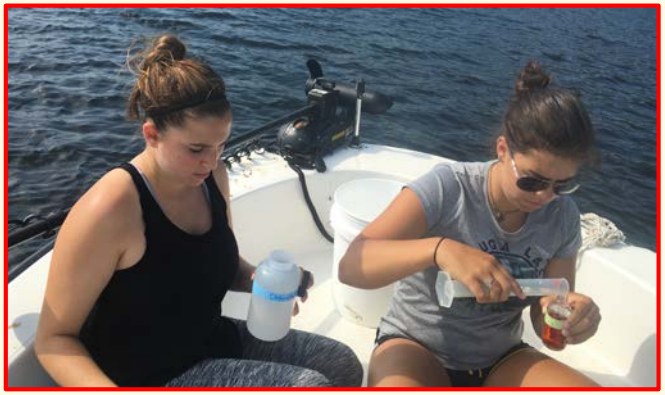
4) **Model lake processes with hydrodynamic model to understand how basin shape, weather, and nutrient supply influence bloom dynamics**

Field Chemistry / Sample Processing – FLCC Muller Lab

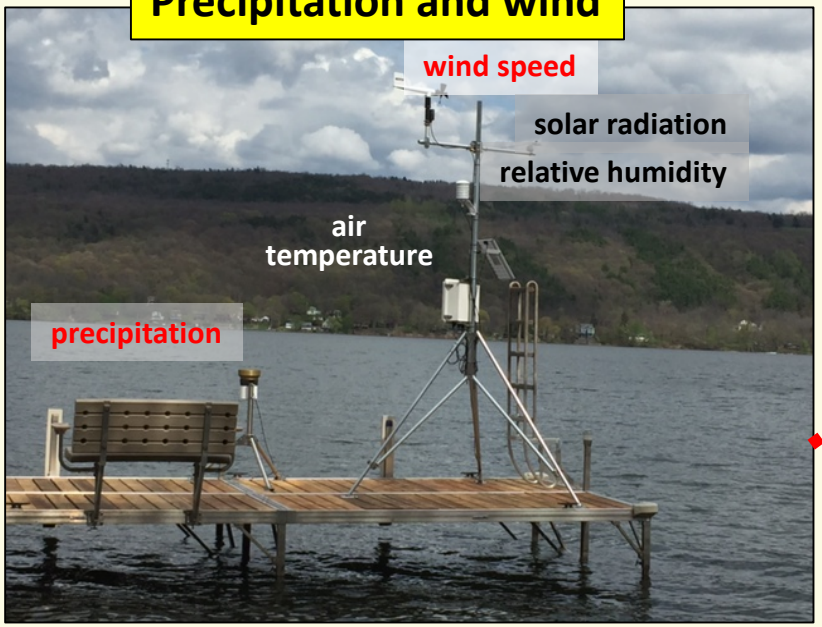
Weekly by depth:
- Dissolved Oxygen
- Soluble Reactive Phosphorus (SRP)
- Total Phosphorus (TP)
- Soluble Iron, Sulfur and TSP

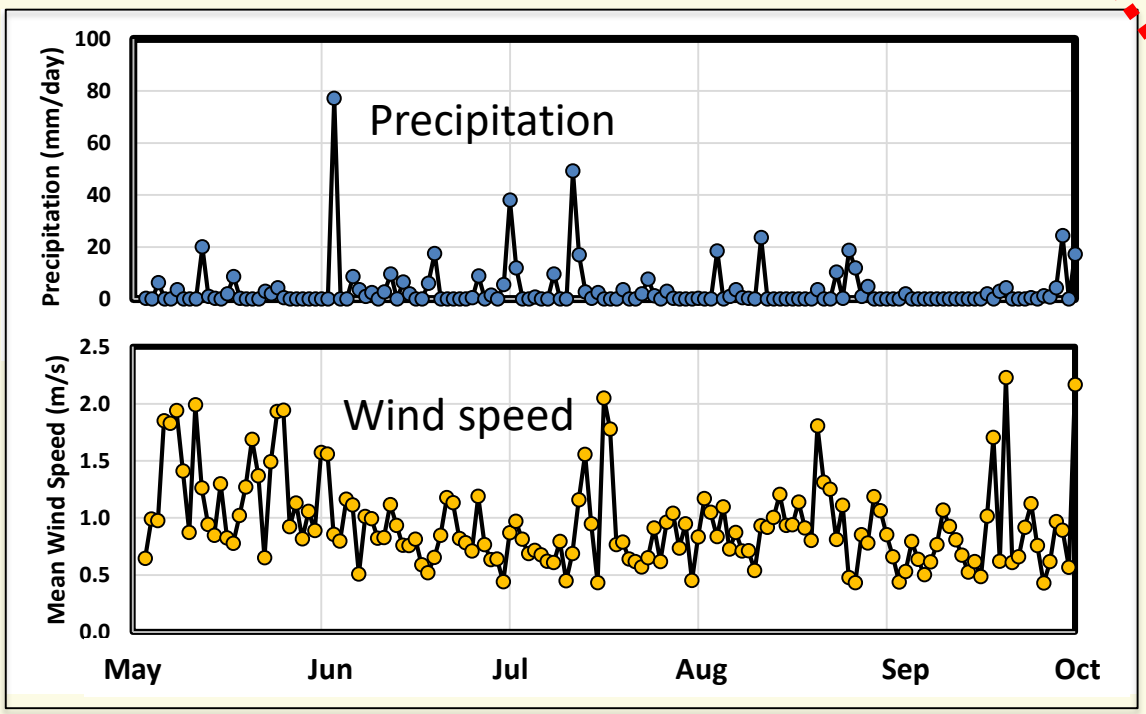
Weekly depth integrated:
- Chlorophyll-a (phytoplankton biomass)
- Phytoplankton (qualitative)
- Zooplankton (qualitative)





Precipitation and wind





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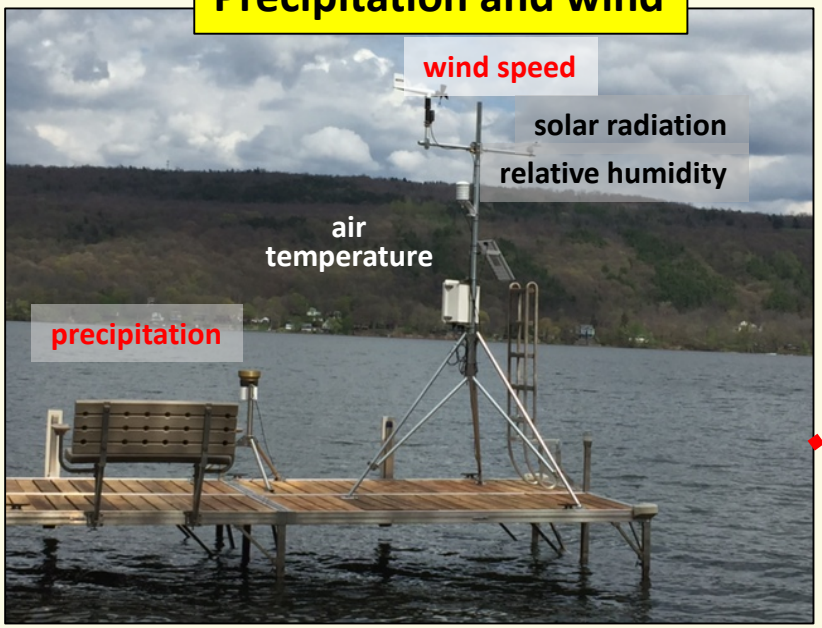
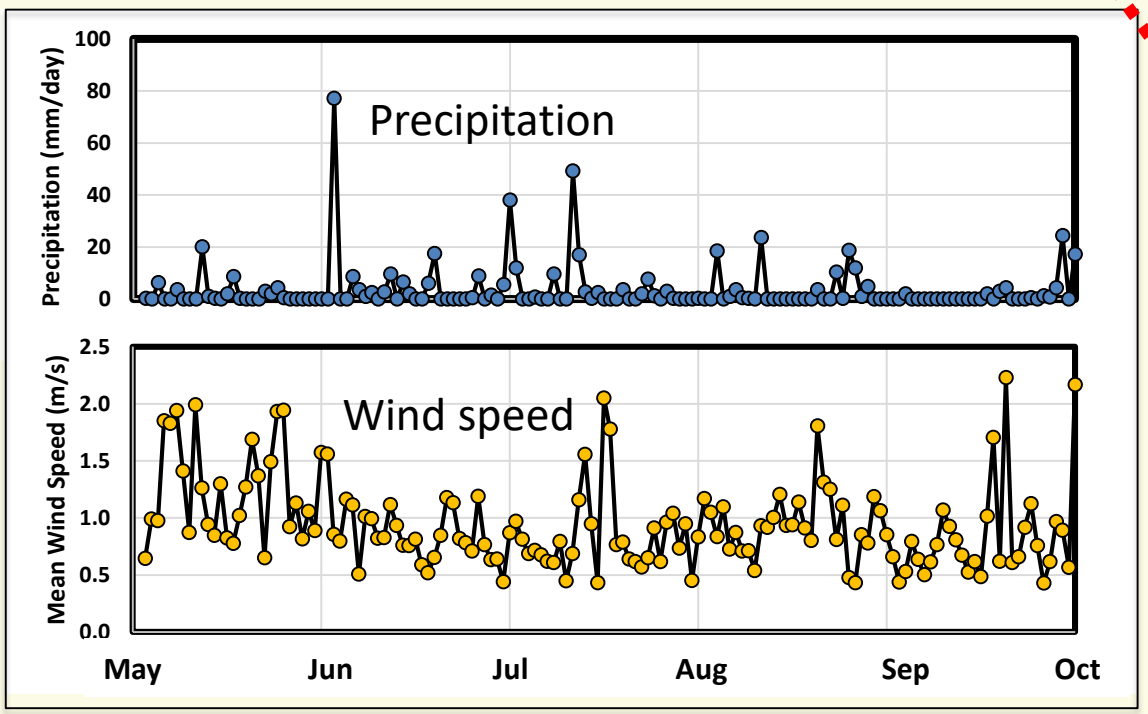
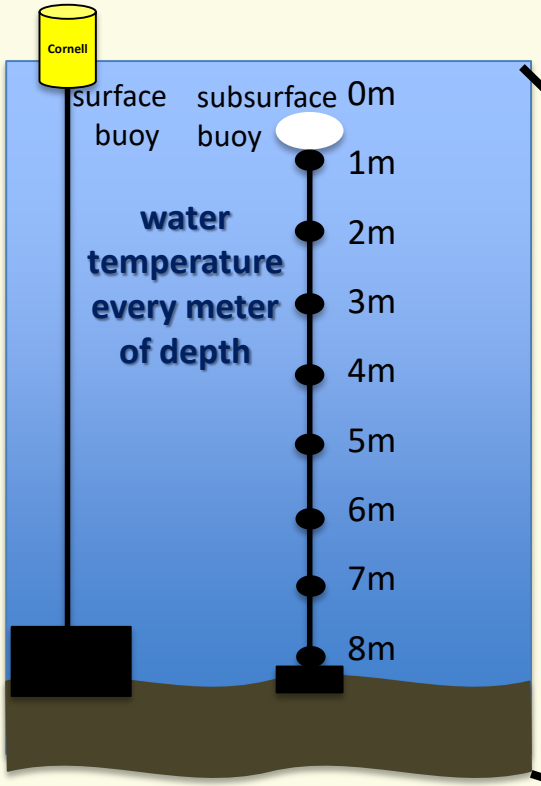
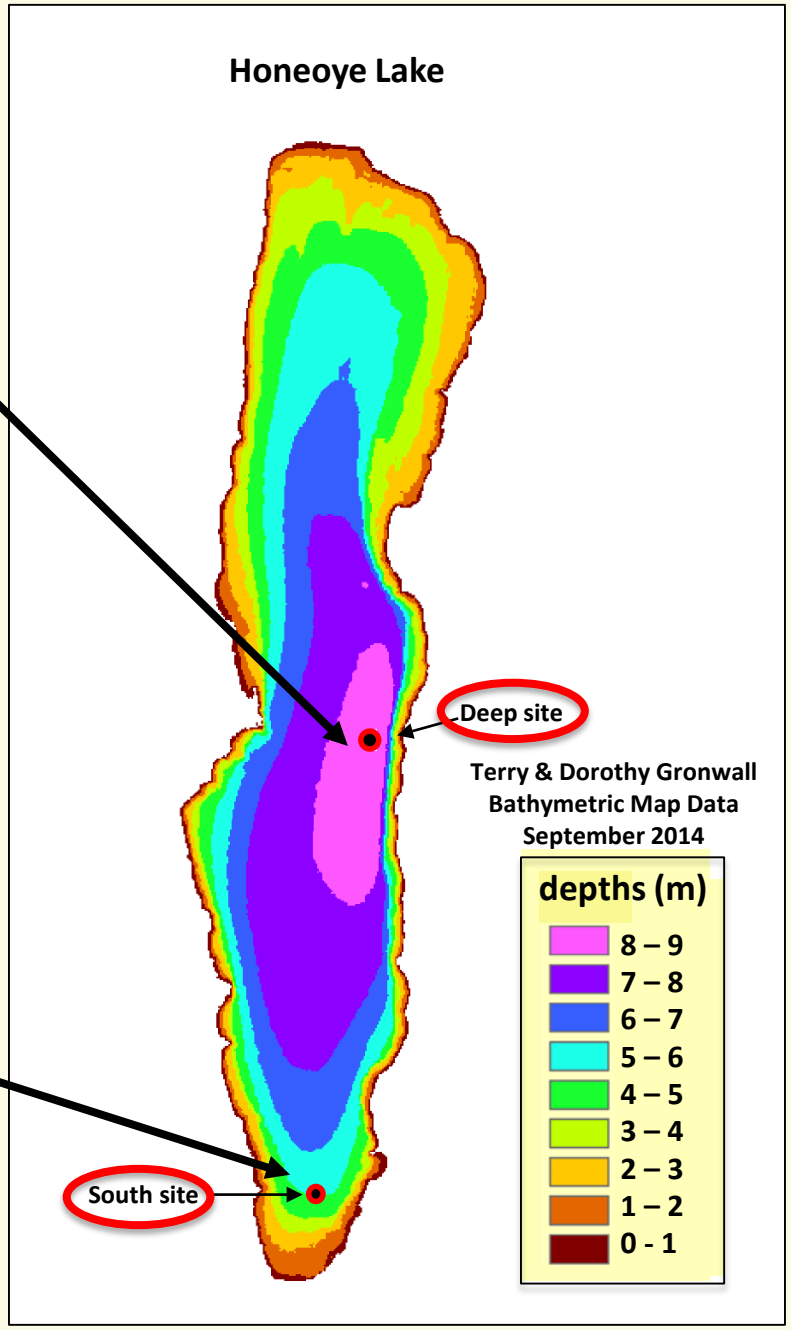




Water temperature by depth





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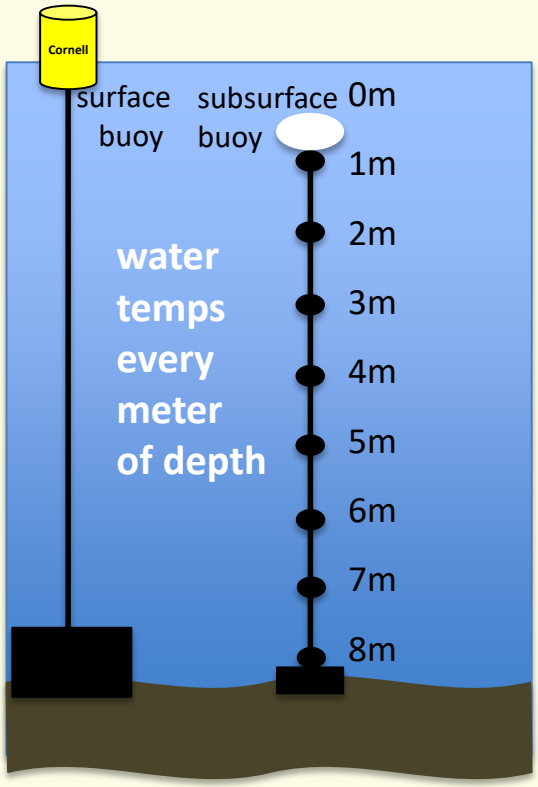
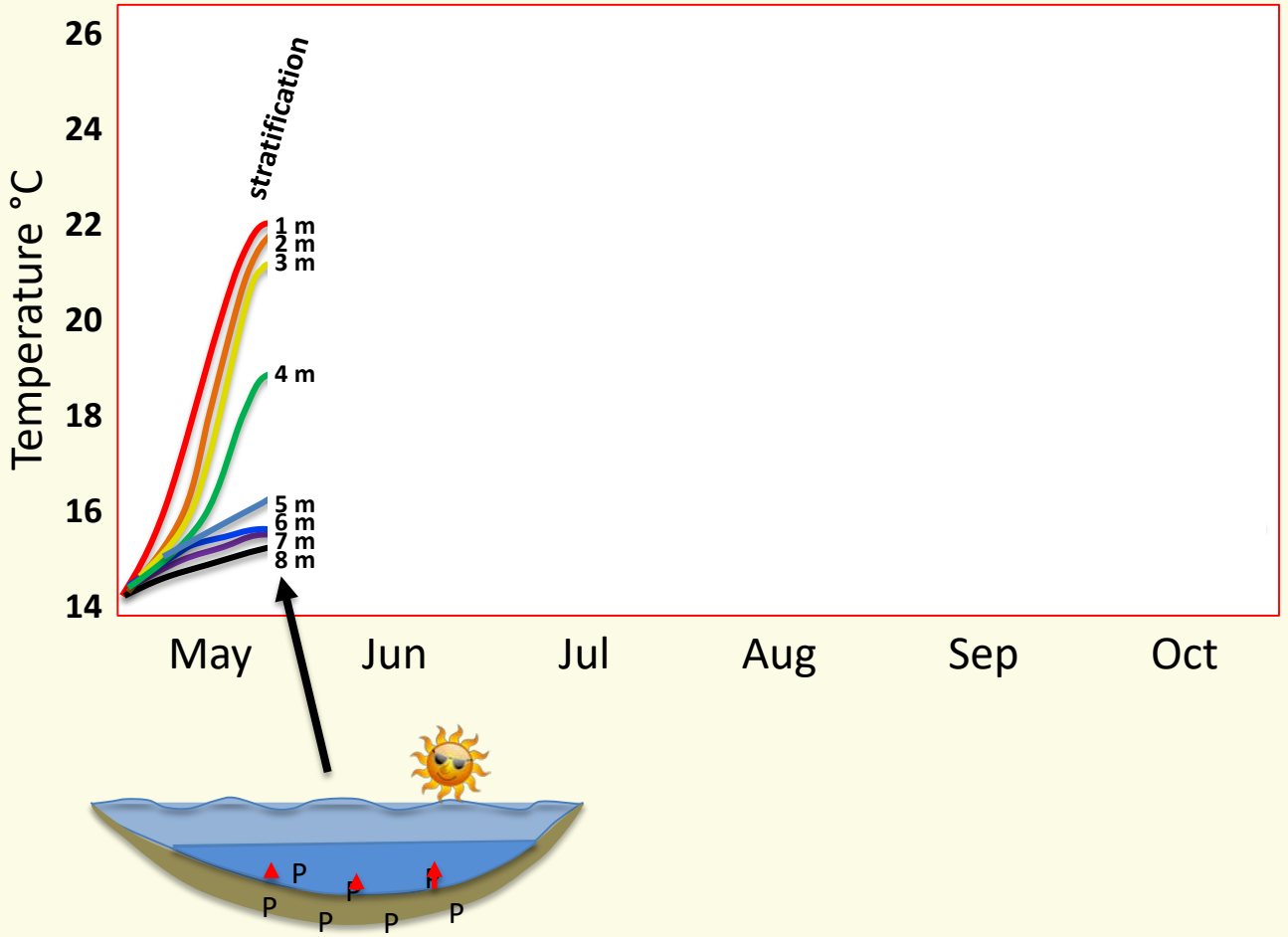
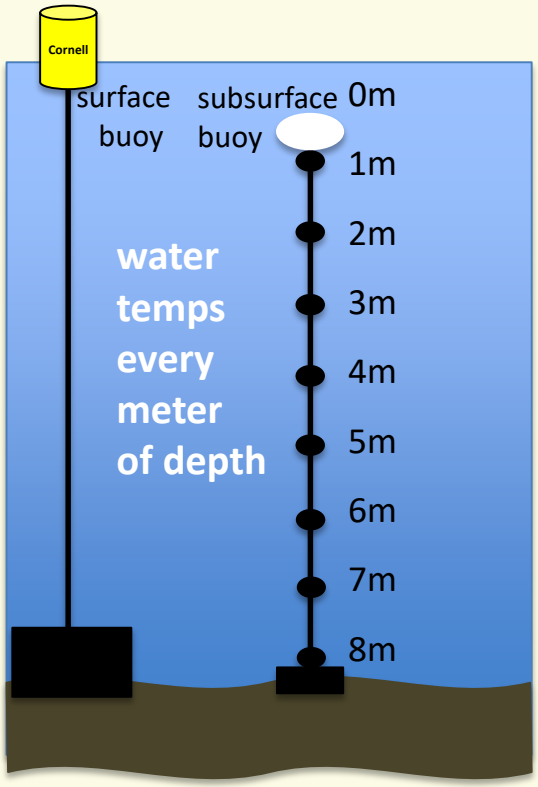


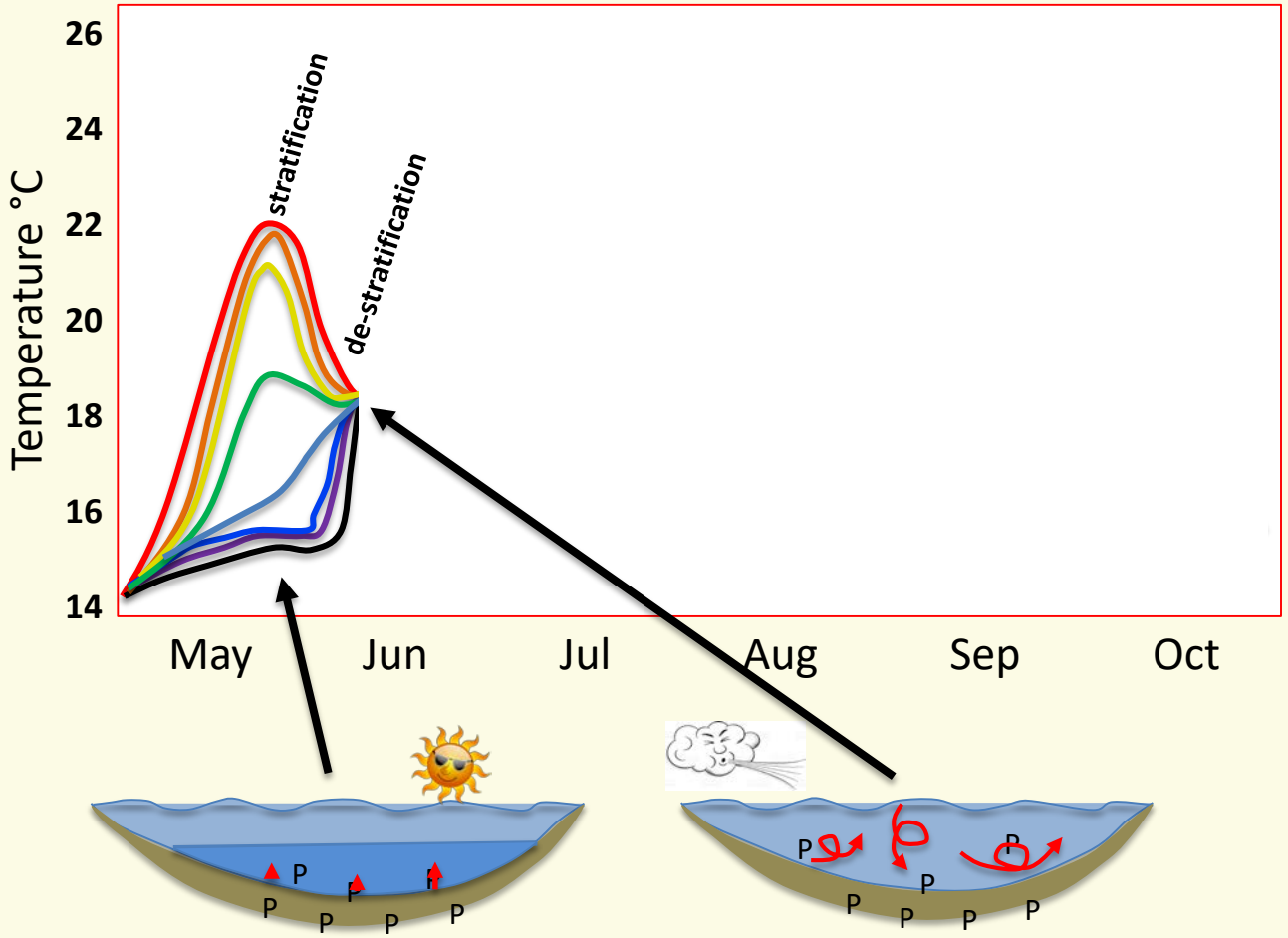
<u>Hypothetical</u> pattern of stratification & de-stratification



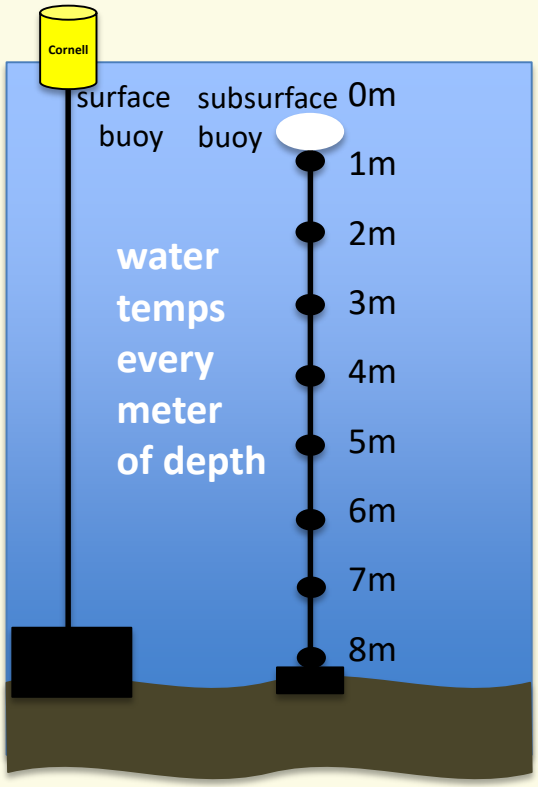
Honeoye Lake: deep enough to stratify, shallow enough to mix.



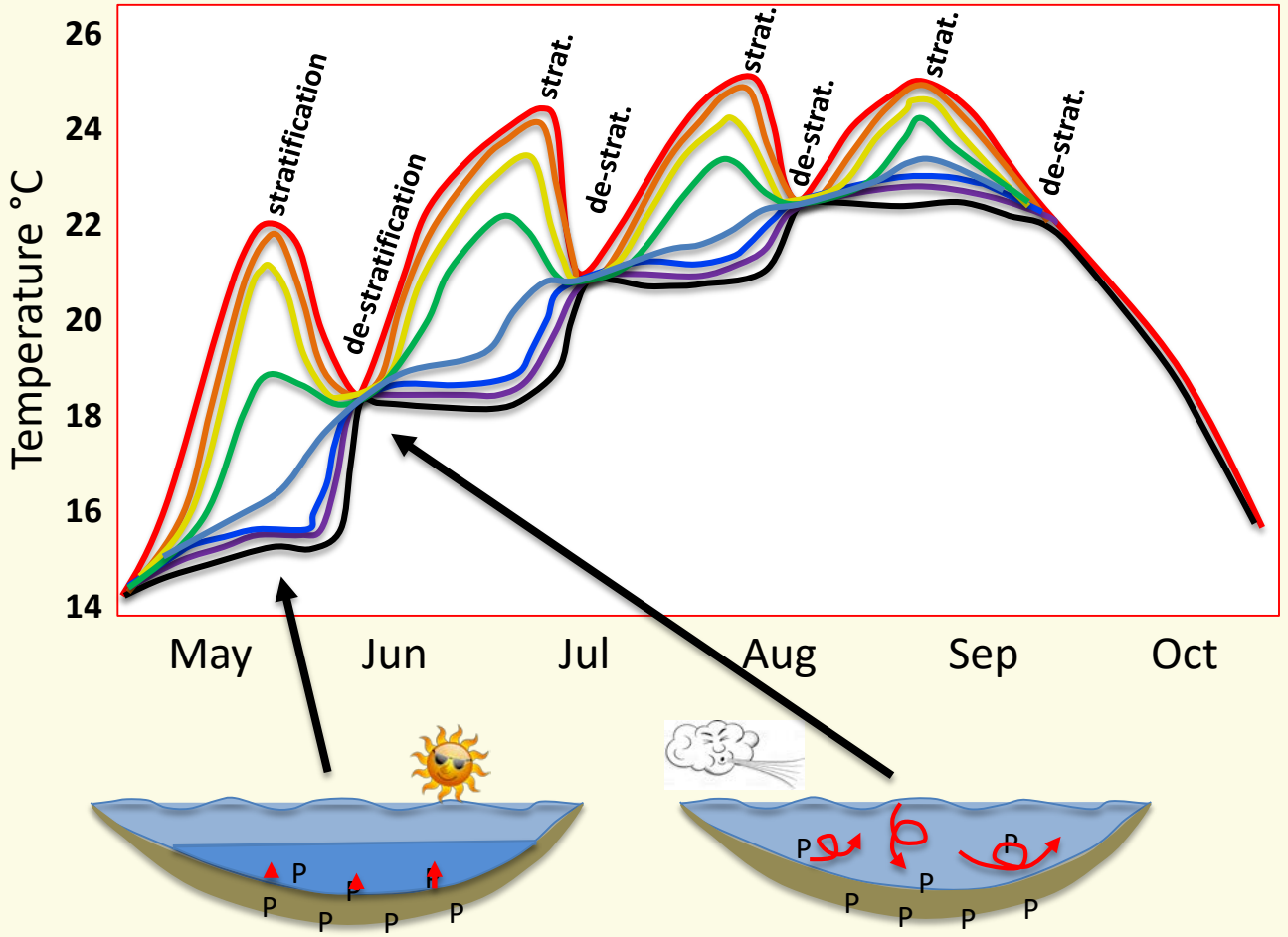
<u>Hypothetical</u> pattern of stratification & de-stratification

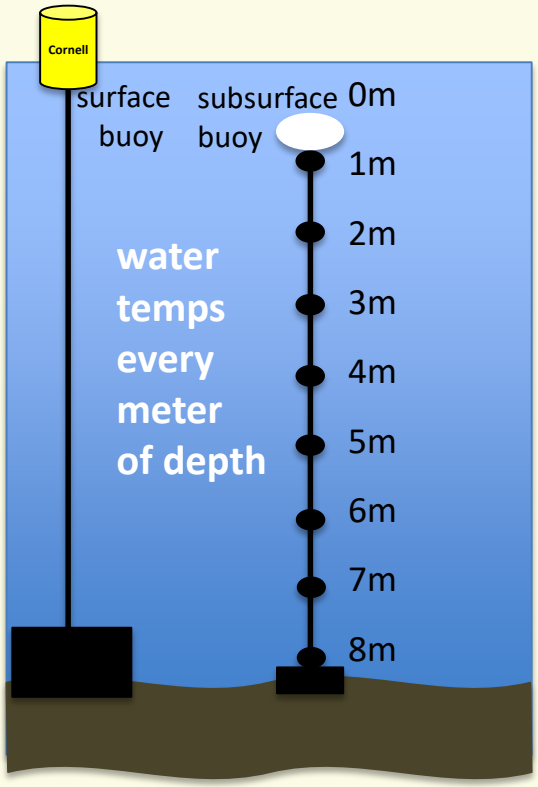


Honeoye Lake: deep enough to stratify, shallow enough to mix.

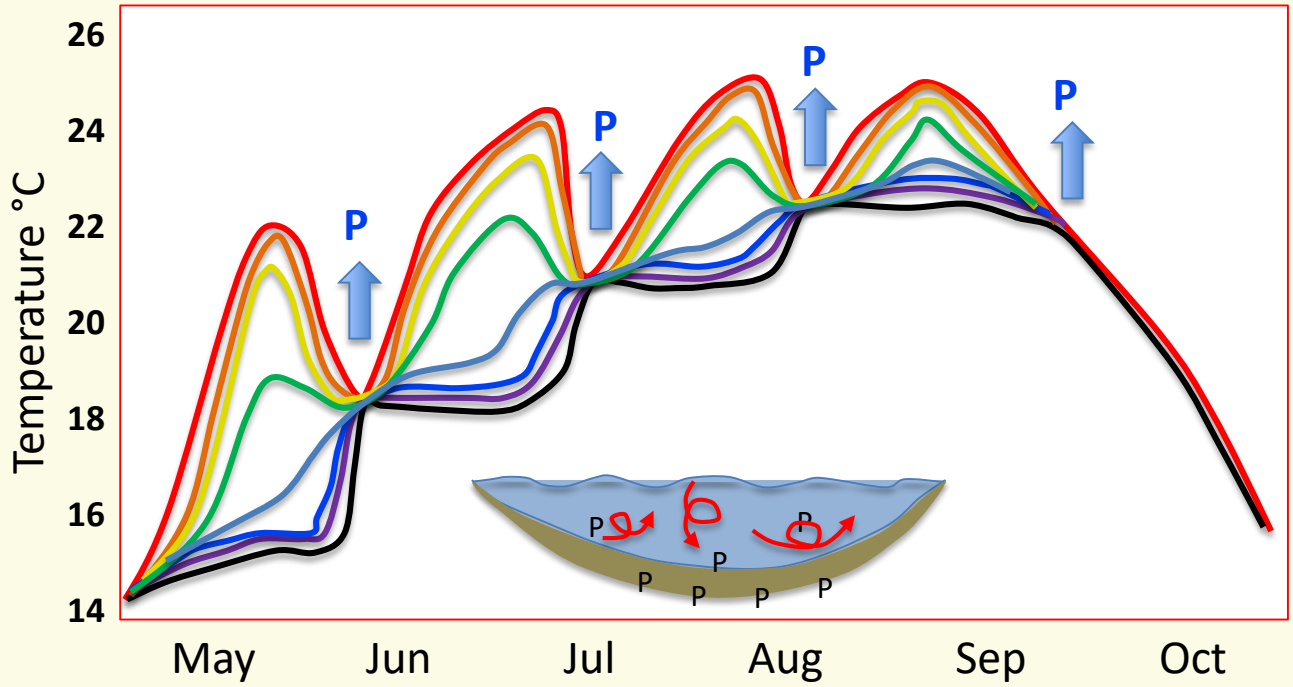


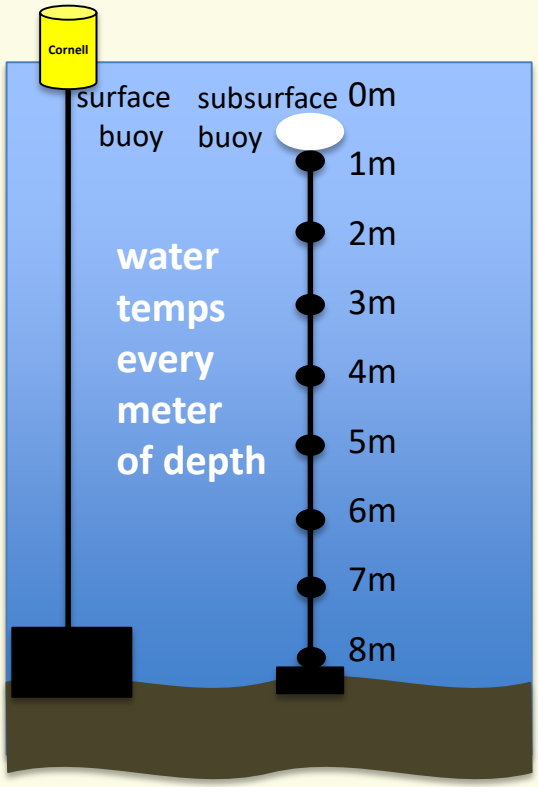
<u>Hypothetical</u> pattern of stratification & de-stratification



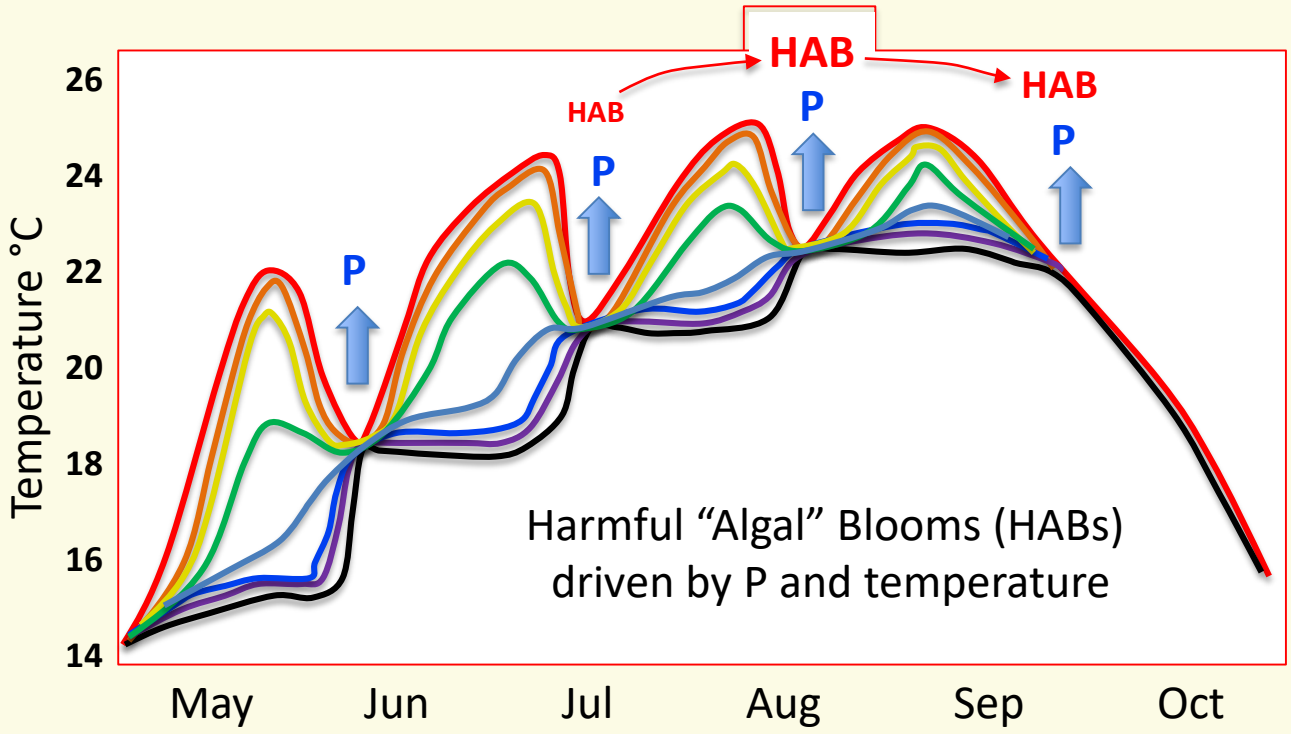


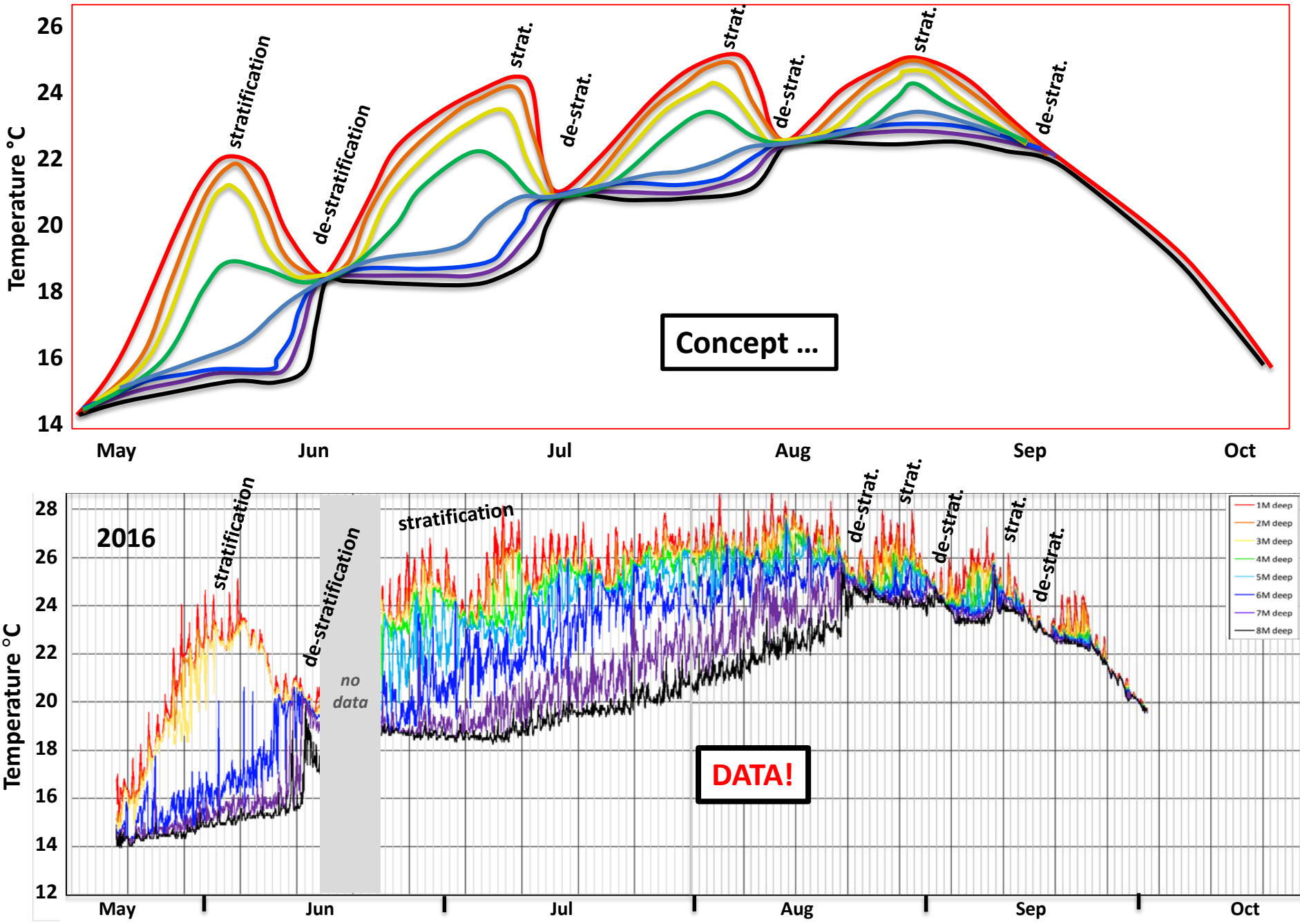
Hypothetical pattern of phosphorus pumping

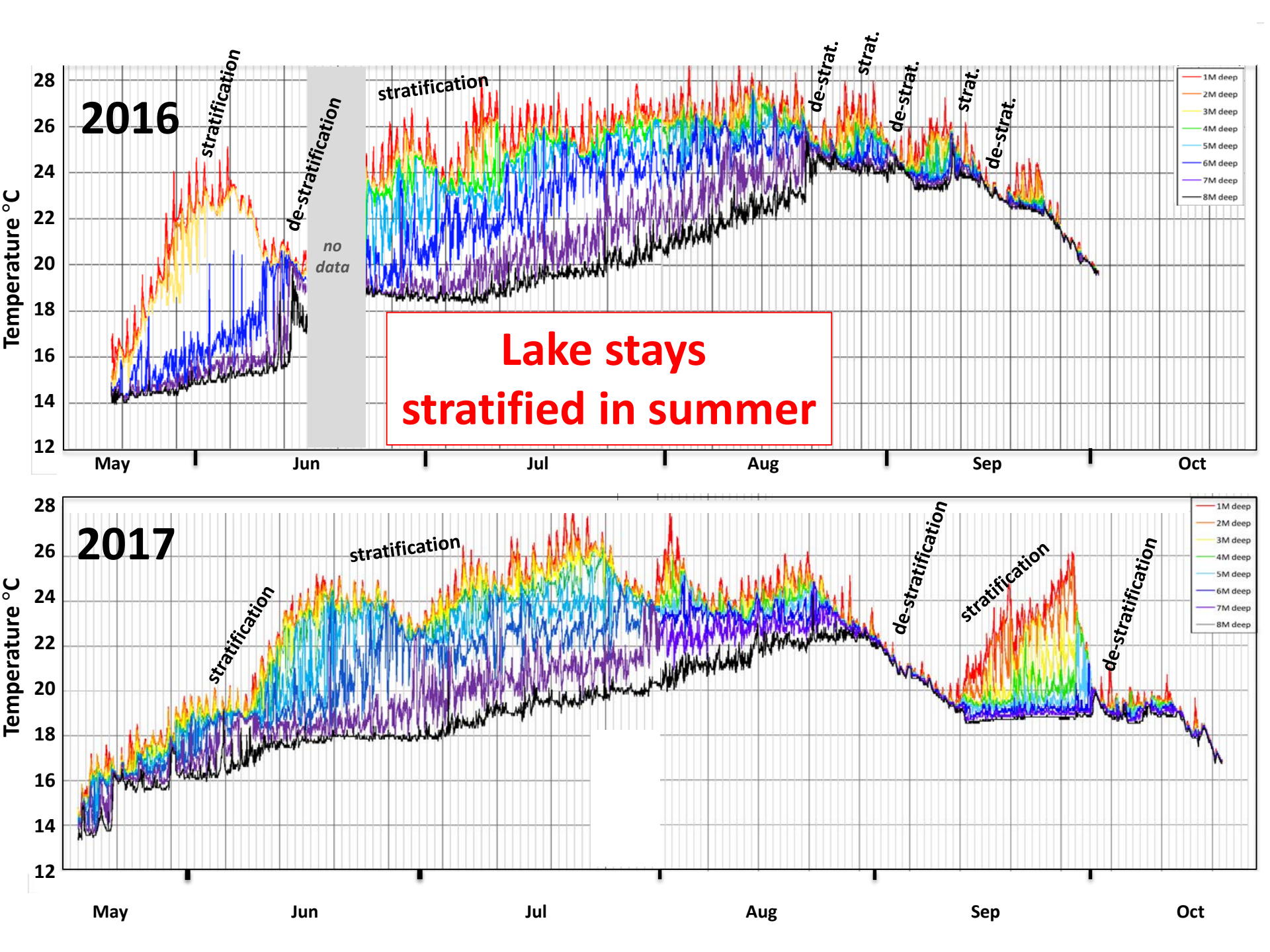


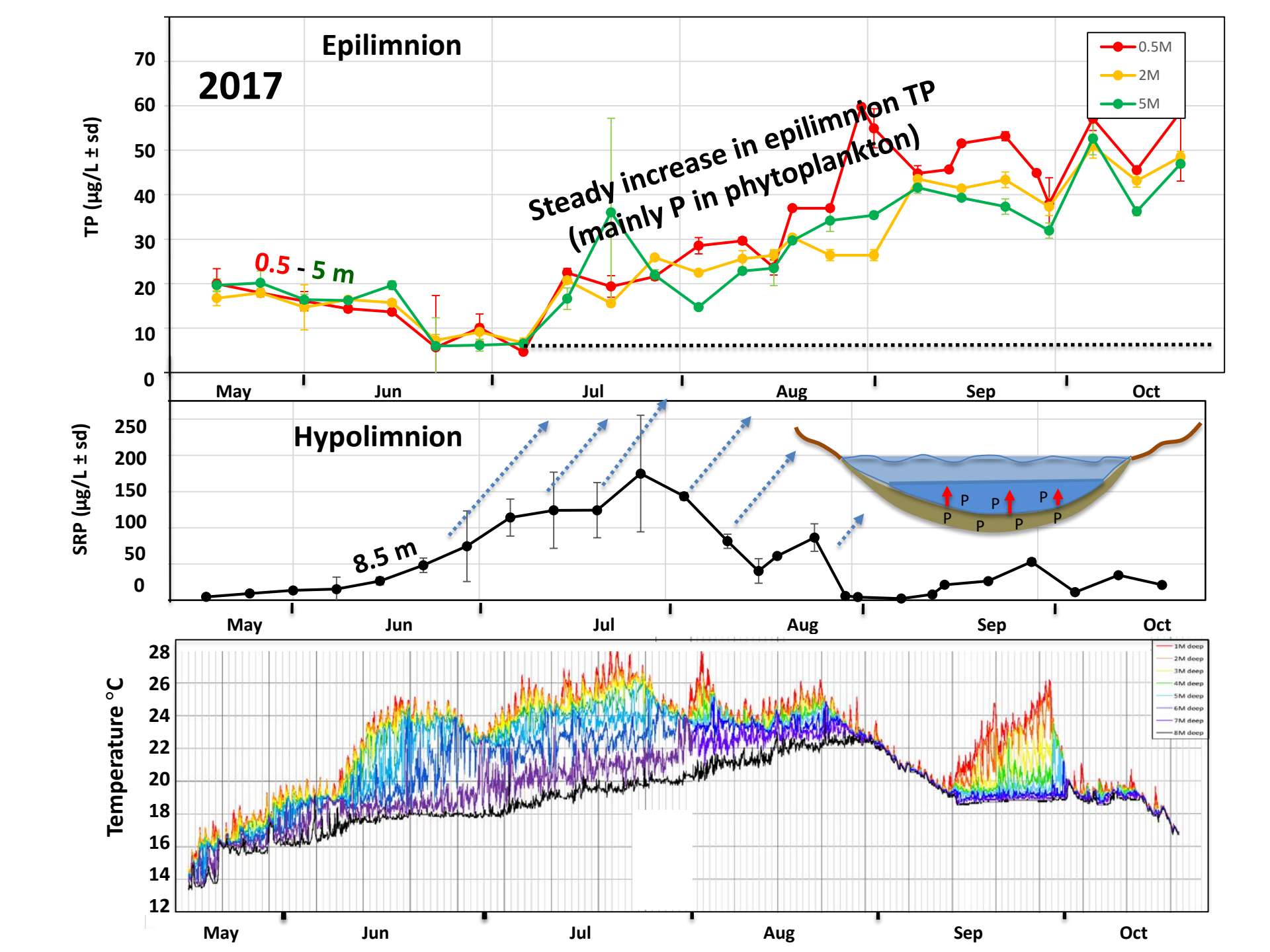


Hypothetical pattern of phosphorus pumping and HABs

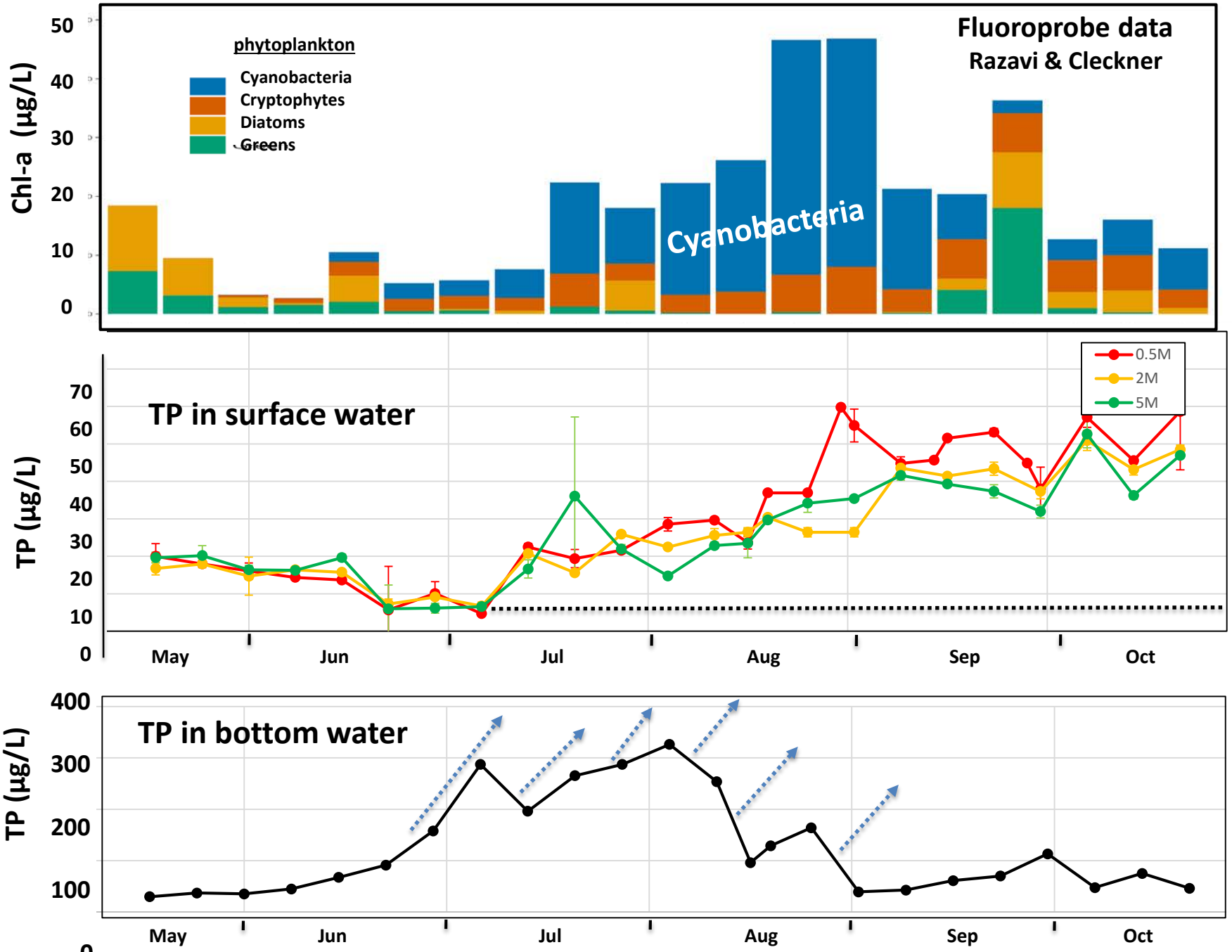


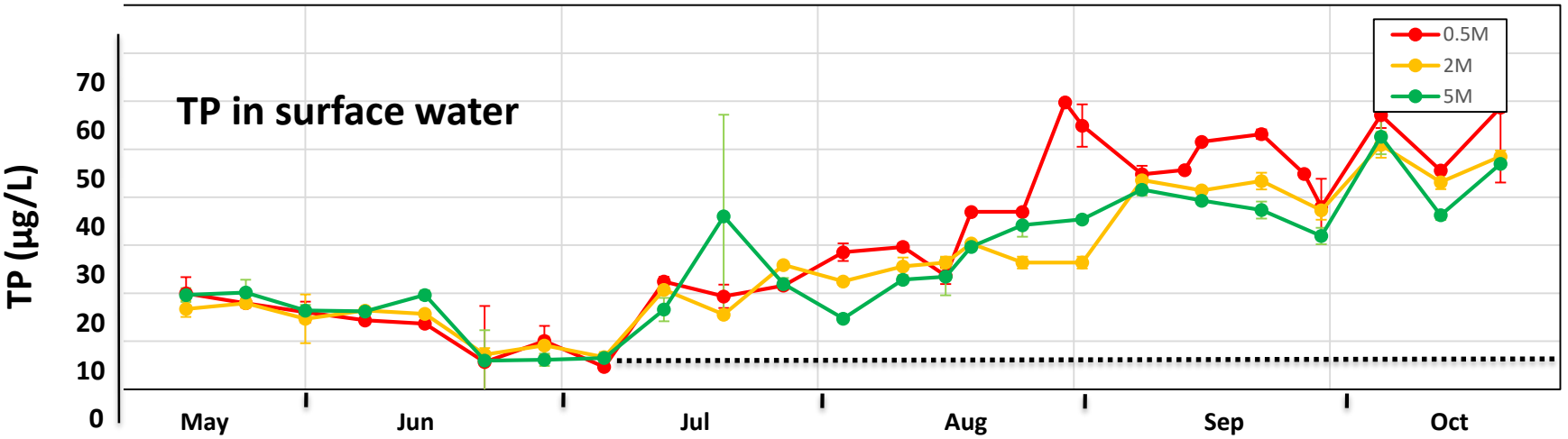

Temperature °C
26
24
22
20
18
16
14
stratification
de-stratification
strat.
de-strat.
strat.
de-strat.
strat.
de-strat.
Concept …
May
Jun
Jul
Aug
Sep
Oct
2016
stratification
de-stratification
no data
stratification
de-strat.
strat.
de-strat.
strat.
de-strat.
DATA!
1M deep
2M deep
3M deep
4M deep
5M deep
6M deep
7M deep
8M deep
28
12


2016
stratification
de-stratification
no data
stratification
de-strat.
strat.
de-strat.
strat.
de-strat.
Lake stays stratified in summer
1M deep
2M deep
3M deep
4M deep
5M deep
6M deep
7M deep
8M deep
Temperature °C
28
26
24
22
20
18
16
14
12
May
Jun
Jul
Aug
Sep
Oct
2017
stratification
stratification
de-stratification
stratification
de-stratification
1M deep
2M deep
3M deep
4M deep
5M deep
6M deep
7M deep
8M deep
Temperature °C
28
26
24
22
20
18
16
14
12
May
Jun
Jul
Aug
Sep
Oct

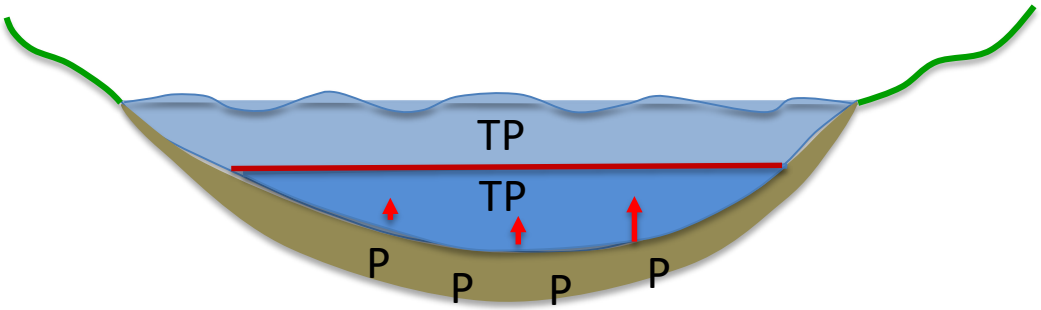

Epilimnion
2017
0.5M
2M
5M
TP (µg/L ± sd)
0.5 - 5 m
Steady increase in epilimnion TP
(mainly P in phytoplankton)
May
Jun
Jul
Aug
Sep
Oct
Hypolimnion
SRP (µg/L ± sd)
8.5 m
P
Temperature °C
1M deep
2M deep
3M deep
4M deep
5M deep
6M deep
7M deep
8M deep

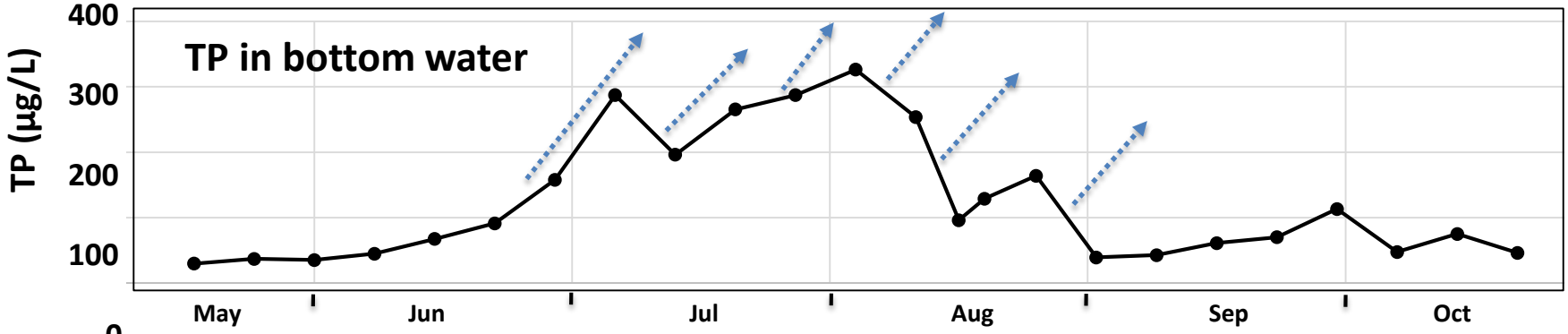
Phytoplankton biomass in surface water (0 – 5 m)

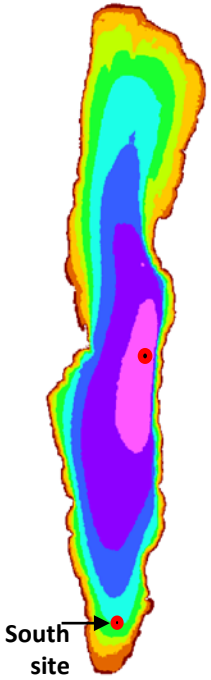


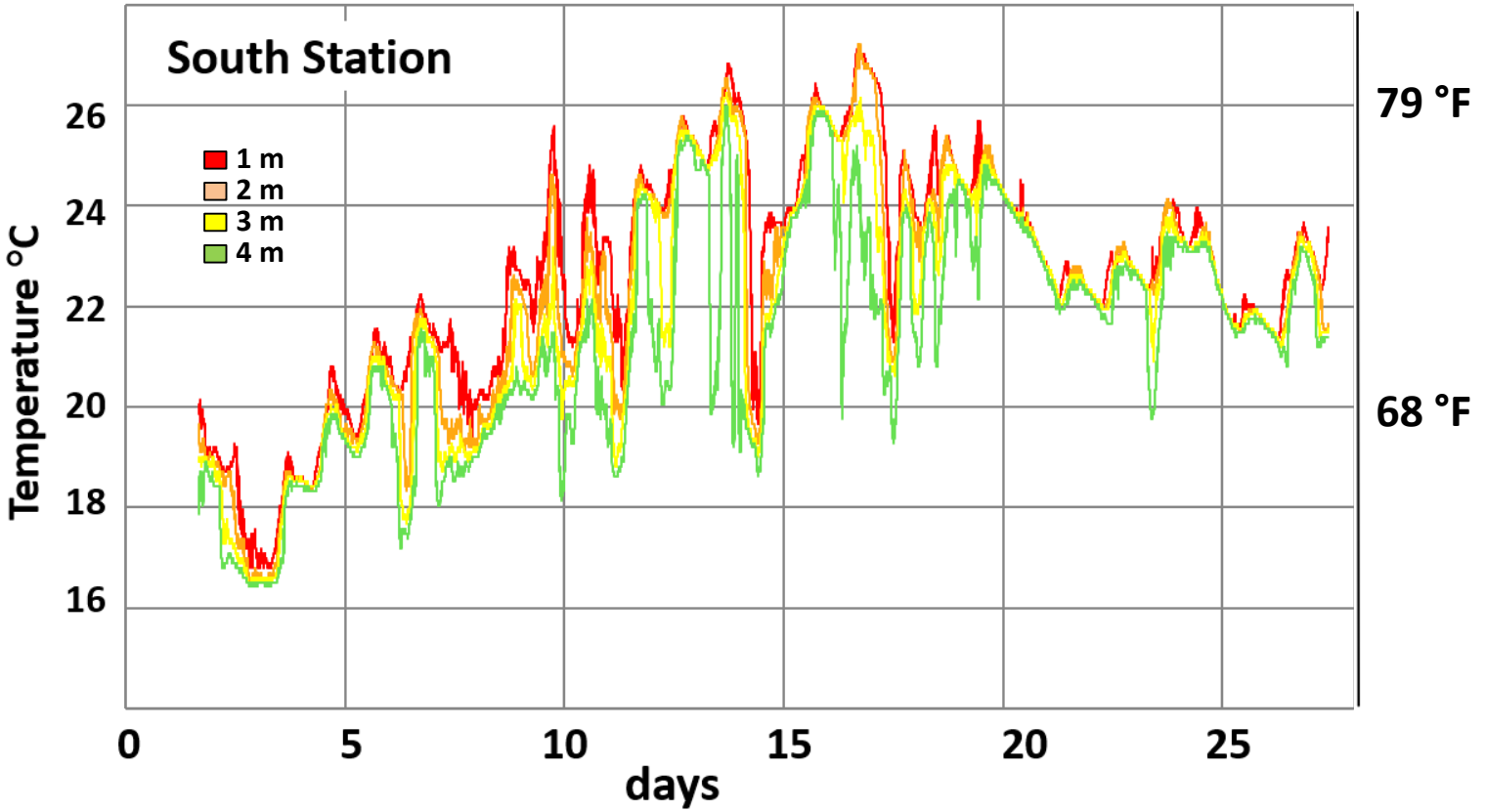


How did the P get into the epilimnion while the lake was stratified?

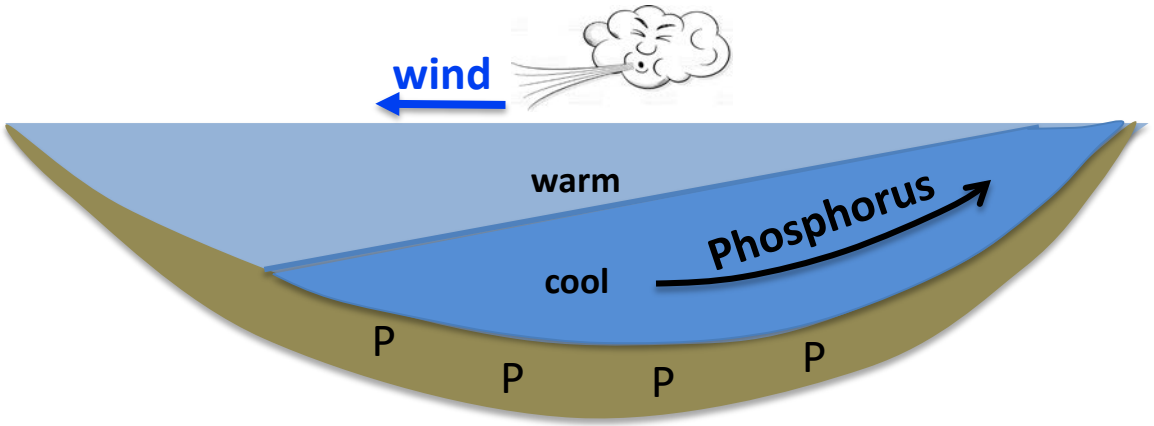


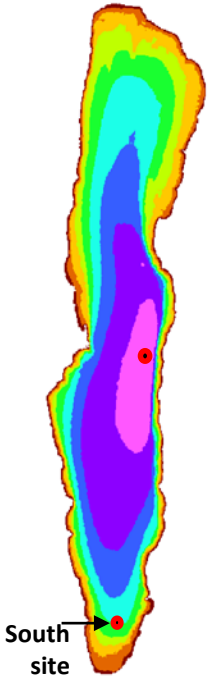


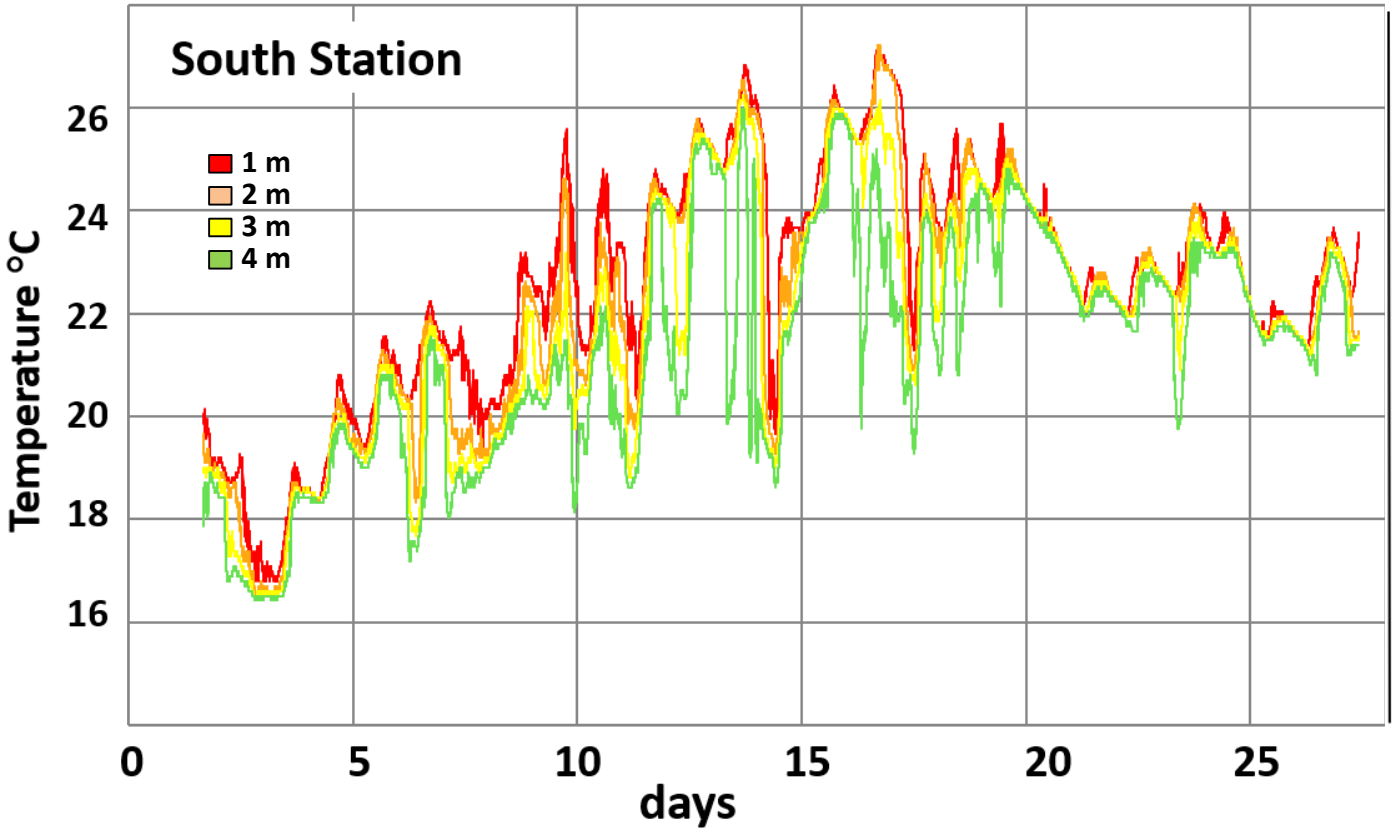




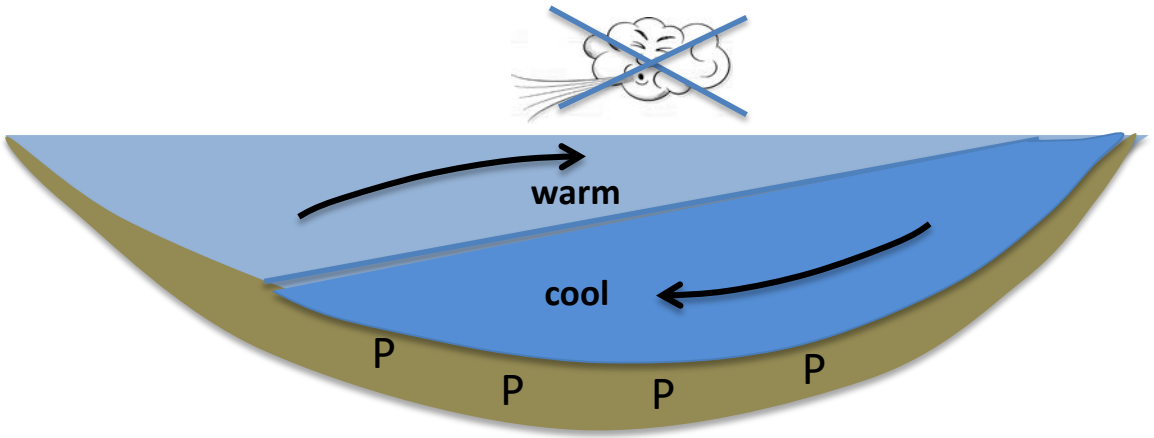
Thermocline tilt: upwelling of cool nutrient-rich bottom water

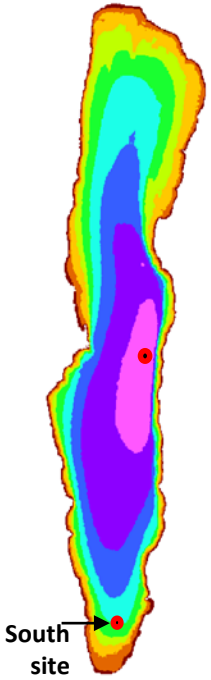


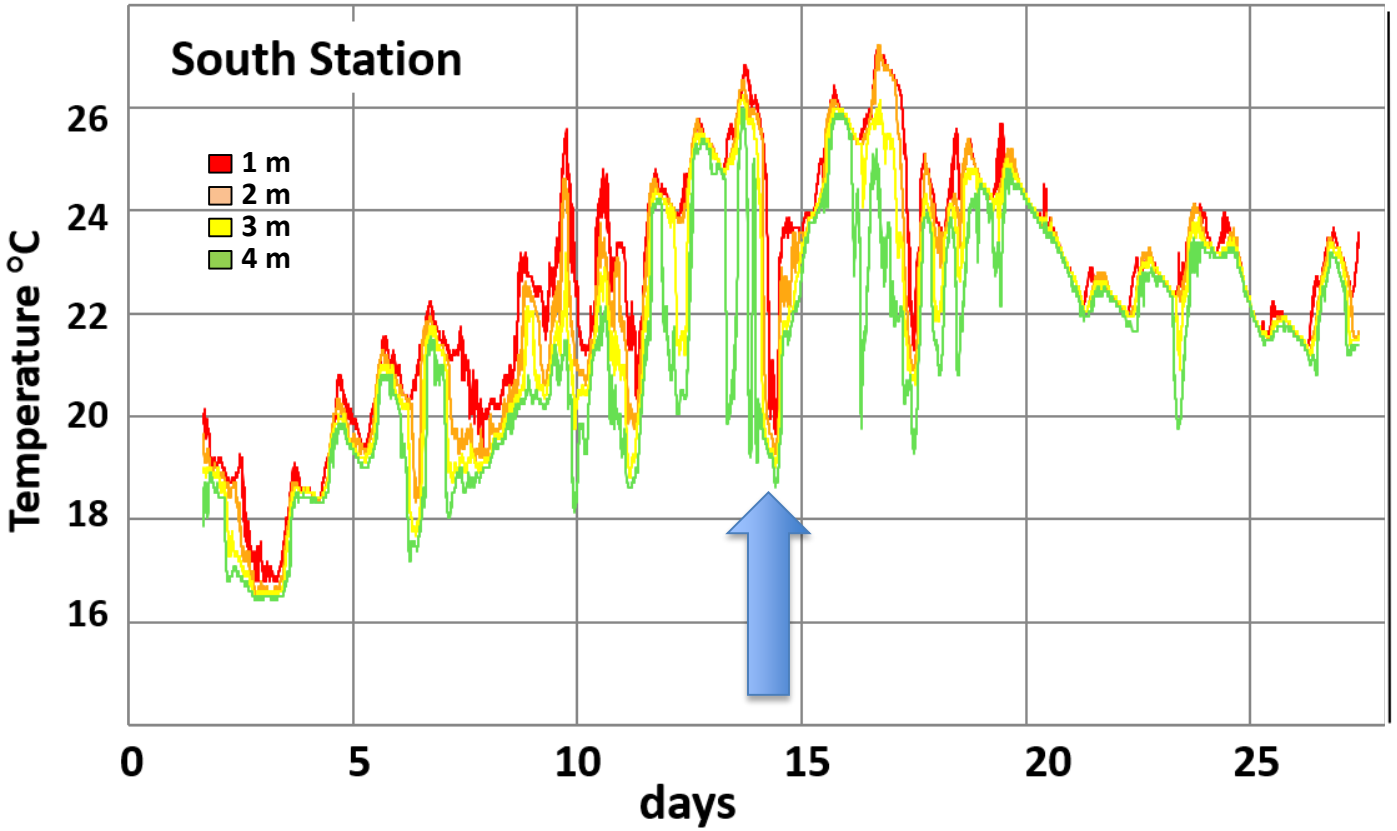




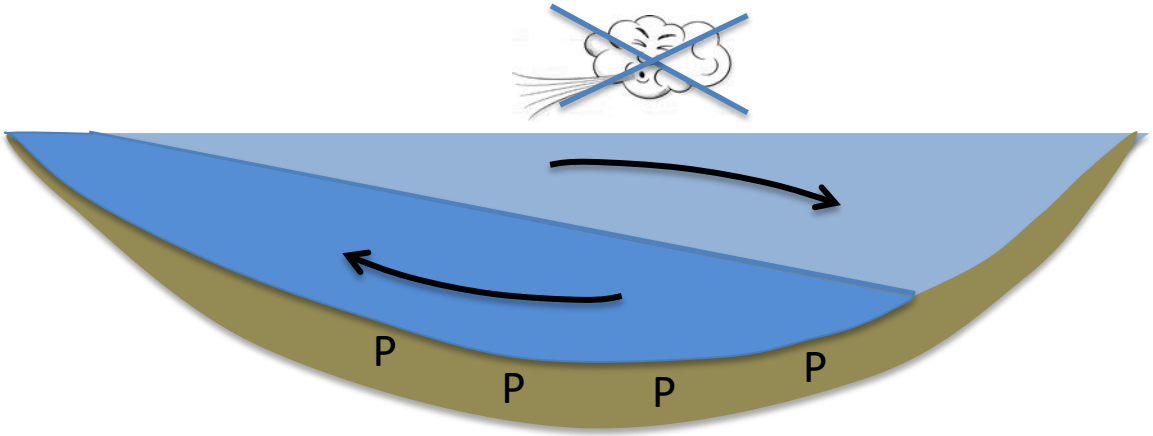
Thermocline tilt: upwelling of cool nutrient-rich bottom water



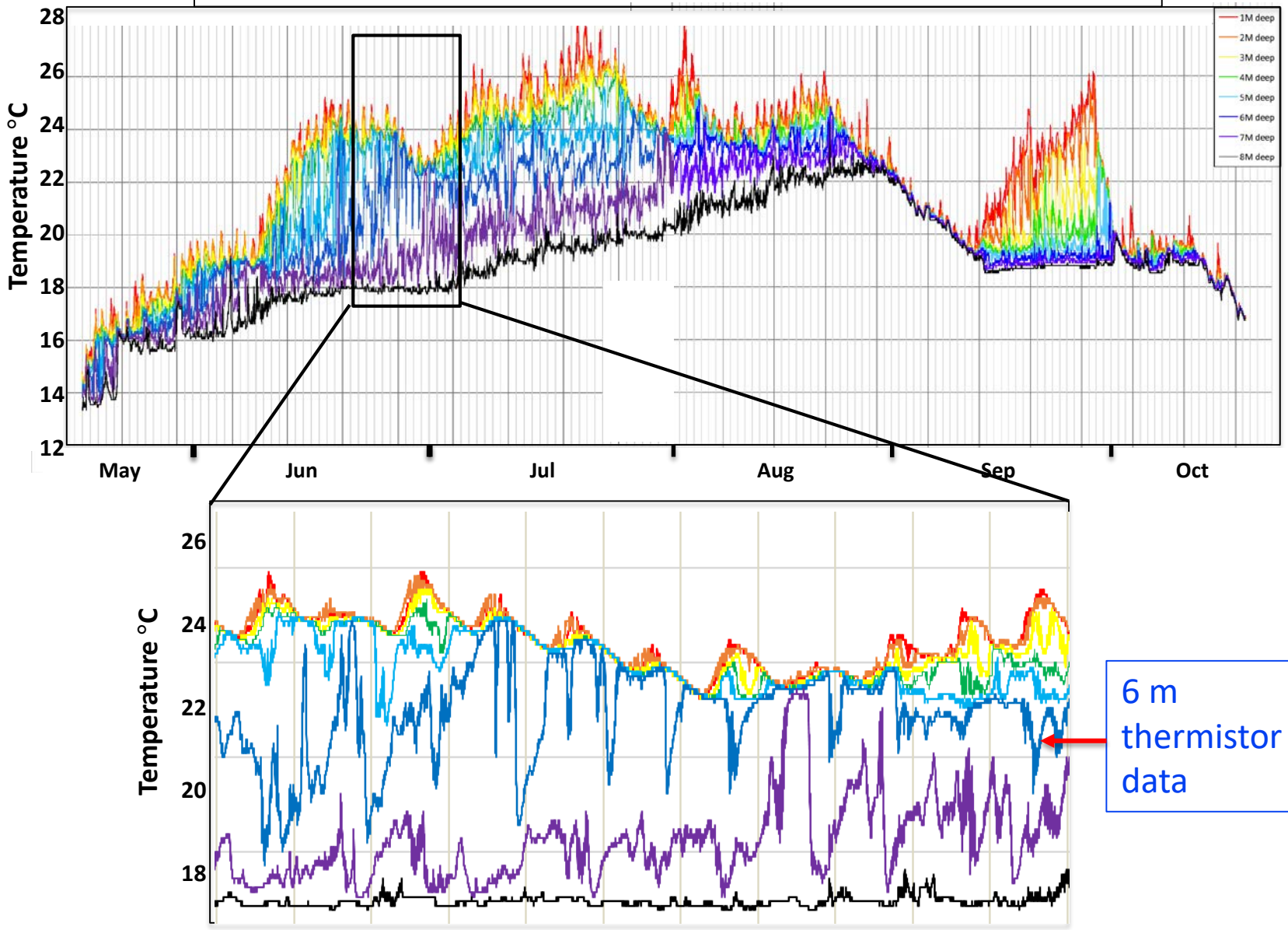




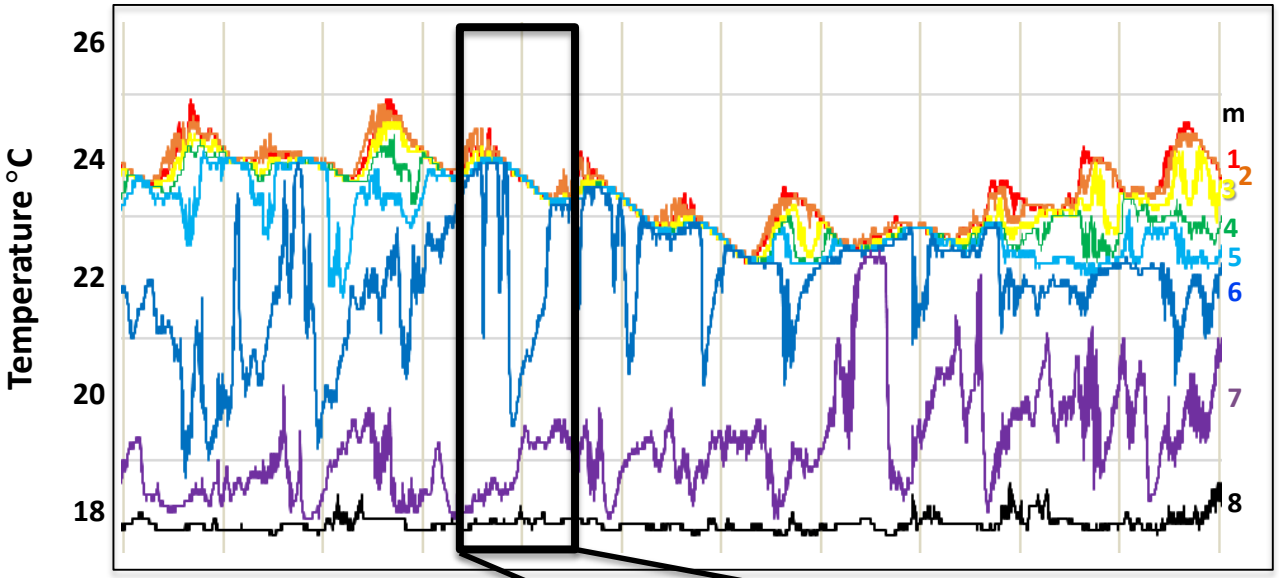
Thermocline tilt: upwelling of cool nutrient-rich bottom water

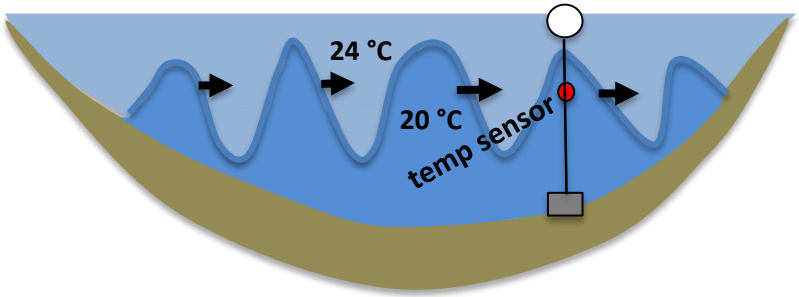


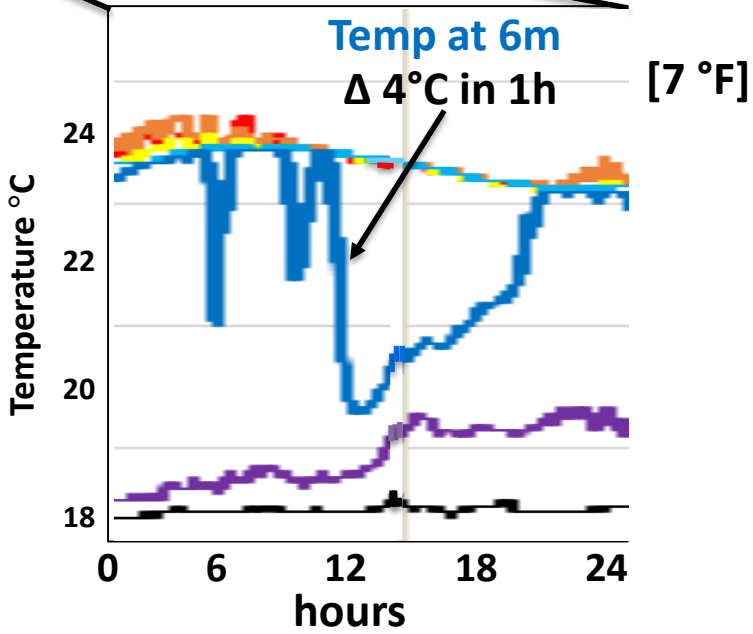
ALSO …Internal waves along the thermocline



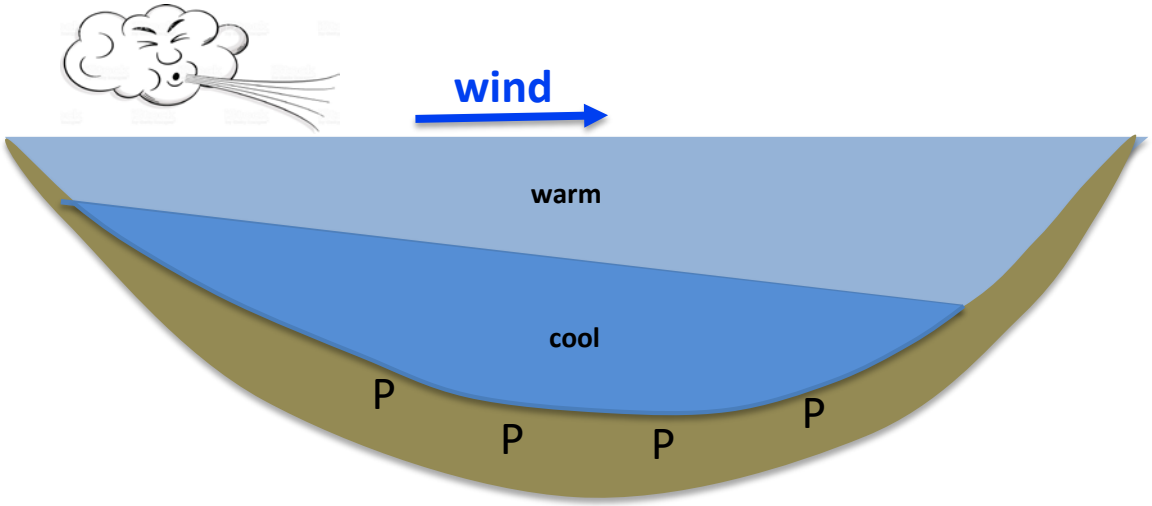
Internal waves along the thermocline

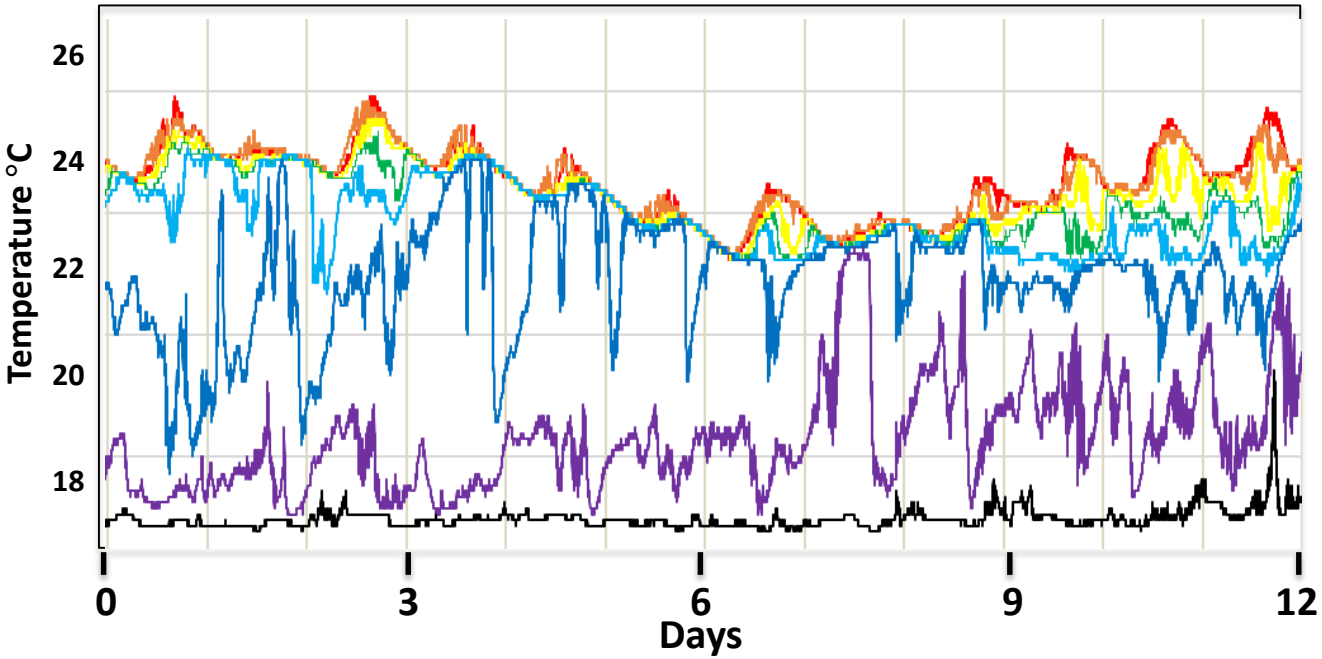




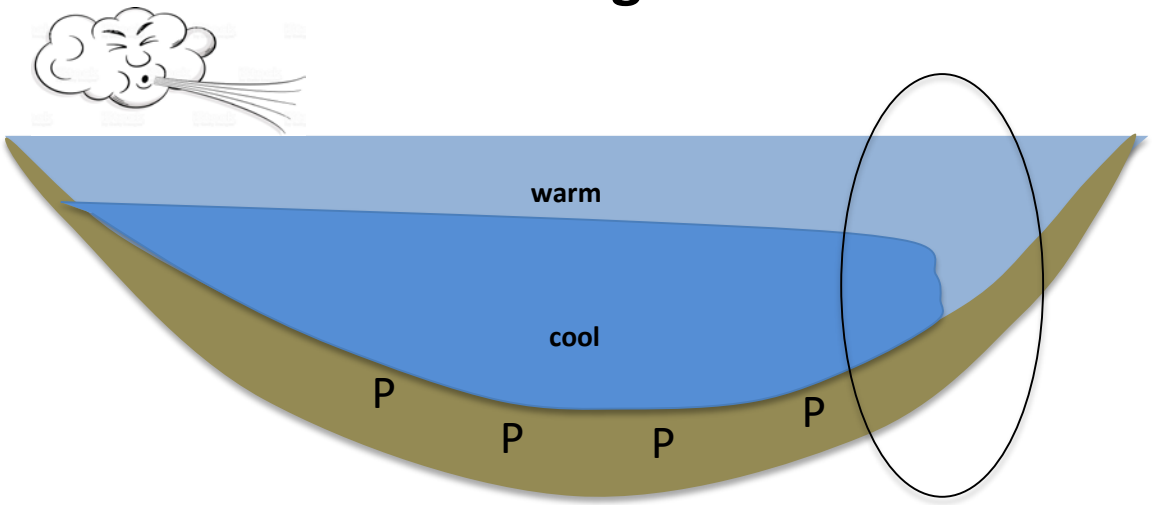


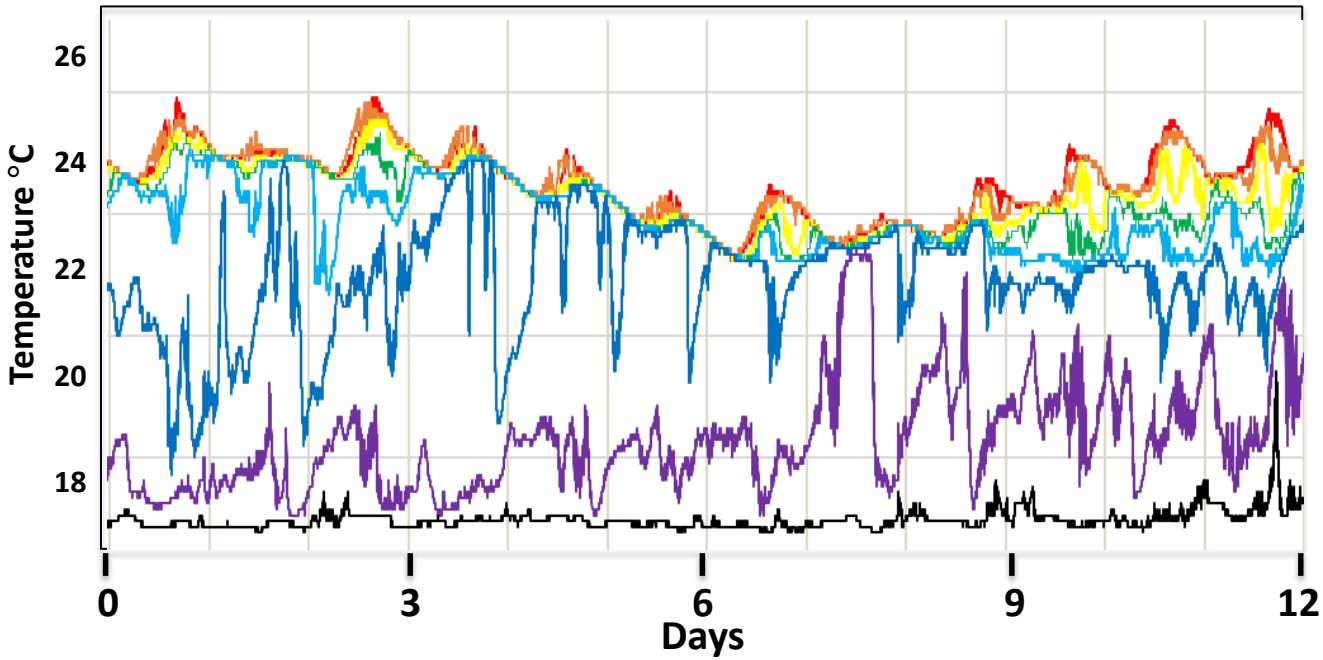
Internal waves along the thermocline



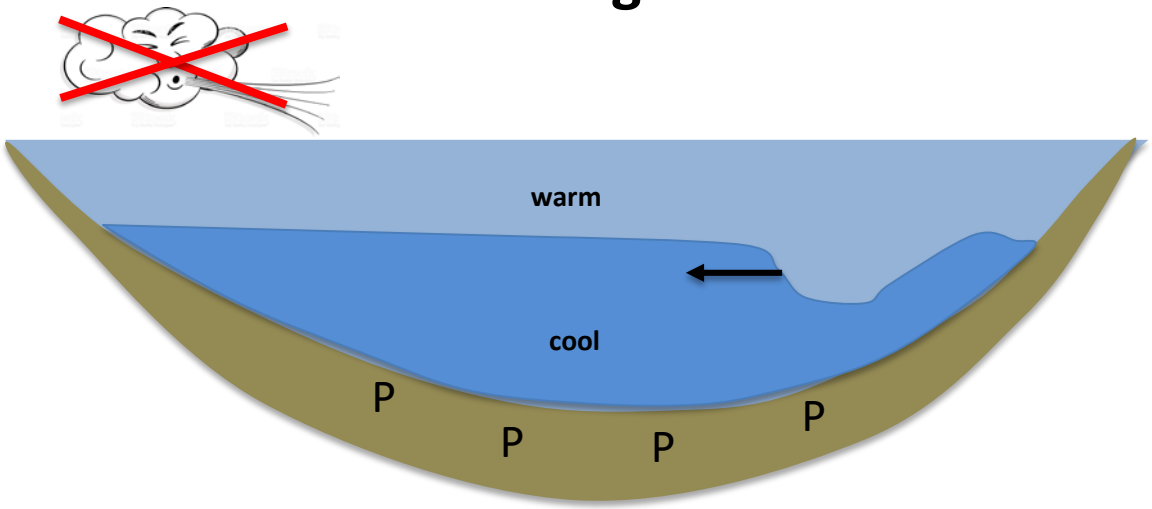


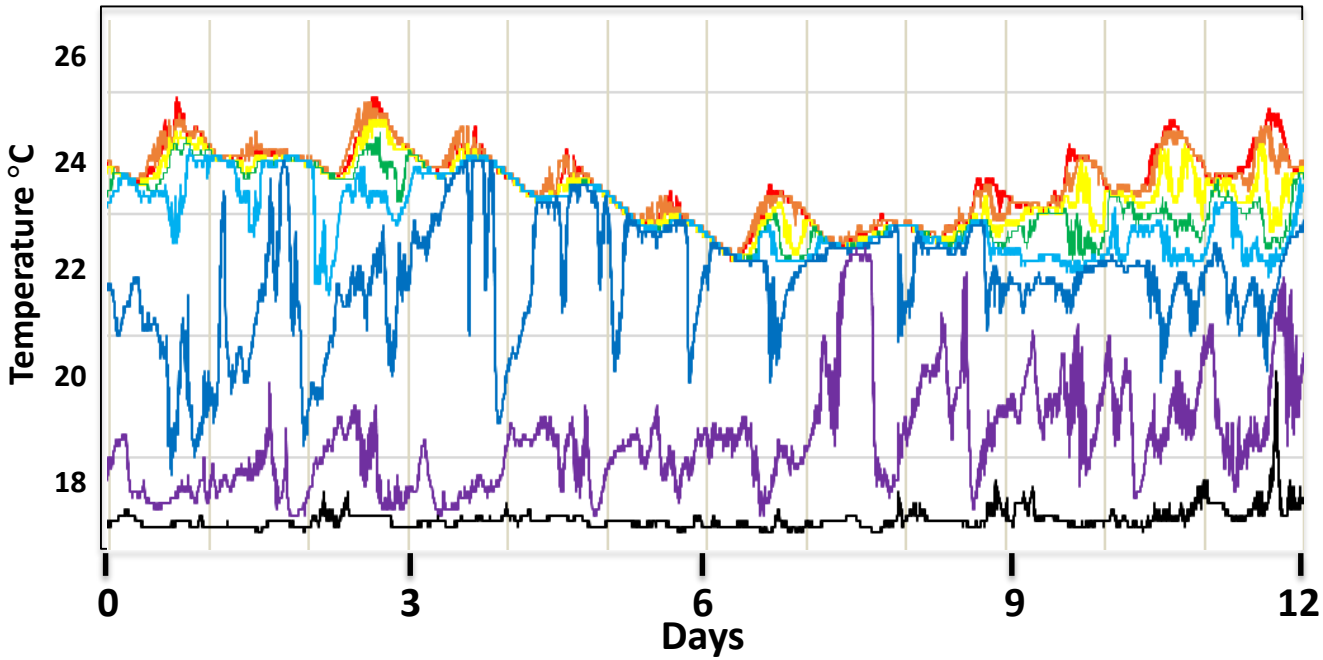
Internal waves along the thermocline



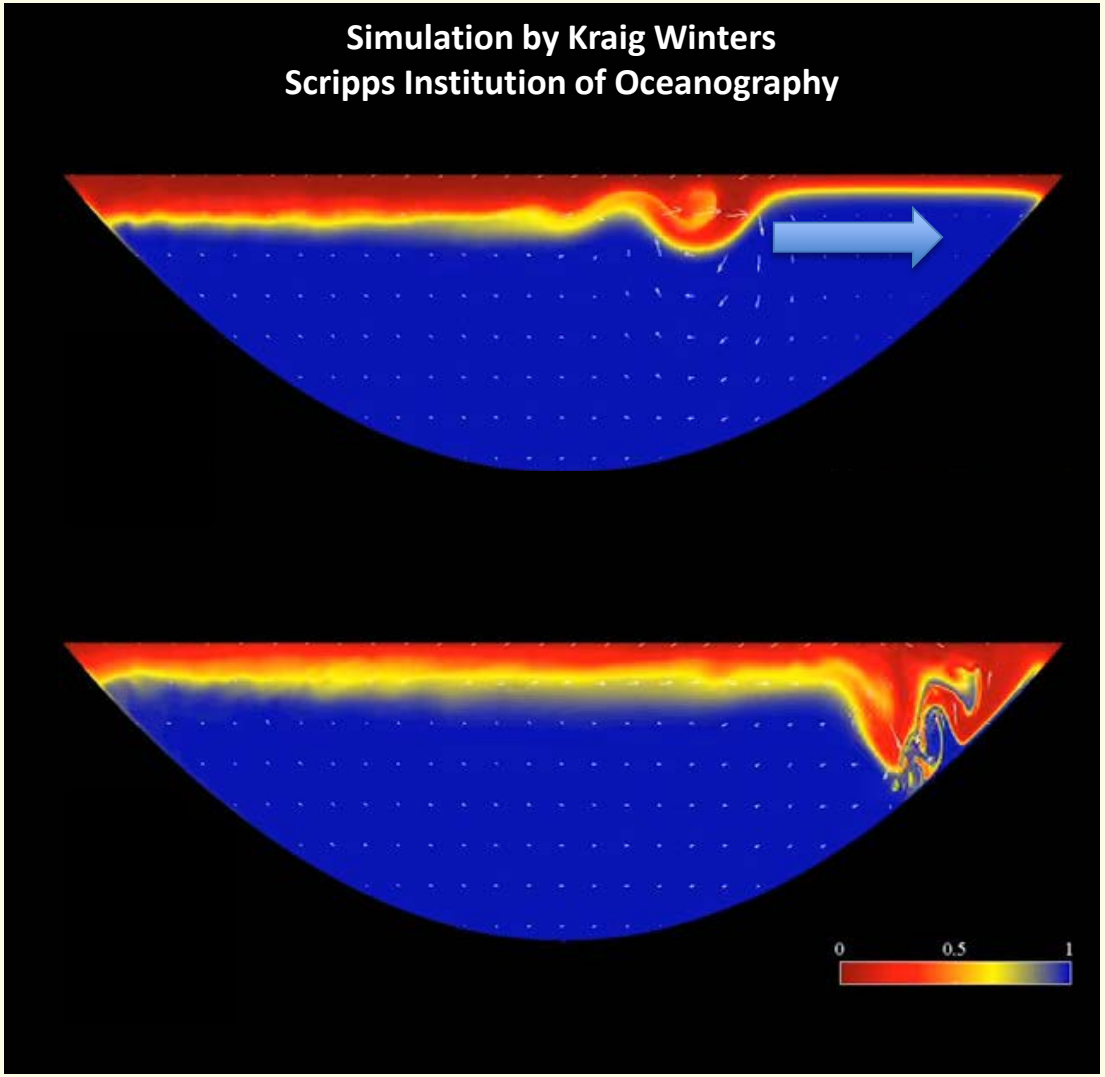


Internal waves along the thermocline

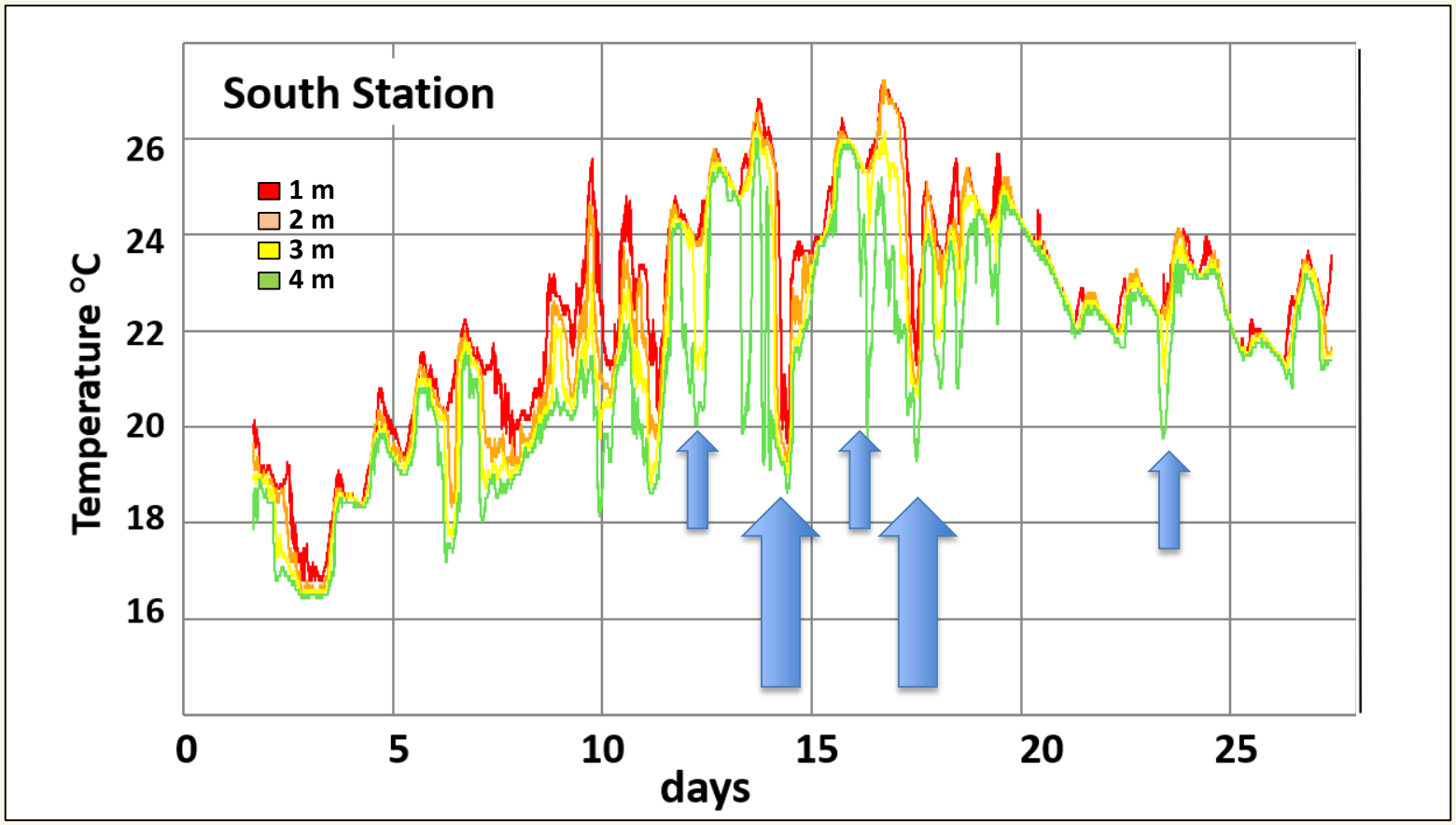




Internal waves hit the slope at the end of the lake → turbulent mixing

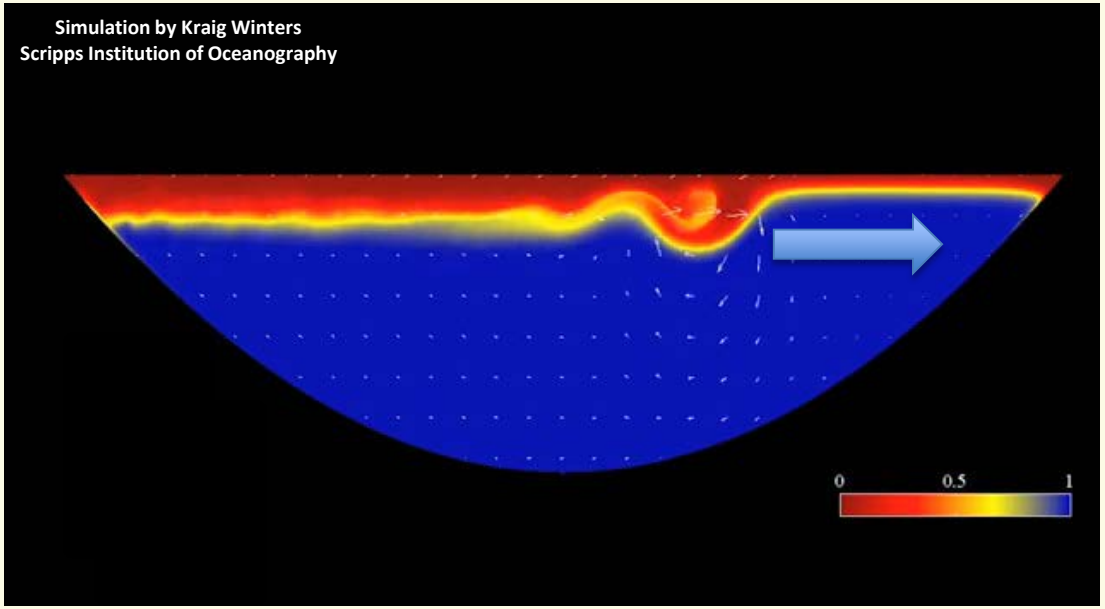


https://www.youtube.com/watch?v=xoROLW5D2X0&feature=youtu.be



Multiple upwellings and internal waves bringin cool nutrient-rich bottom water to illuminated surface

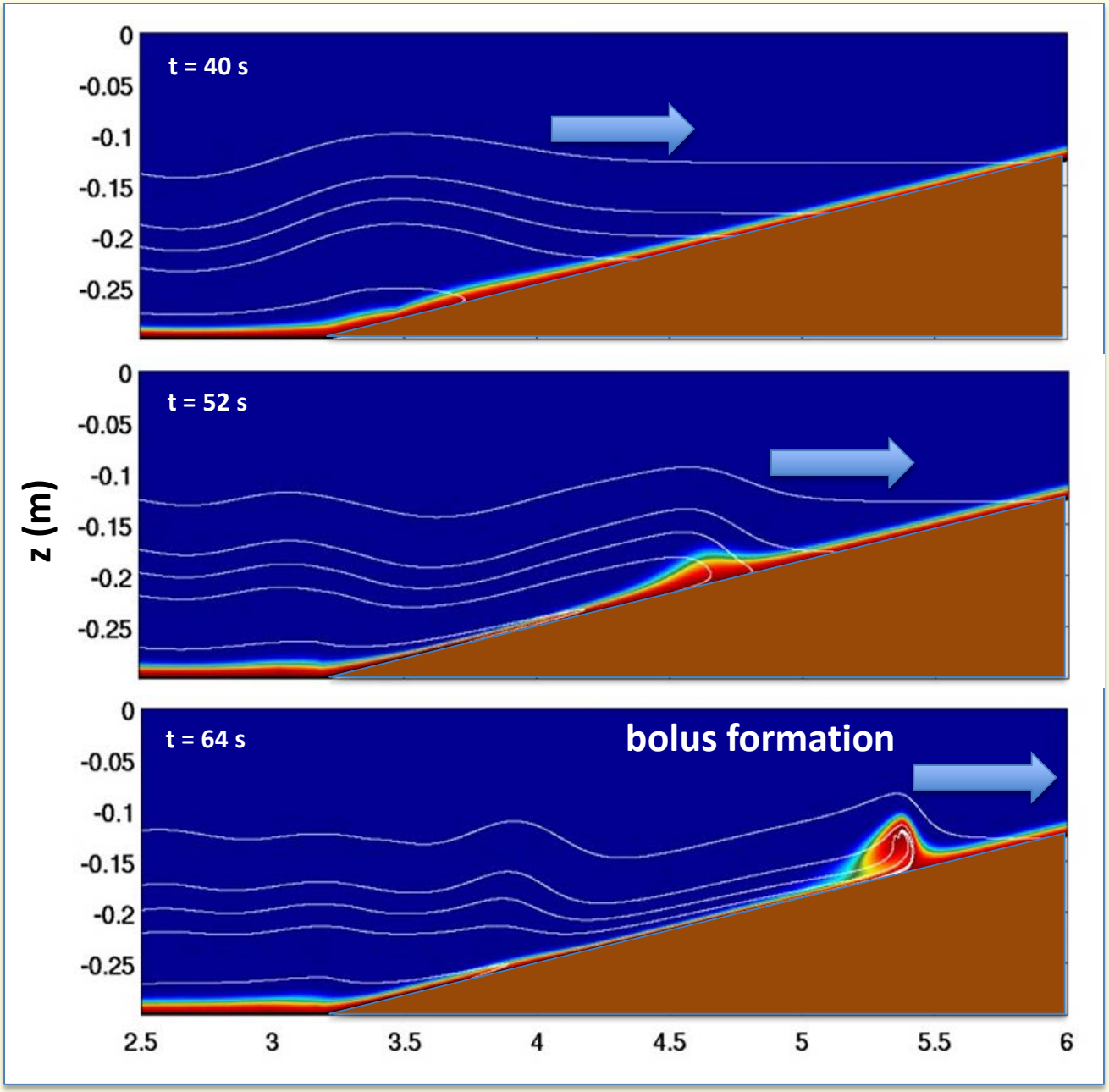
Internal waves hit the slope at the end of the lake → other mixing?



http://loyalkng.com/2010/06/14/the-shorebreak-art-of-clark-little-photography-inside-30ft-40ft-waves-surfs-up/

Clark Little Photography

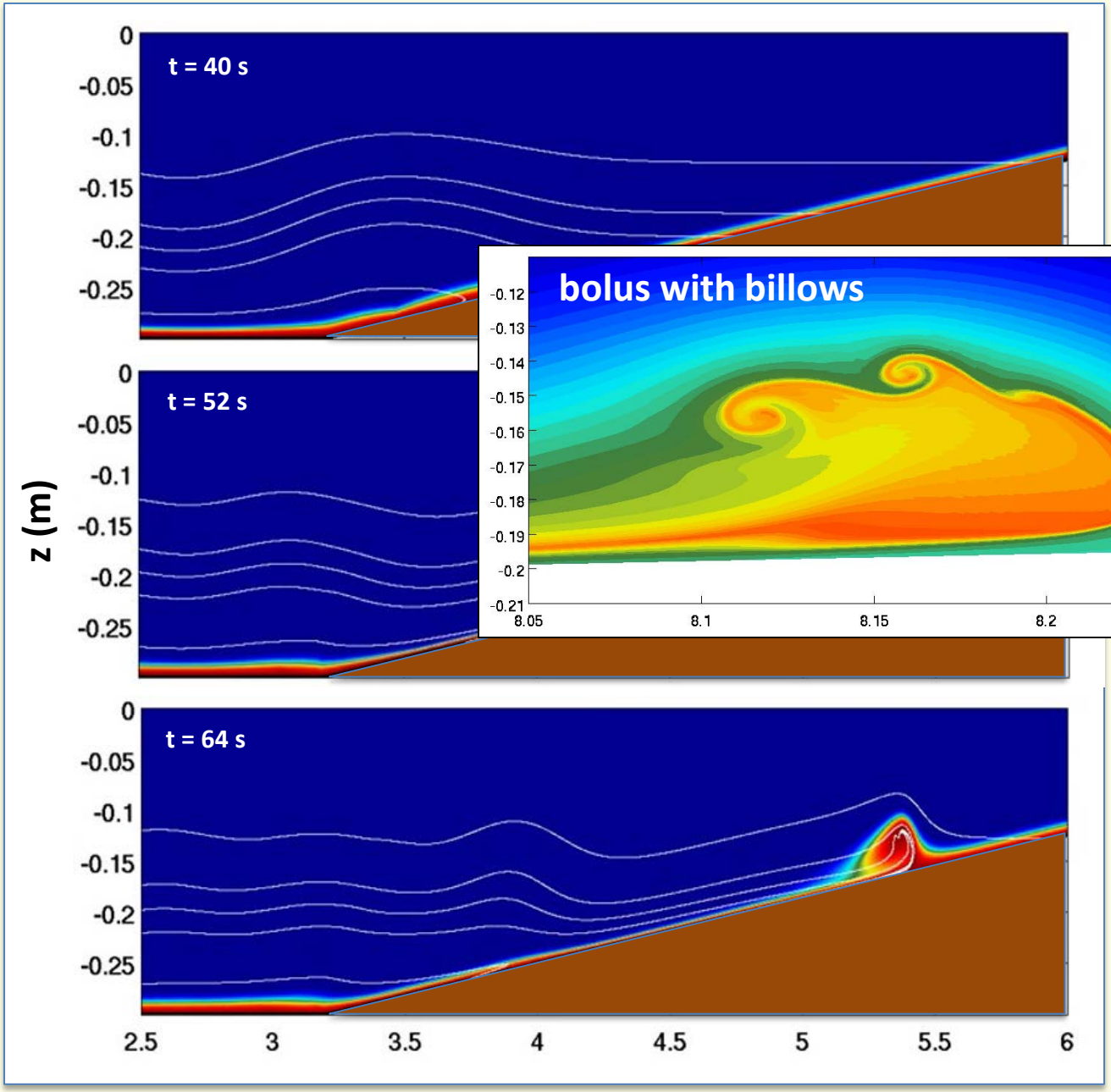
Wave steepens and draws up nutrient rich boundary layer water and sediment



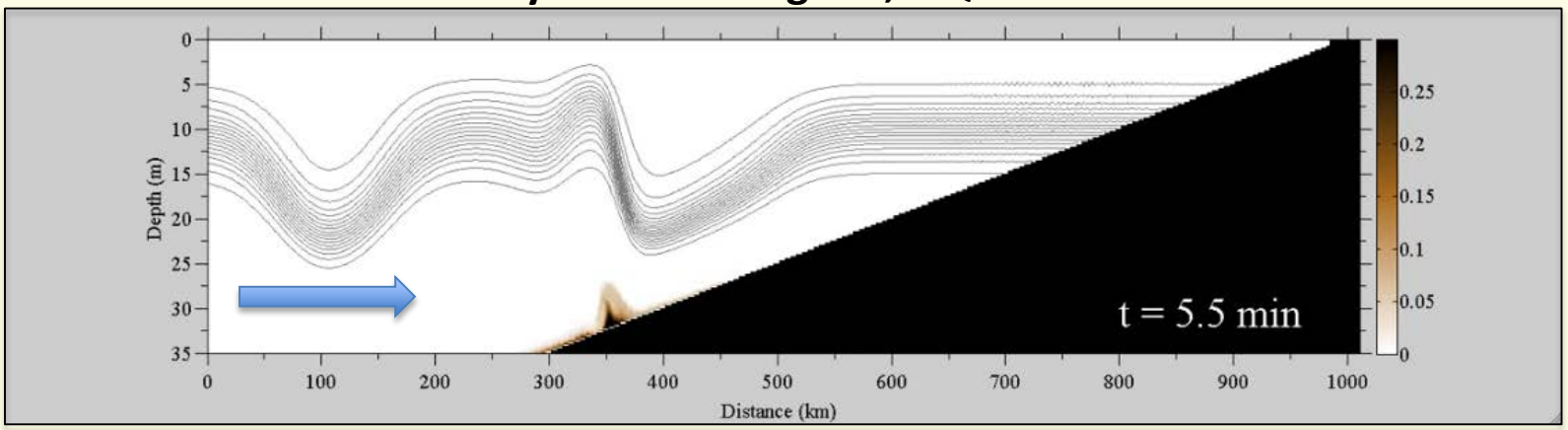
Marek Stastna

With mixing …

Marek Stastna



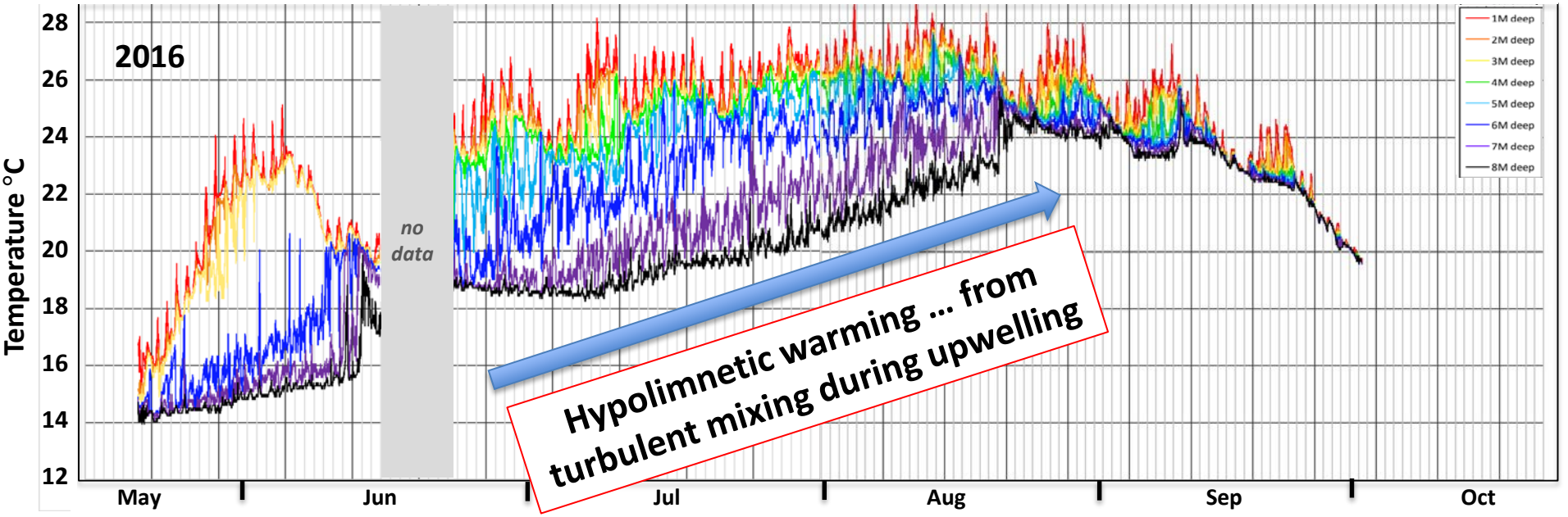
Simulation of internal waves bringing up sediment
by Daniel Bourgault, UQAR

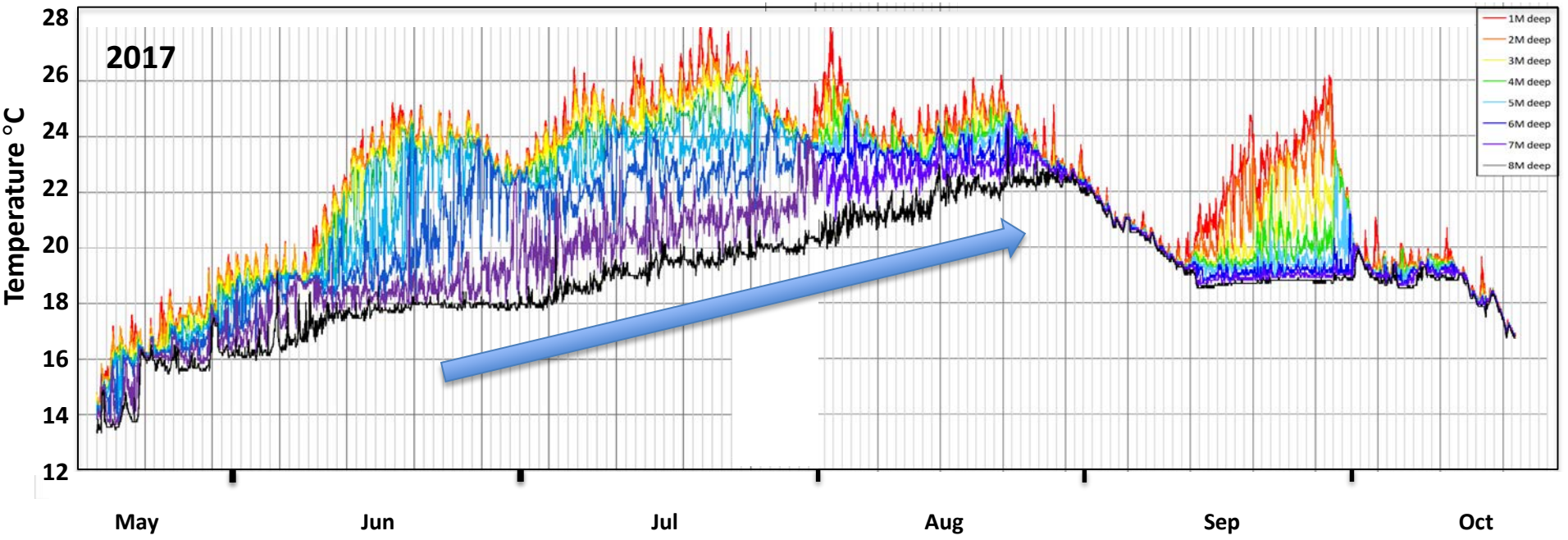


https://www.youtube.com/watch?v=VbNbxBIrsXY

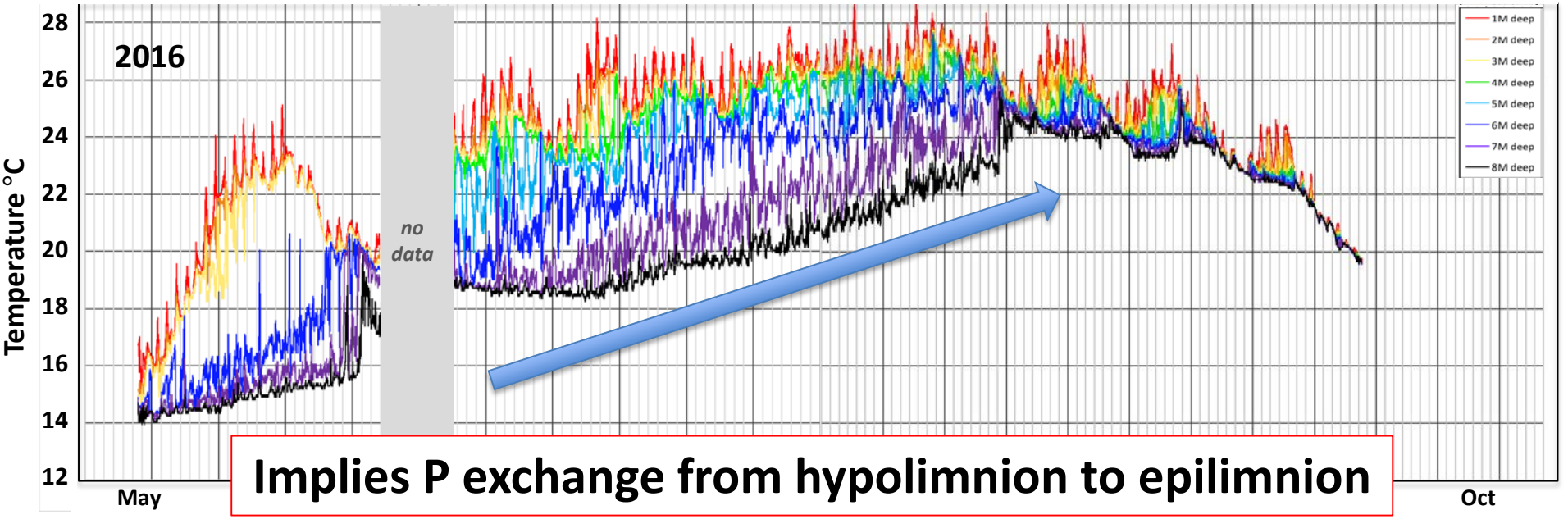
I didn't show this slide but the link is to a nice video that shows bolus formation as interal wave climbs slope at end of lake

Evidence for exchange between epilimnion and hypolimnion

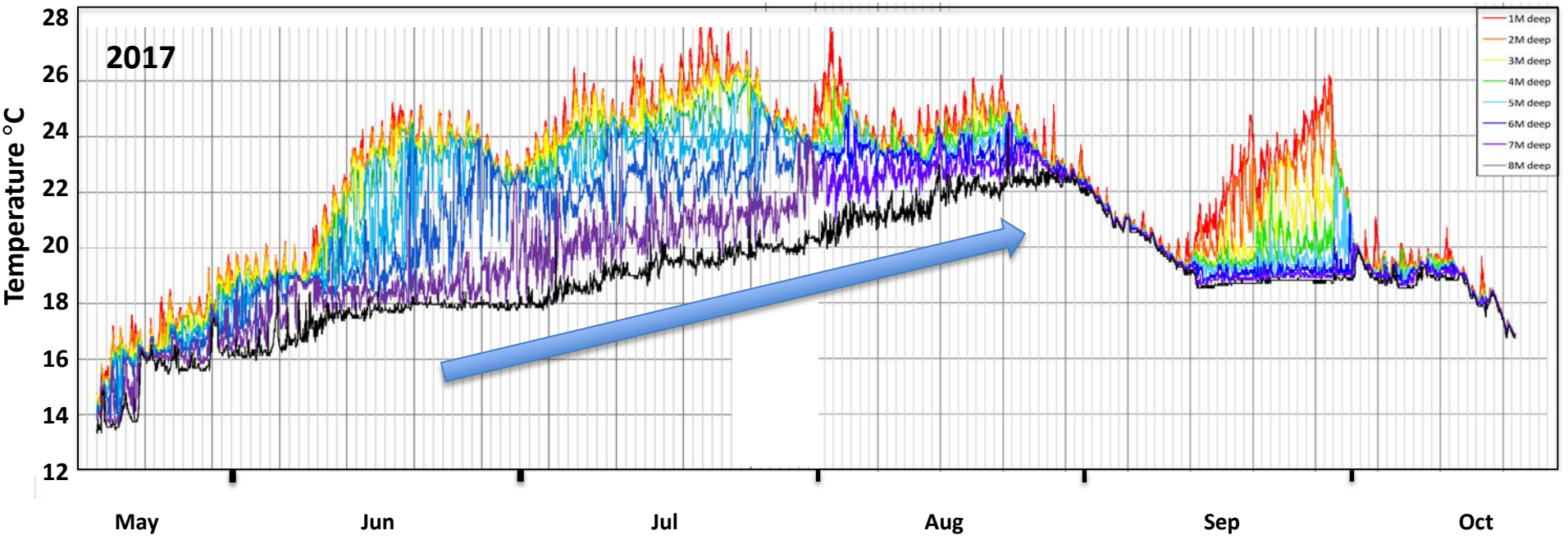


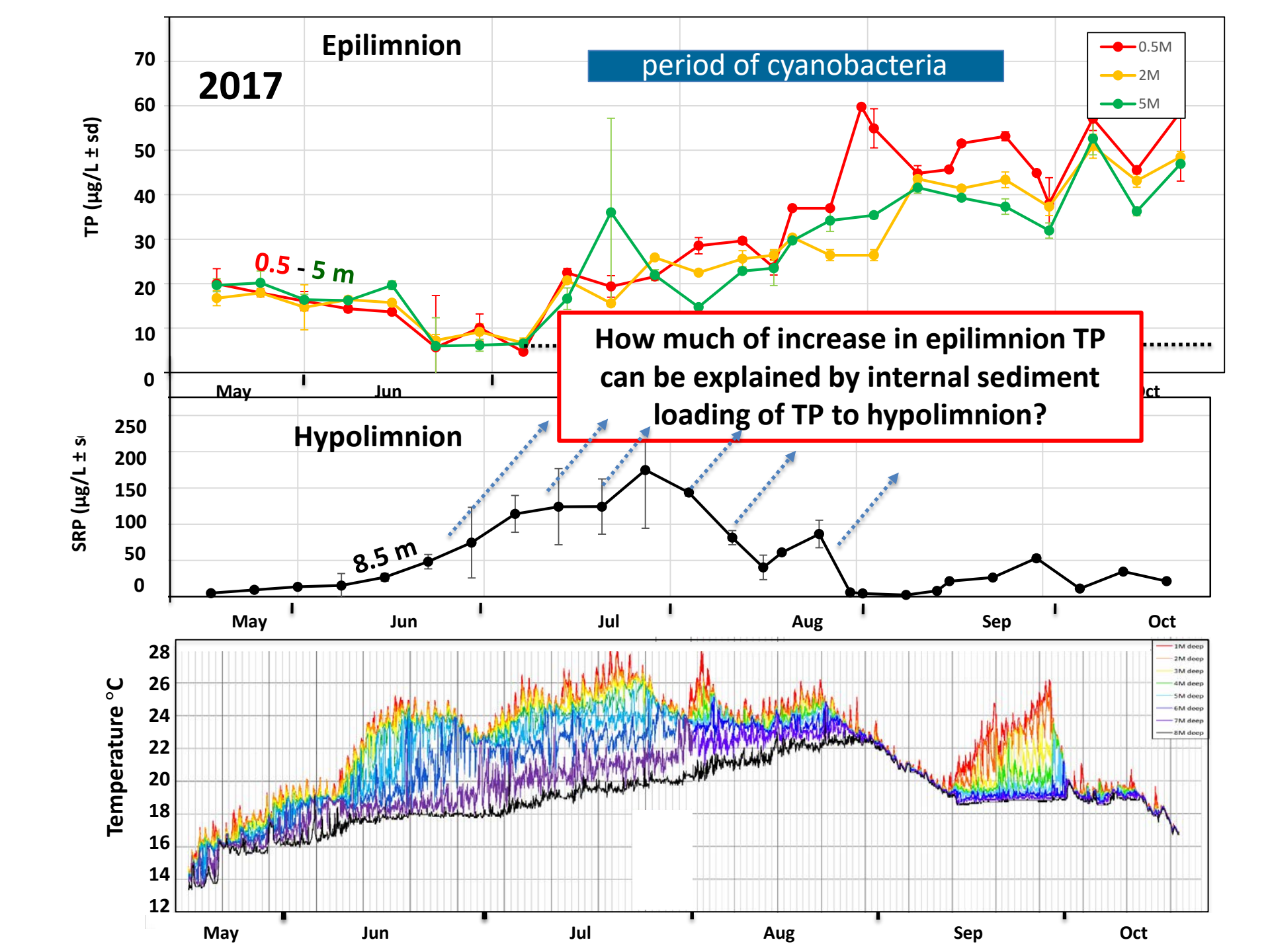


Evidence for exchange between epilimnion and hypolimnion

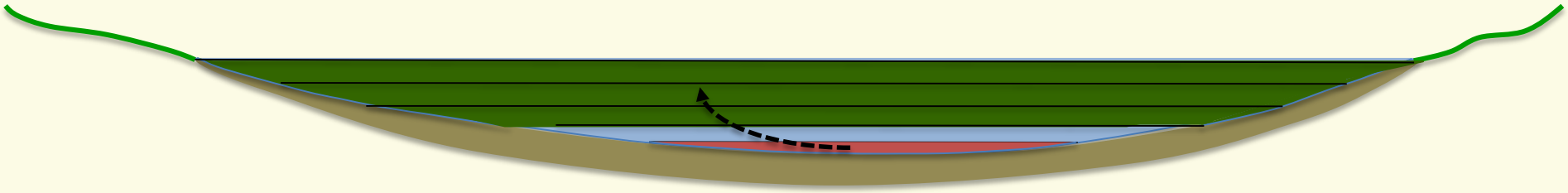


Implies P exchange from hypolimnion to epilimnion




Epilimnion
2017
period of cyanobacteria
0.5M
2M
5M
TP (µg/L ± sd)
0.5 - 5 m
How much of increase in epilimnion TP can be explained by internal sediment loading of TP to hypolimnion?
Hypolimnion
SRP (µg/L ± sd)
8.5 m
Temperature °C
May
Jun
Jul
Aug
Sep
Oct

How much of TP increase in epilimnion can be attributed to P release from sediments into hypolimnion?



Calculation:

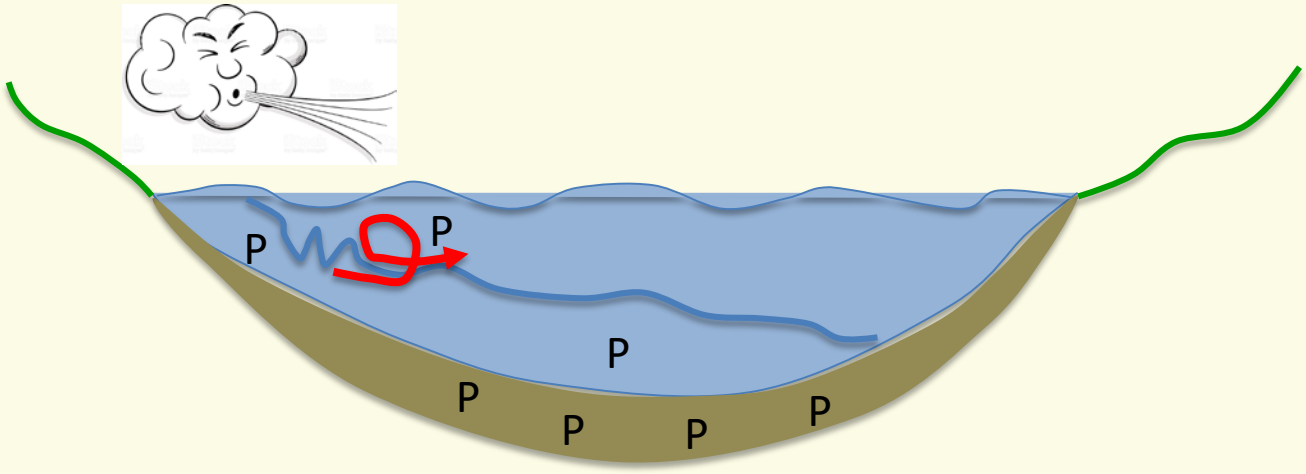
1) Average *rate of increase* in TP mass in hypolimnion
2) Convert to total TP mass increase
3) Compare with TP mass increase in epilimnion

How much of TP increase in epilimnion can be attributed to P release from sediments into hypolimnion?

Internal loading (lake-sediment release of P)

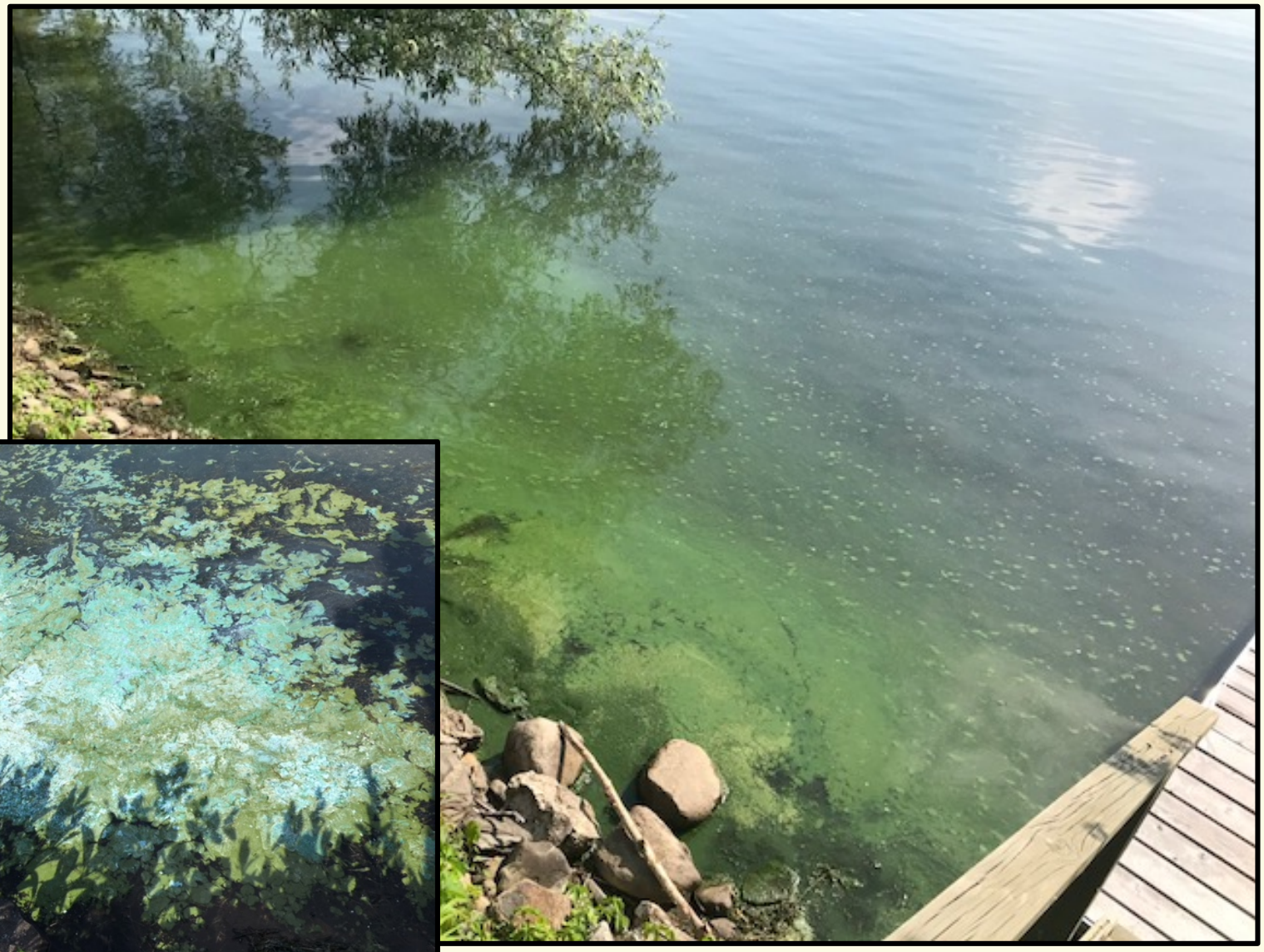
2016 – *a dry year* - Between 68% and 100% of HAB phosphorus

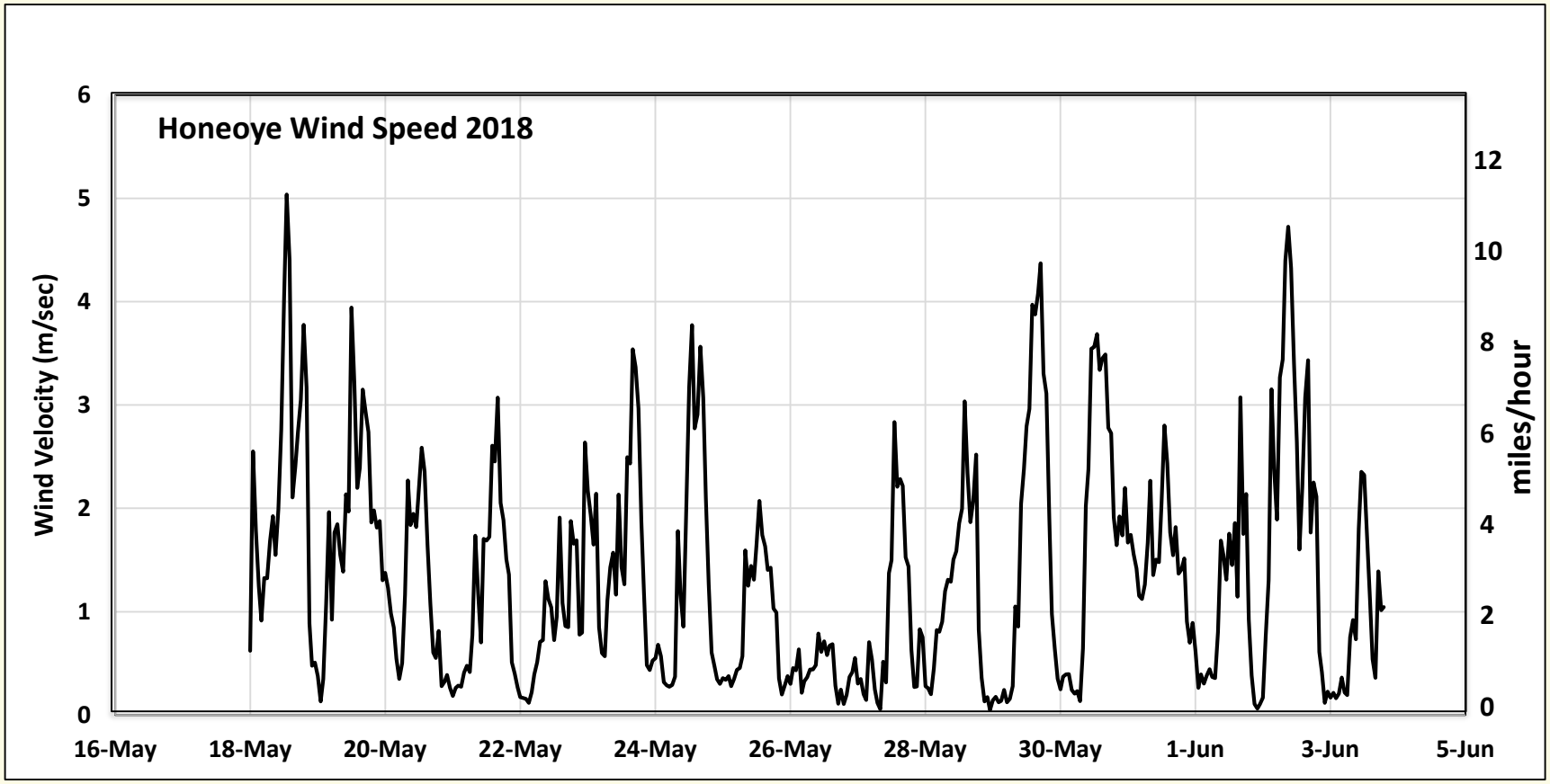
2017 – *a wet year* - Between 41% and 78% of HAB phosphorus explained by P release from sediments

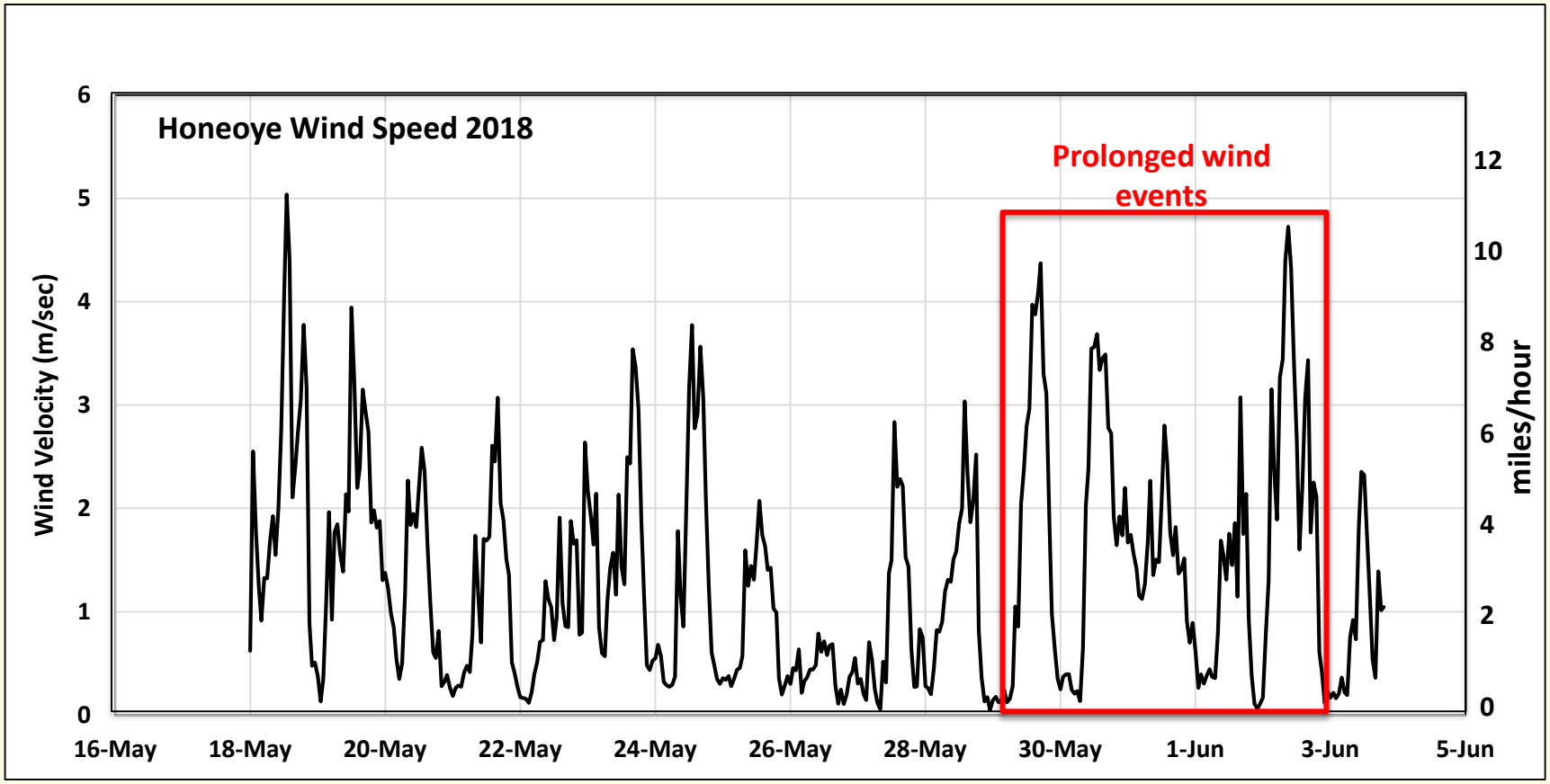


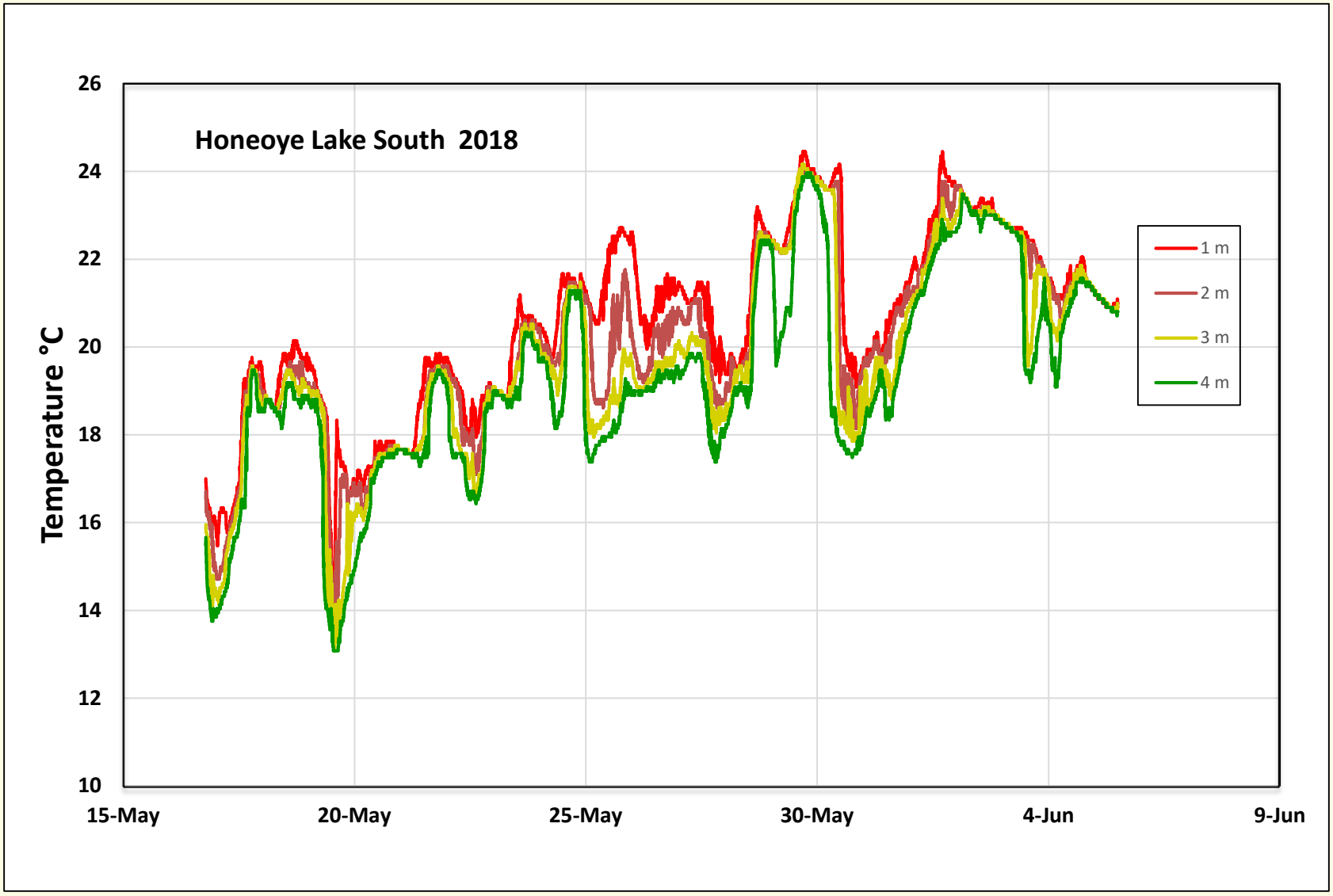
Honeoye Lake cyanobacteria Bloom

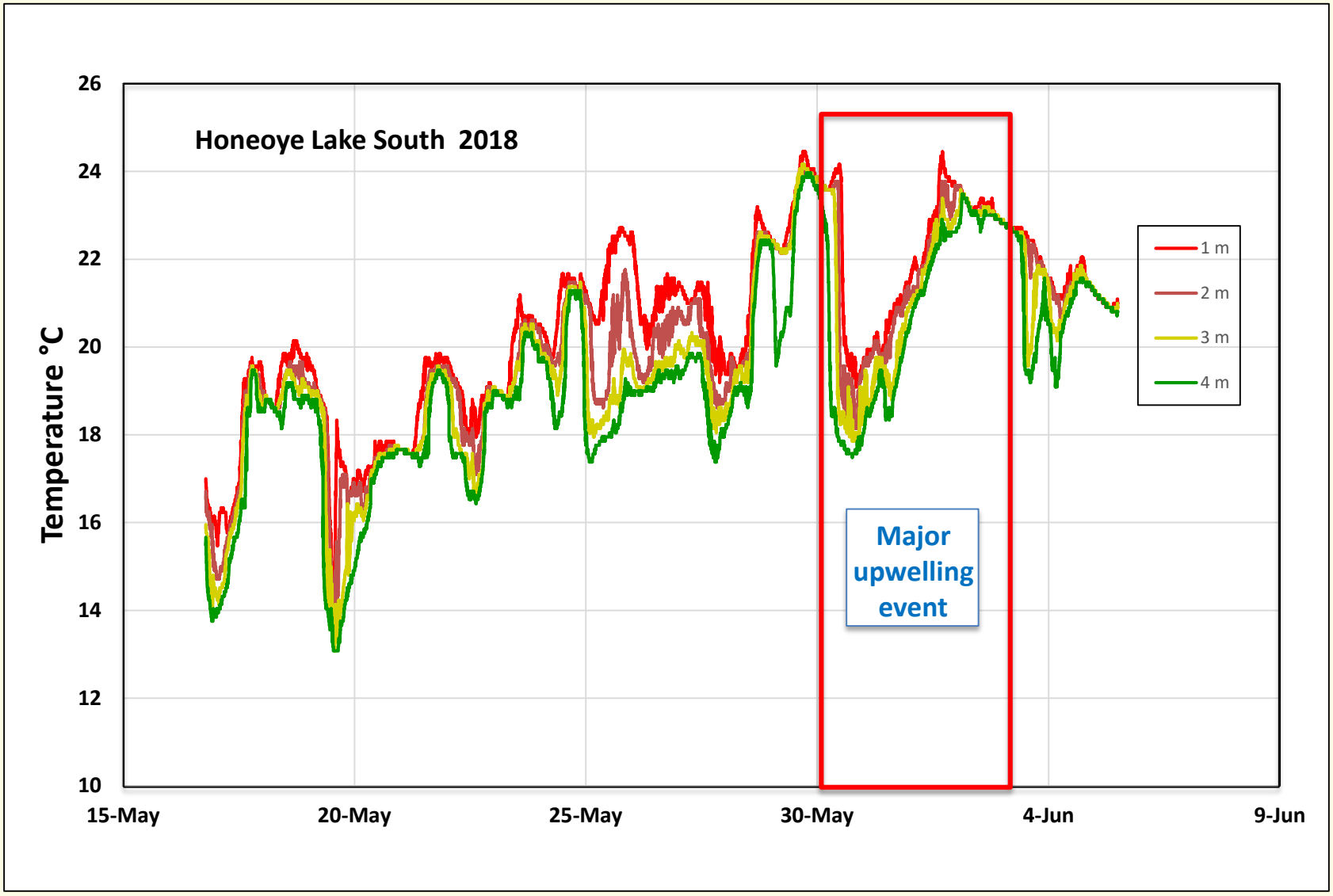
Thursday
7 June 2018




Honeoye Wind Speed 2018
Wind Velocity (m/sec)
miles/hour
0
1
2
3
4
5
6
0
2
4
6
8
10
12
16-May
18-May
20-May
22-May
24-May
26-May
28-May
30-May
1-Jun
3-Jun
5-Jun


Honeoye Wind Speed 2018
Prolonged wind events
Wind Velocity (m/sec)
miles/hour
0
1
2
3
4
5
6
0
2
4
6
8
10
12
16-May
18-May
20-May
22-May
24-May
26-May
28-May
30-May
1-Jun
3-Jun
5-Jun


Honeoye Lake South 2018
Temperature °C
26
24
22
20
18
16
14
12
10
15-May
20-May
25-May
30-May
4-Jun
9-Jun
1 m
2 m
3 m
4 m


Honeoye Lake South 2018
Temperature °C
26
24
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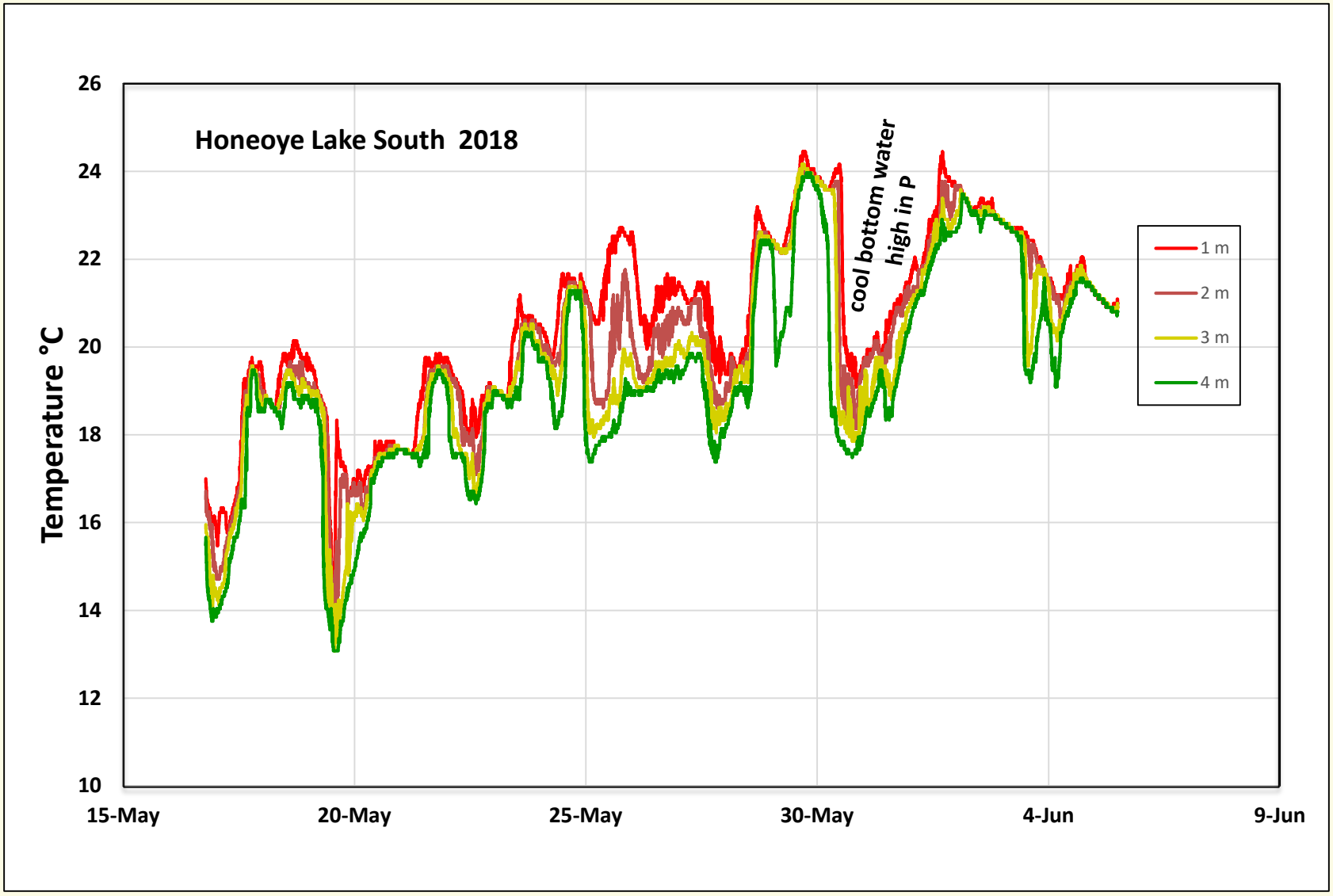
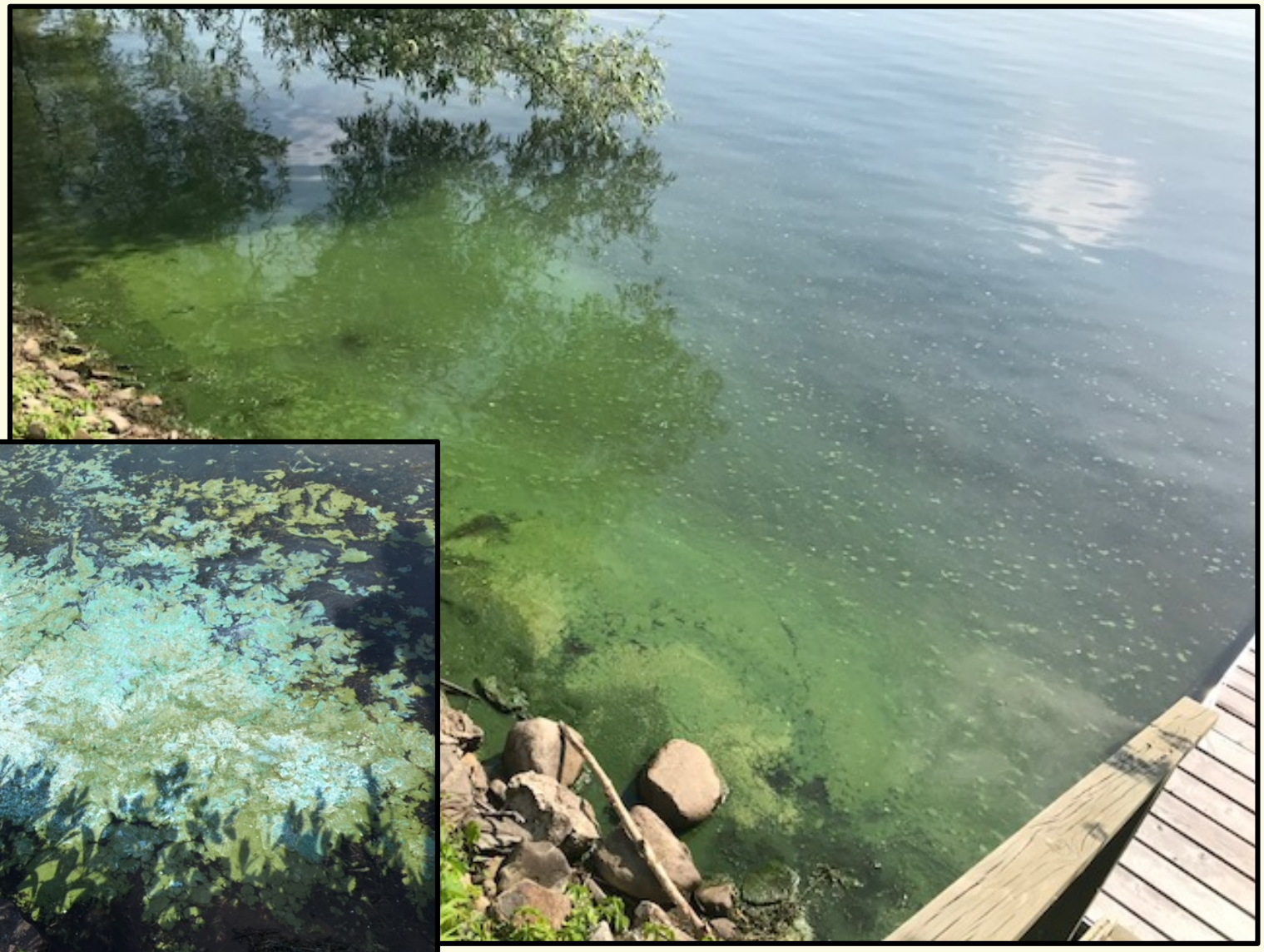
20
18
16
14
12
10
15-May
20-May
25-May
30-May
4-Jun
9-Jun
1 m
2 m
3 m
4 m
Major upwelling event


Honeoye Lake South 2018
Temperature °C
26
24
22
20
18
16
14
12
10
15-May
20-May
25-May
30-May
4-Jun
9-Jun
cool bottom water
high in P
1 m
2 m
3 m
4 m

Honeoye Lake cyanobacteria Bloom

Thursday
7 June 2018



Next steps:

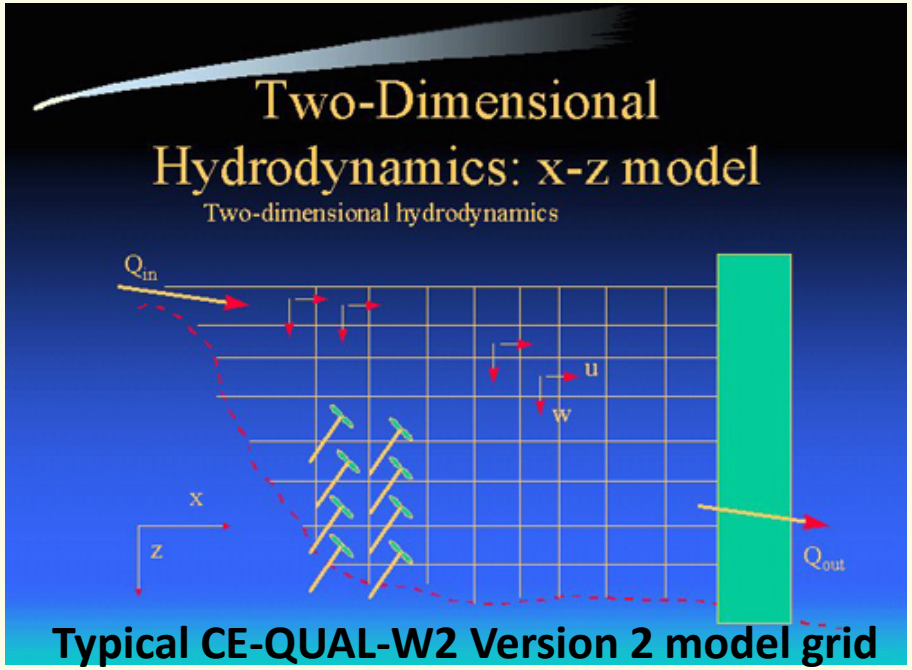
Research Associate on project:
Allie King – hydrodynamics PhD

Consultant on project:
Sue O'Donnell, UFI
***CE-QUAL-W2* expert**

Model of water-column mixing and nutrient loading – *CE-QUAL-W2* (driven by weather data)

Get model to "do what the lake does" in terms of seasonal nutrient and HAB concentrations

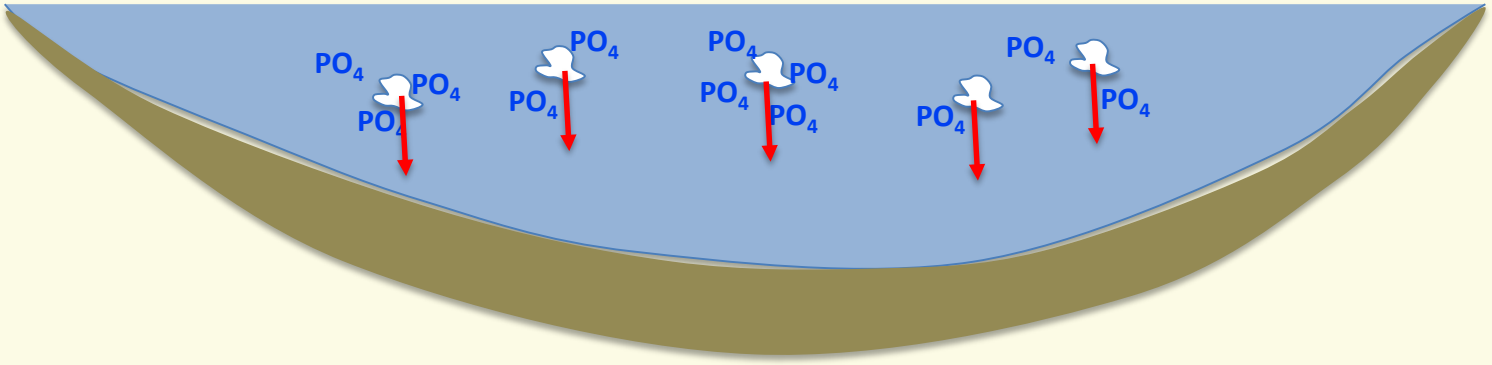
Use model to try out different management options to see what works to control HABs



Typical CE-QUAL-W2 Version 2 model grid

Management options for internal loading:

1) Apply Alum or Phoslock
   – particles bind phosphate in water and carries it to lake bottom

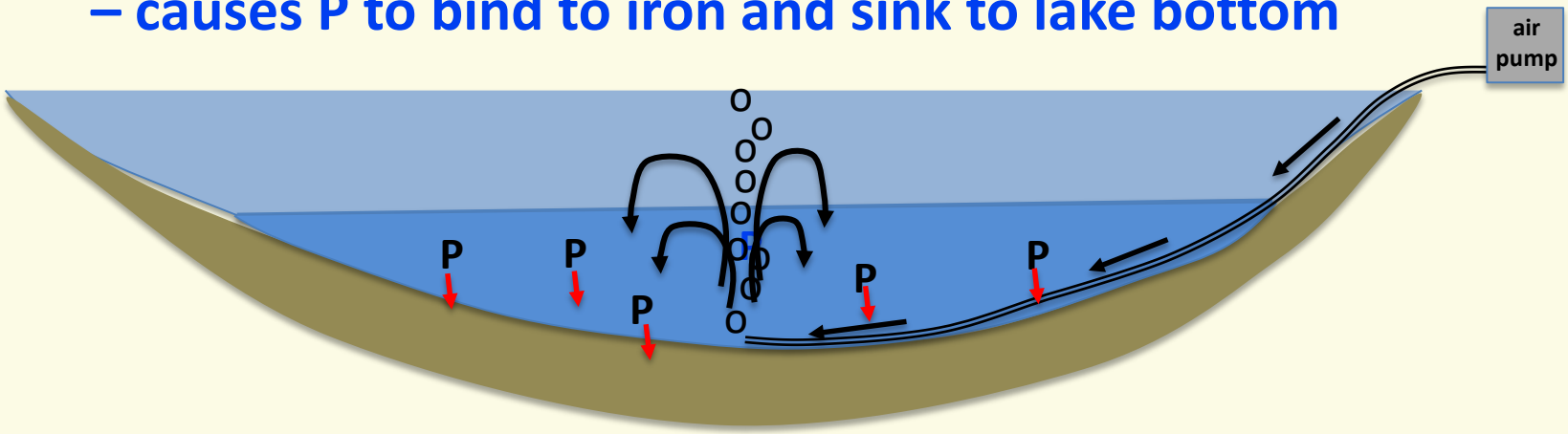


Expensive – requires repeated application – current strict gov't regulation

Management options for internal loading:

1) Apply Alum or Phoslock
   – binds phosphate in water and carries it to lake bottom

2) Bubble bottom water with air to introduce oxygen
   – causes P to bind to iron and sink to lake bottom



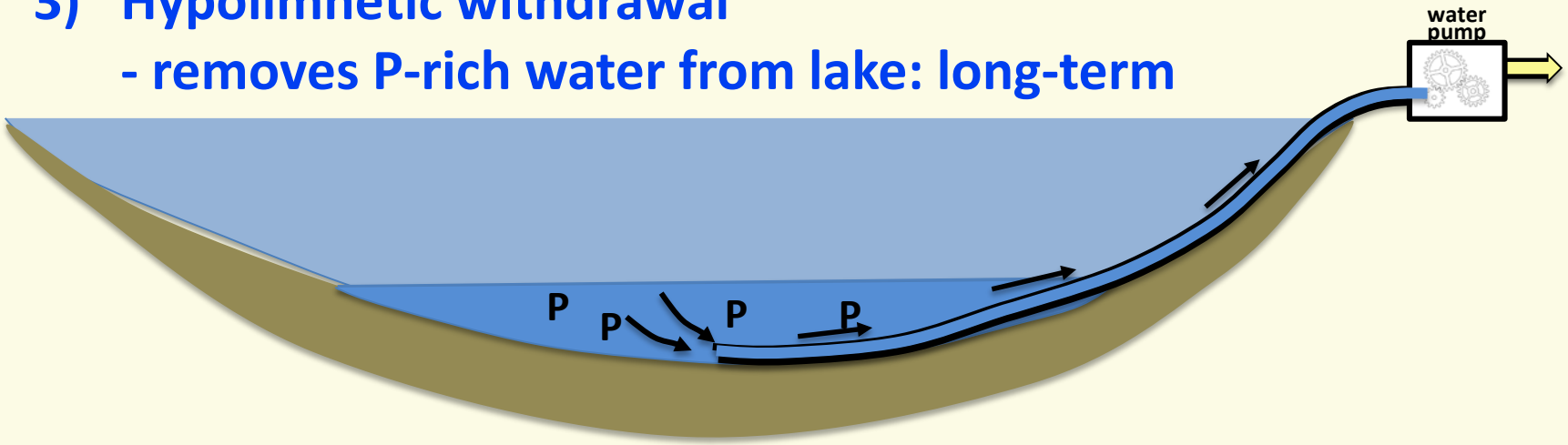
Also de-stratifies lake with potential to bring P to surface, if iron-binding is ineffective

Management options for internal loading:

1) Apply Alum or Phoslock
   – binds phosphate in water and carries it to lake bottom

2) Bubble bottom water with air to introduce oxygen
   – causes P to bind to iron and sink to lake bottom

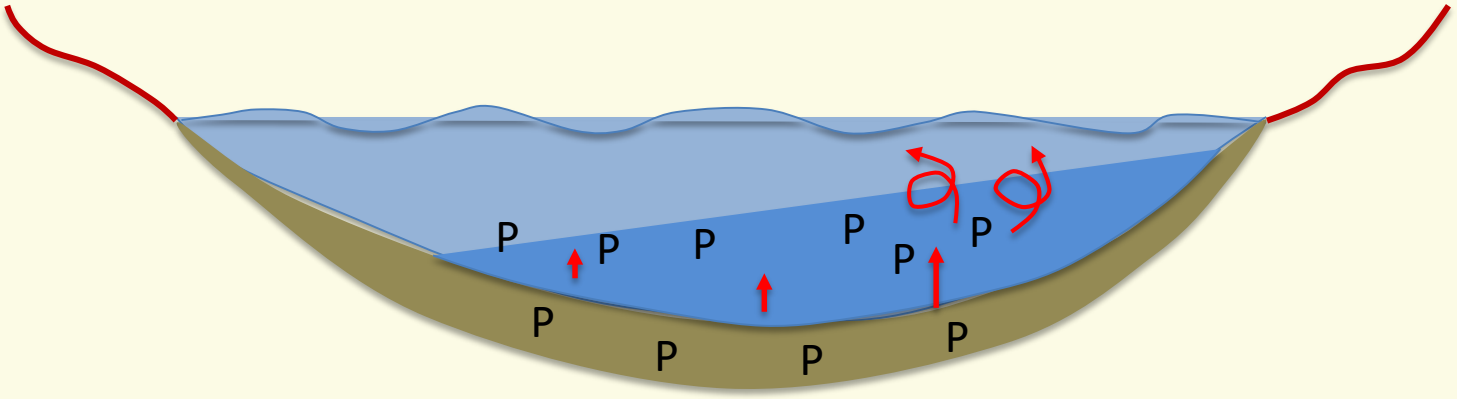
3) Hypolimnetic withdrawal
   - removes P-rich water from lake: long-term



Where does the P-rich water go?
Also de-stratifies lake with potential to bring P to surface, if iron-binding is ineffective

Honeoye is Special

Honeoye is Special



AND … Thanks!

Honeoye Lake internal loading study

Dorothy and Terry Gronwall

Allie King & Bruce Gillman

Elizabeth Yardley & Roxanne Razavi

Max Cassell

Ludi Sanchez Arias

Emma Dietz & Corinne Klohmann

Marek Stastna

USDA National Institute of Food and Agriculture

Cornell University
Atkinson Center for a Sustainable Future

Cornell University Founded A.D. 1865

FingerLakes Community College

Honeoye Lake Watershed Task Force

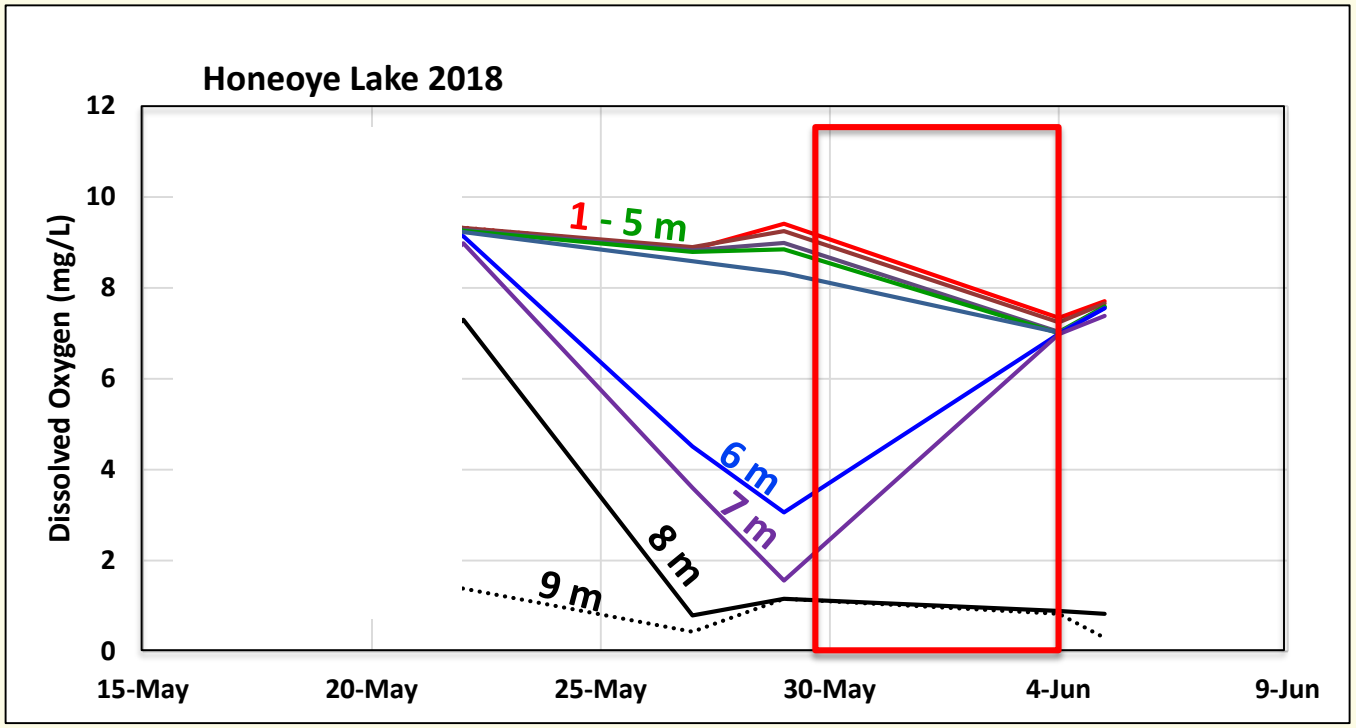
Finger Lakes Institute
Hobart and William Smith Colleges

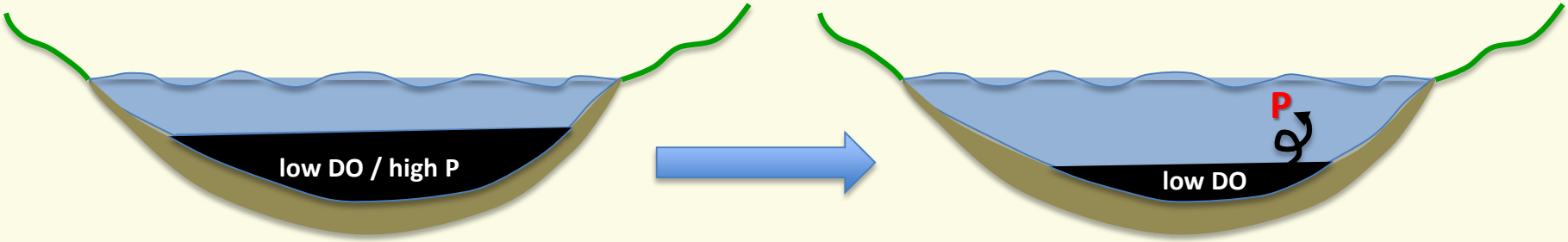
ESF

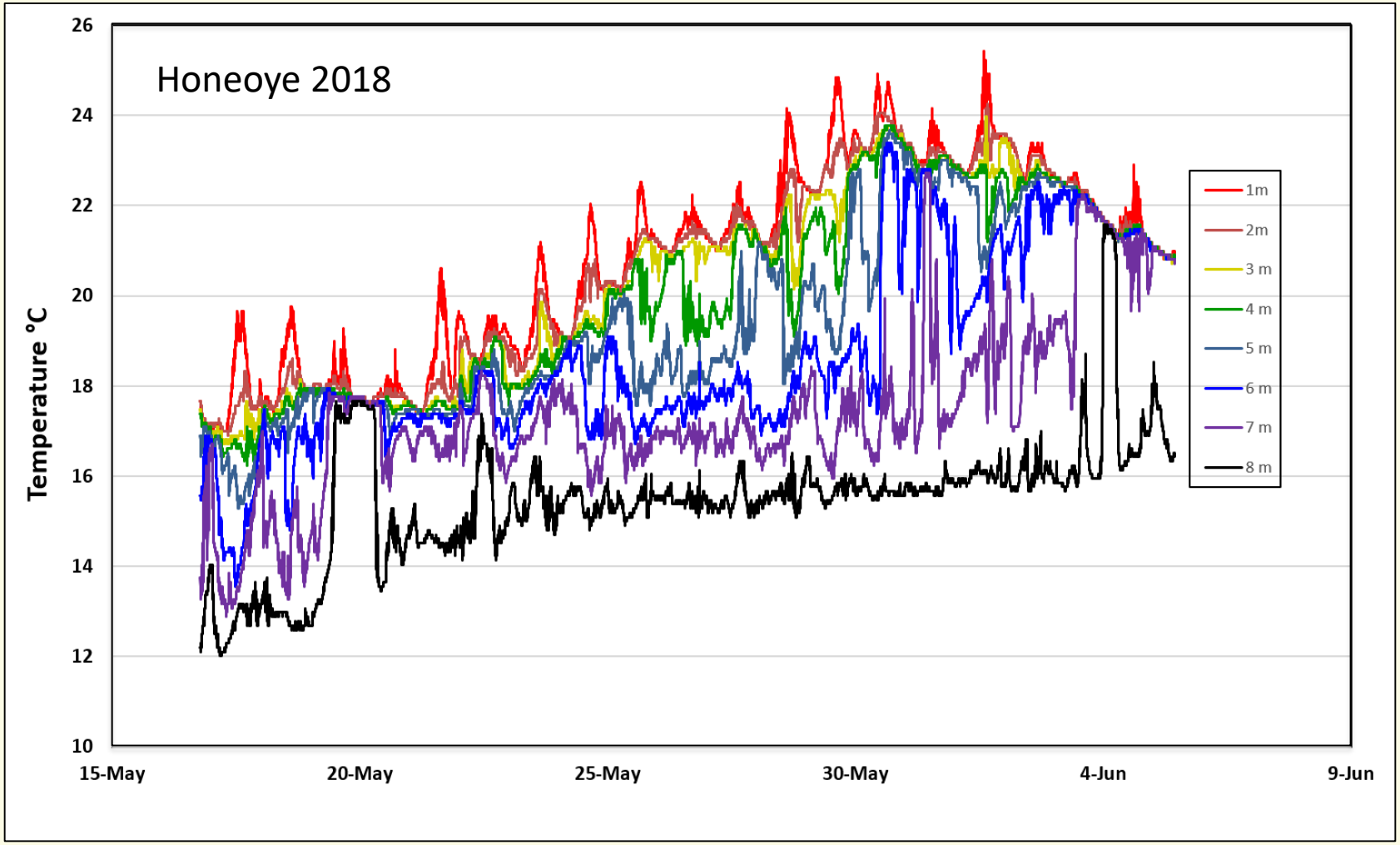
University of Waterloo

END

Upwelling event mixed deep water up to surface






Honeoye 2018
Temperature °C
26
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15-May
20-May
25-May
30-May
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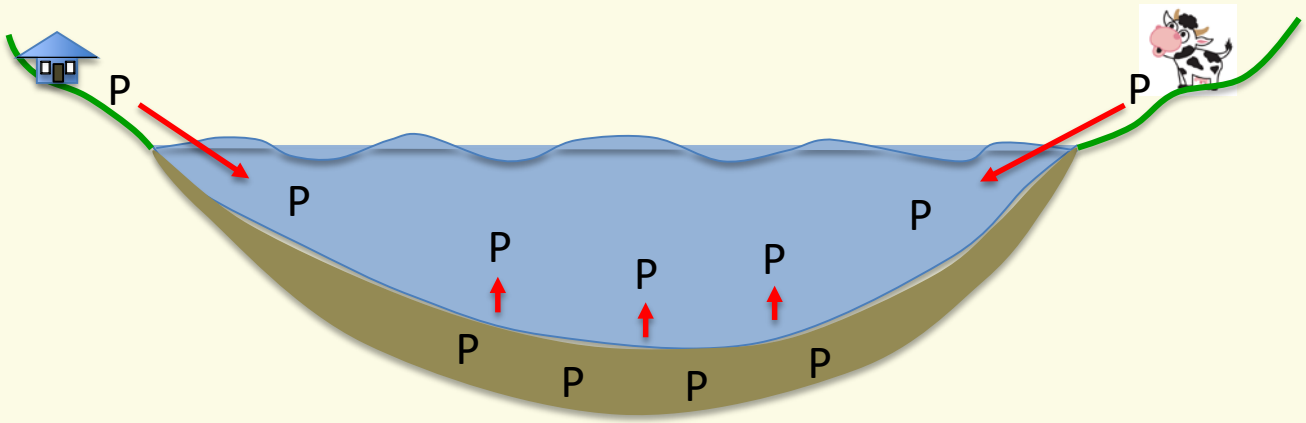
9-Jun
1m
2m
3 m
4 m
5 m
6 m
7 m
8 m

What about other lakes?
How important will internal loading be?

All lakes have *both* <u>external</u> and <u>internal</u> loading of nutrients.
Relative importance will vary.



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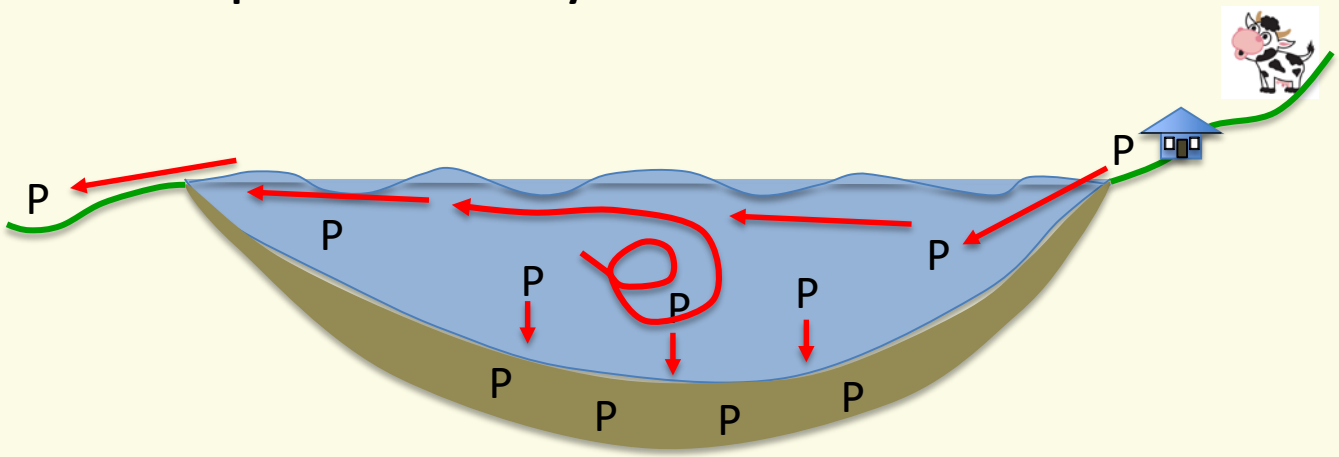


Depends on amount of past external nutrient loading.

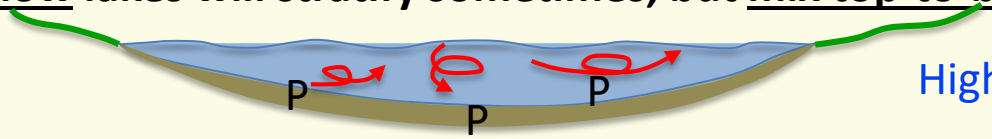
How much of that was retained in the lake sediments vs. being <u>washed out</u>.

Honeoye Lake water retention time in summer is about 1 year, so not much washes out.

What about other lakes?
How important will internal loading be?

Summer temperature stratification varies with lake depth.

Really <u>shallow</u> lakes will stratify sometimes, but <u>mix top-to-bottom</u> frequently.



High chance for internal loading

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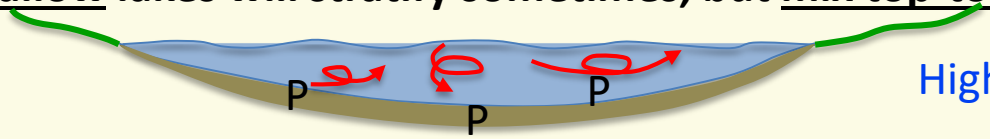
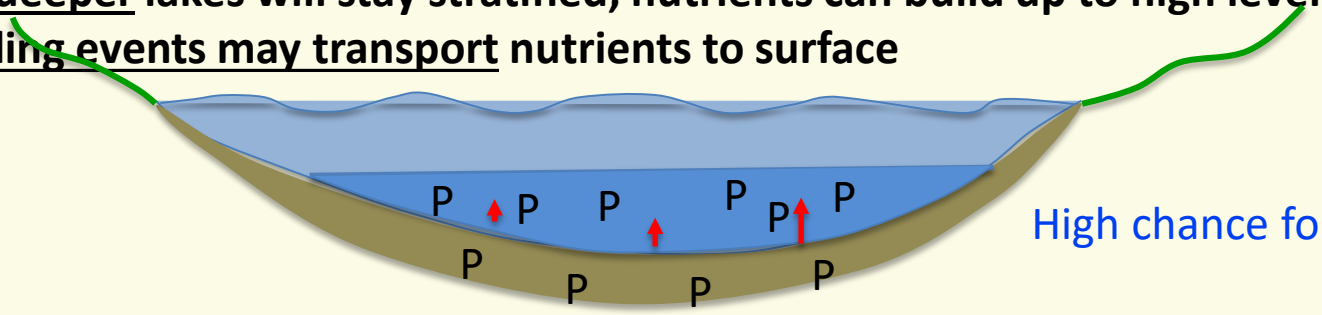


High chance for internal loading

<u>Slightly deeper</u> lakes will stay stratified, nutrients can build up to high levels in bottom water.

<u>upwelling events may transport</u> nutrients to surface



High chance for internal loading

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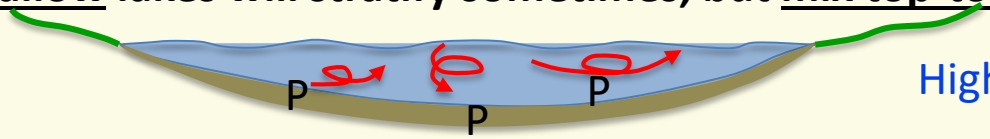

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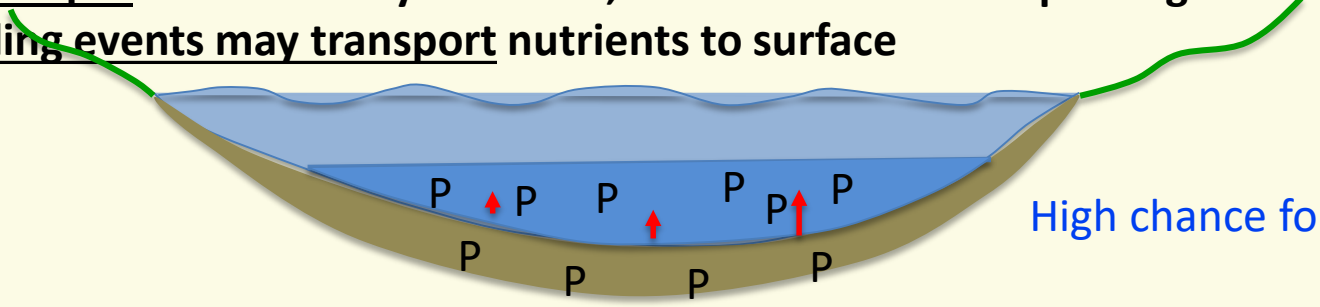

Honeoye

High chance for internal loading

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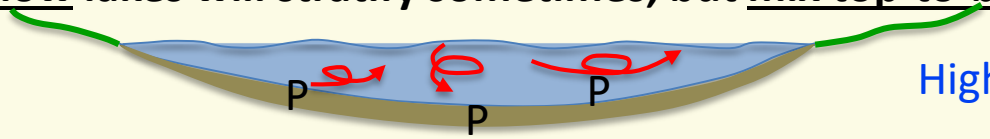

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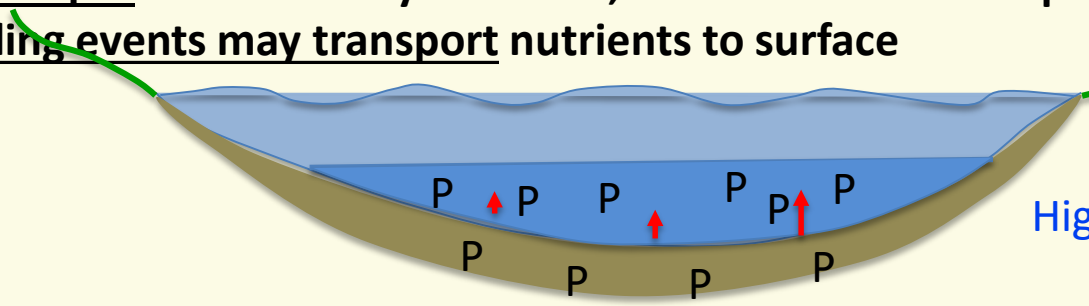
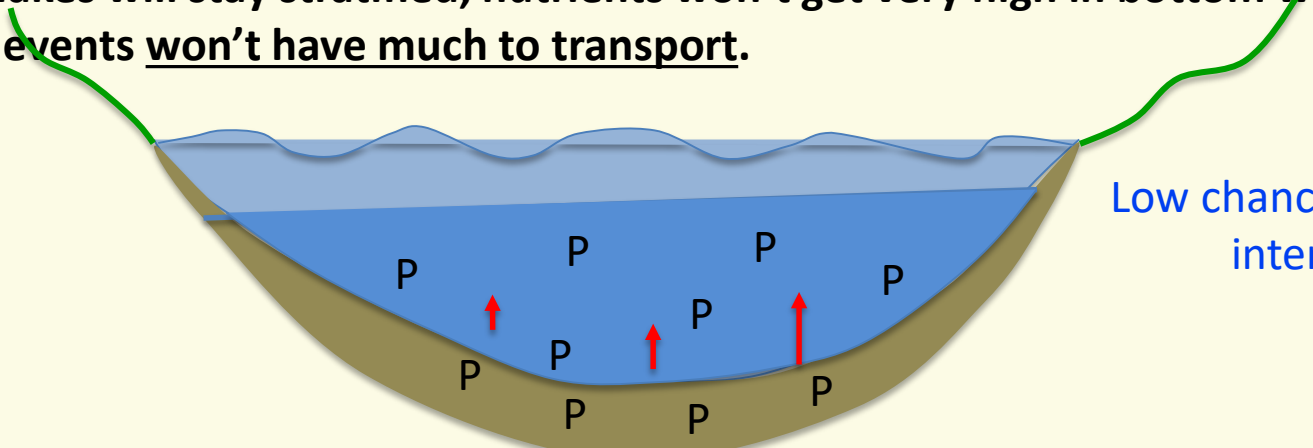


Honeoye

High chance for internal loading

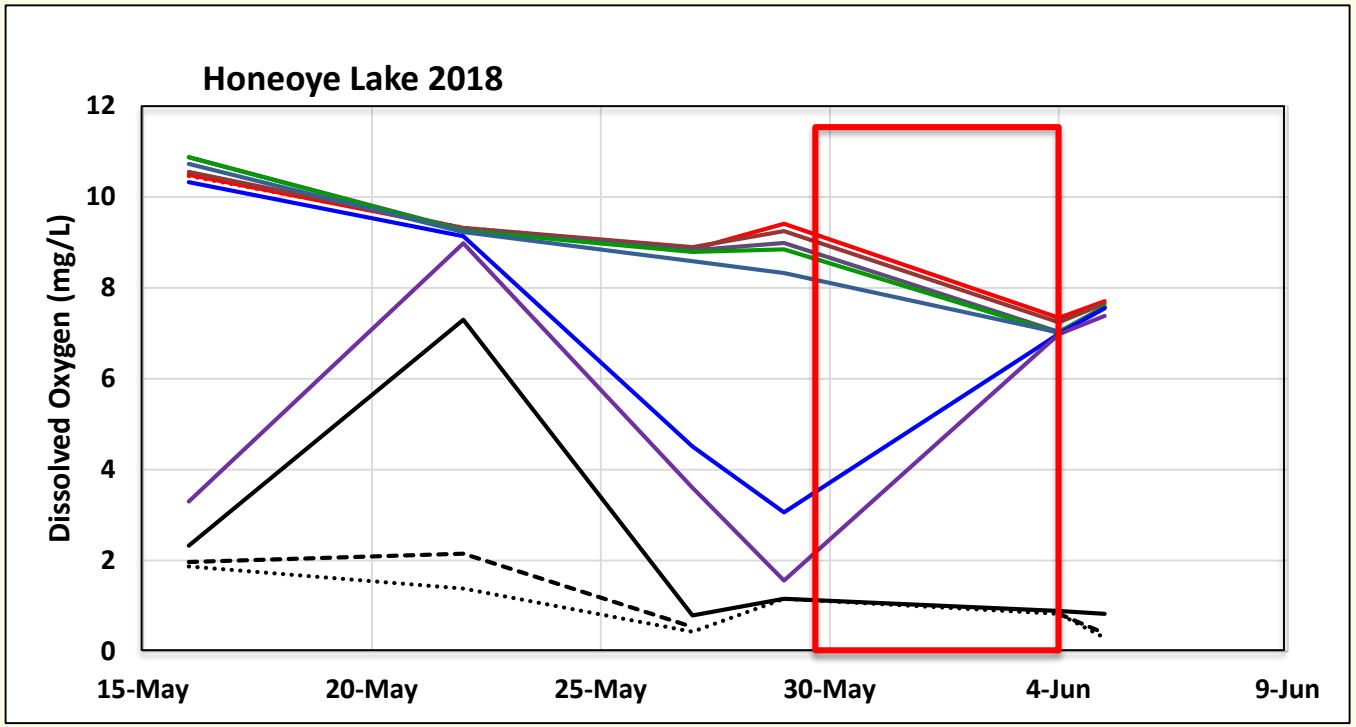
<u>Really deep</u> lakes will stay stratified, nutrients won't get very high in bottom water

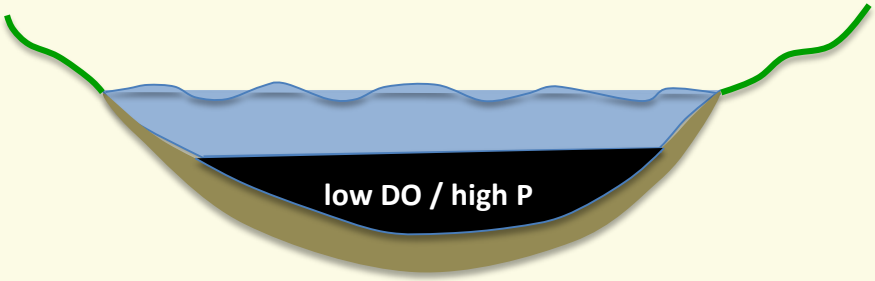
upwelling events <u>won't have much to transport</u>.

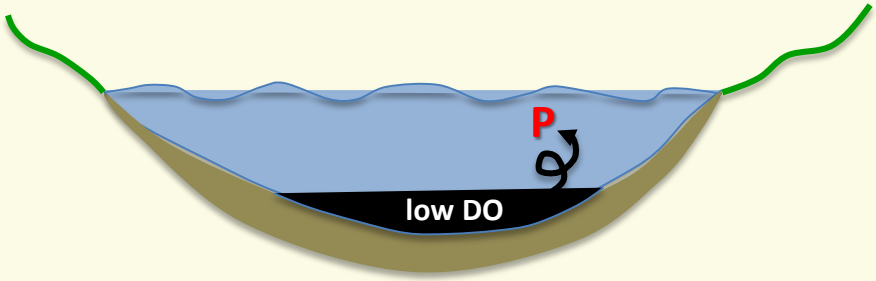


Low chance for internal loading

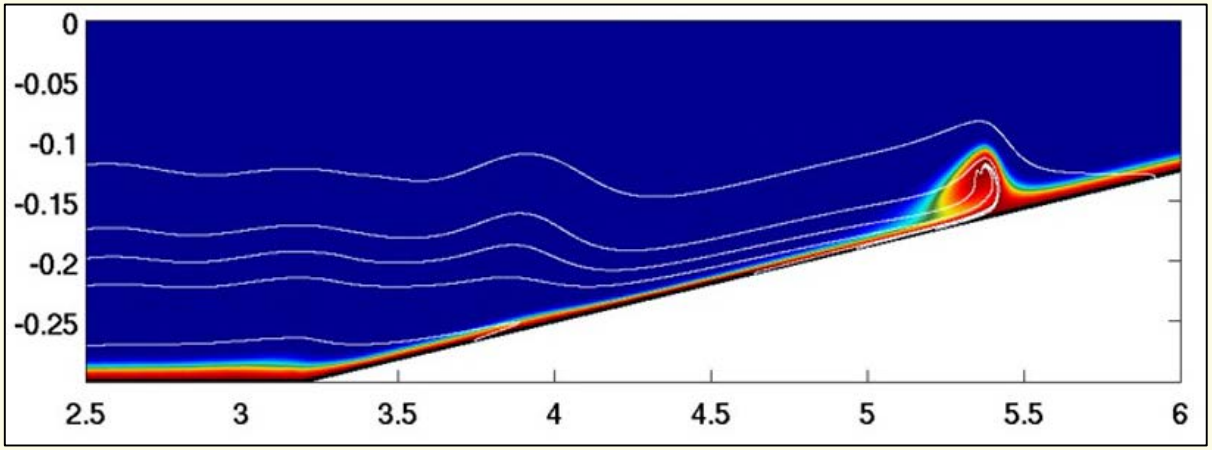
Upwelling event mixed deep water up to surface

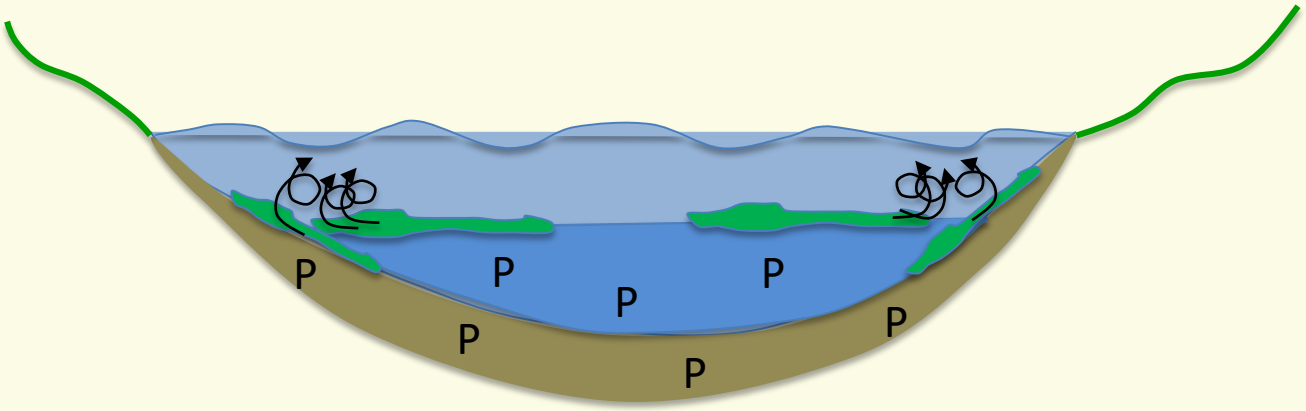




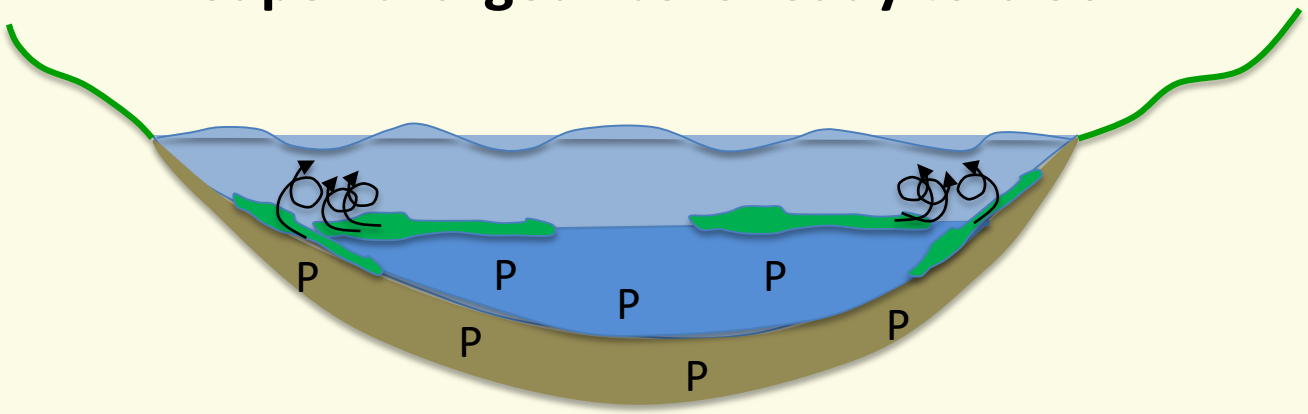


Not only transport up of nutrients, but also <u>living phytoplankton</u> that has sunk to the thermocline or to the lake sediments





Does bolus transport and mixing in shallow water bring up "super-charged" cells ready to bloom?



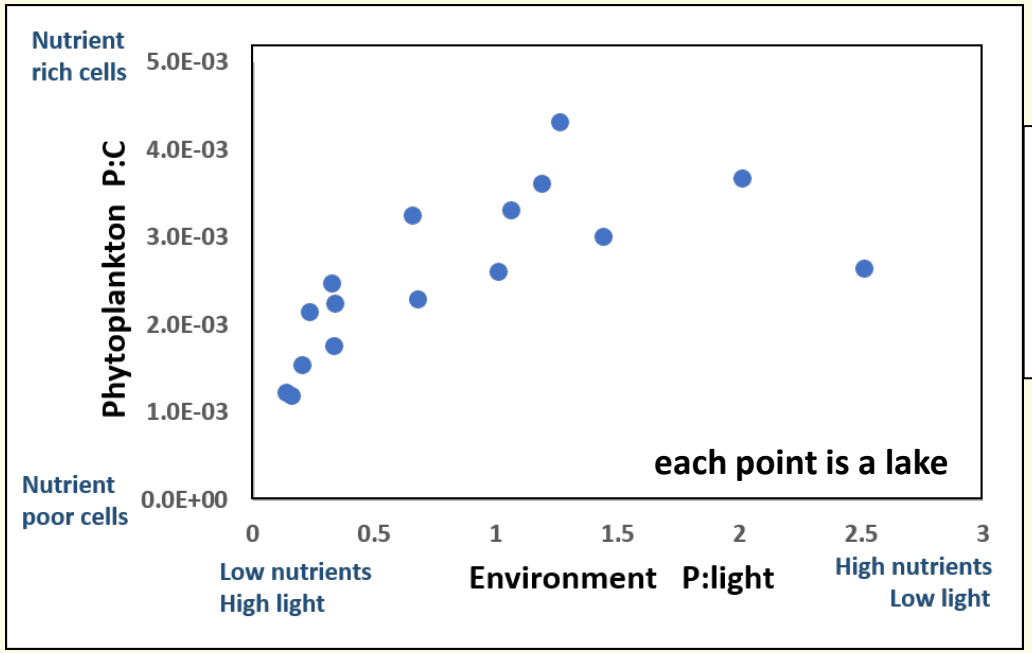
Ludivine Sanchez Arias

ENGEES
NATIONAL SCHOOL FOR WATER AND ENVIRONMENTAL ENGINEERING

Phytoplankton in <u>high nutrients</u>, <u>low light</u>

→ "luxury nutrient uptake"

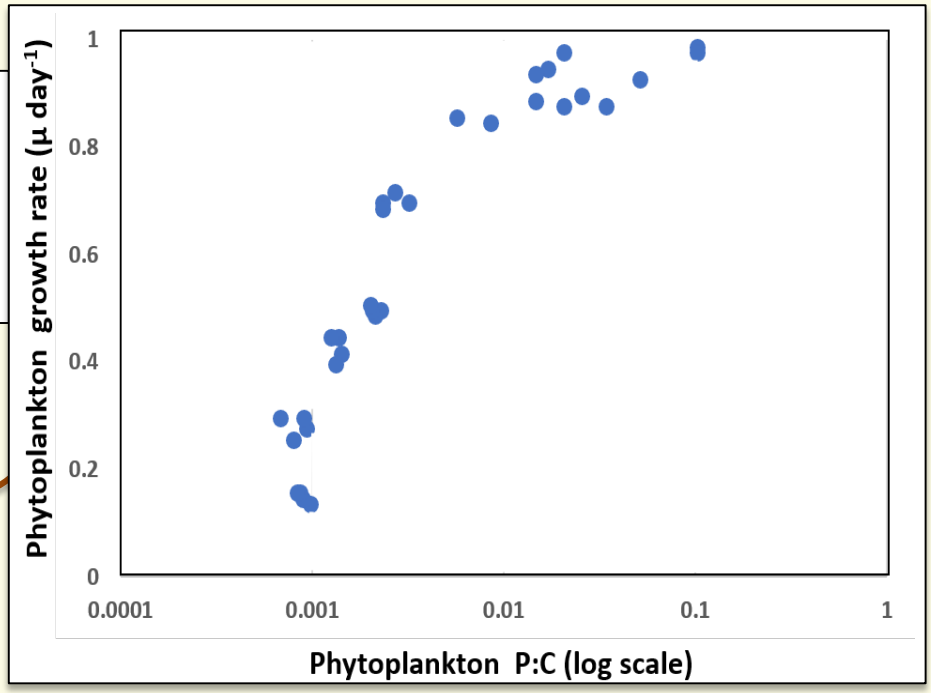
Cells are high in P and N relative to C … and ready to divide when given light …



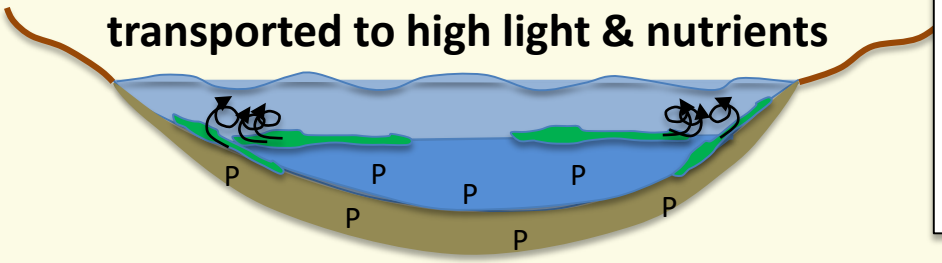
Phytoplankton cells from low light and high P have a high P:C content

Redrawn from Sterner et al. 1997

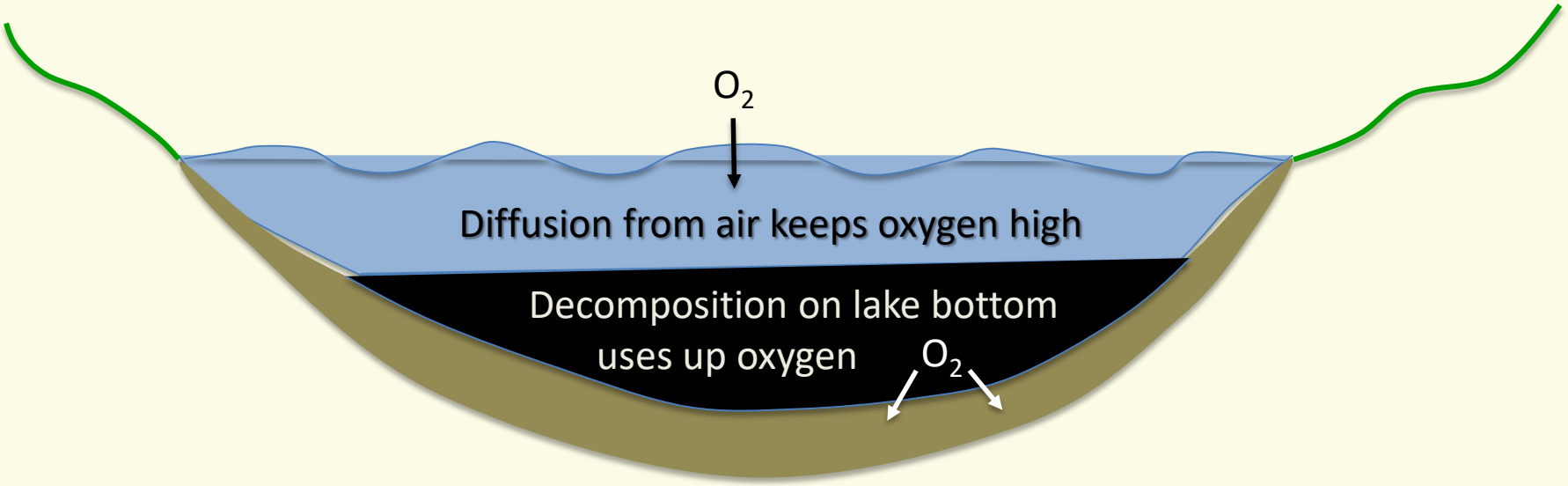
Cells with a high C:P content grow fastest

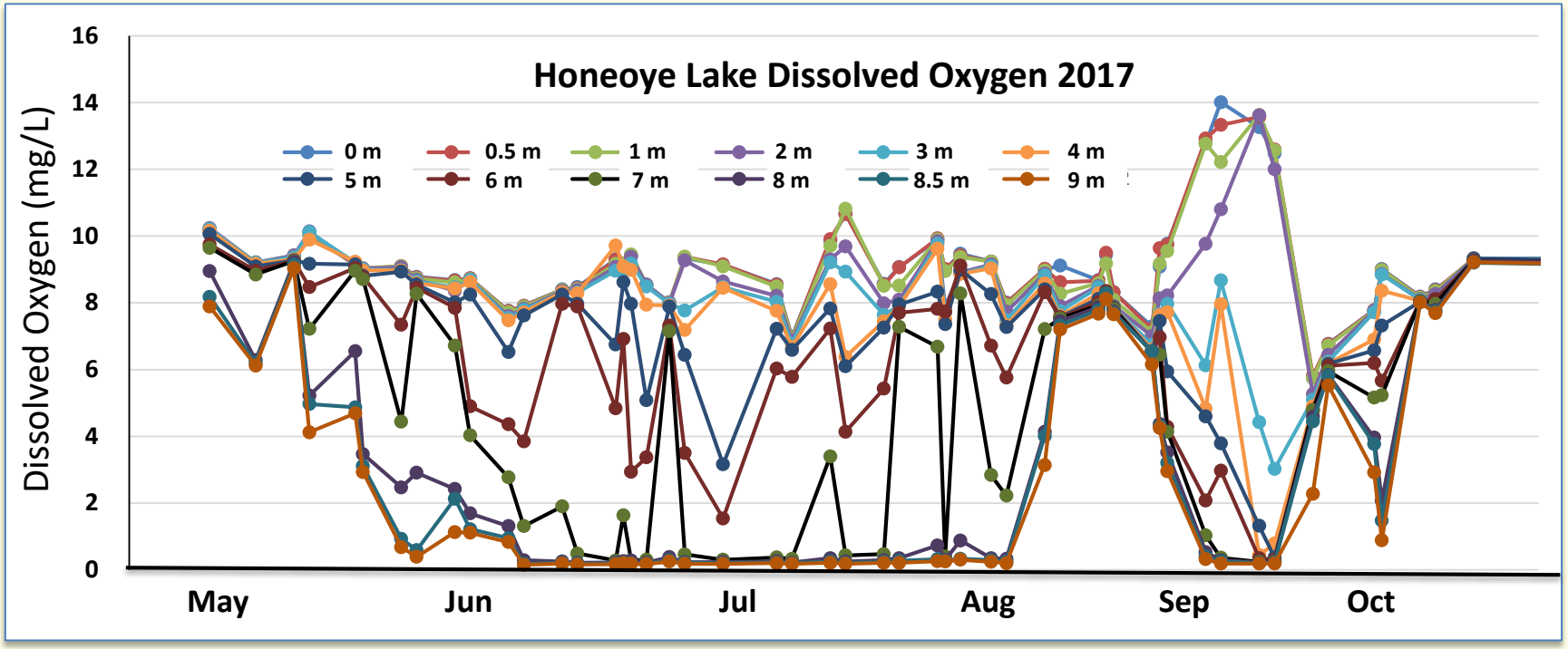


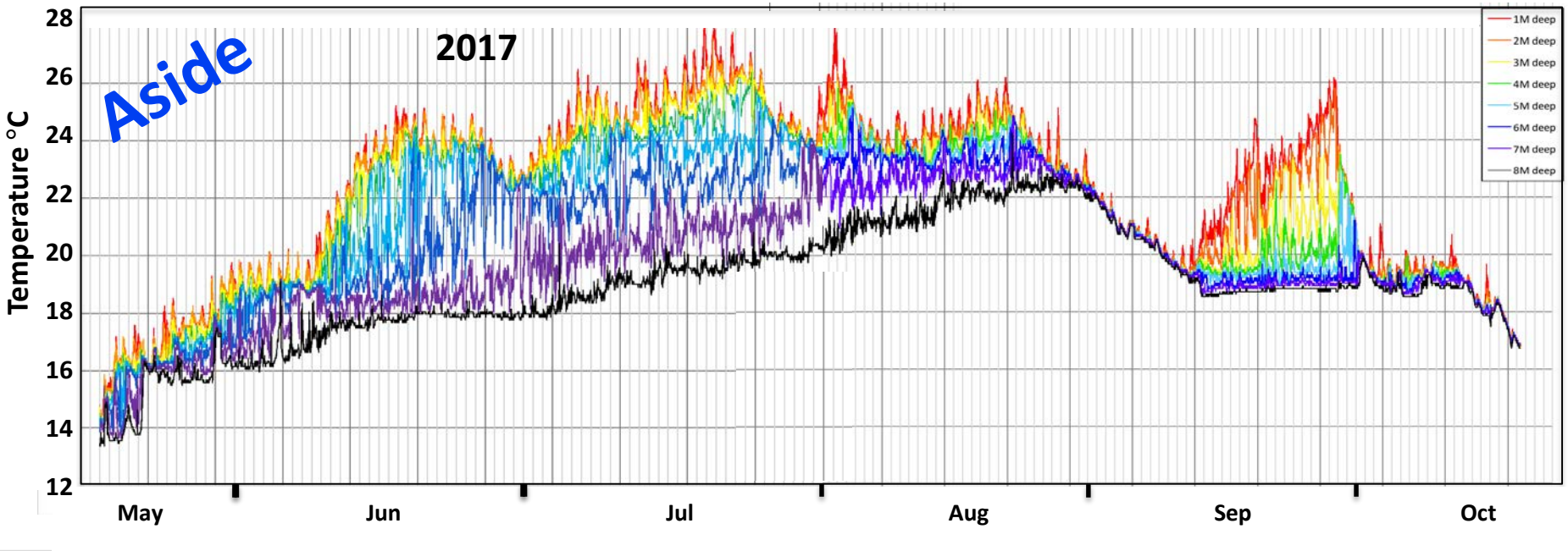
Cells in low light, high P transported to high light & nutrients

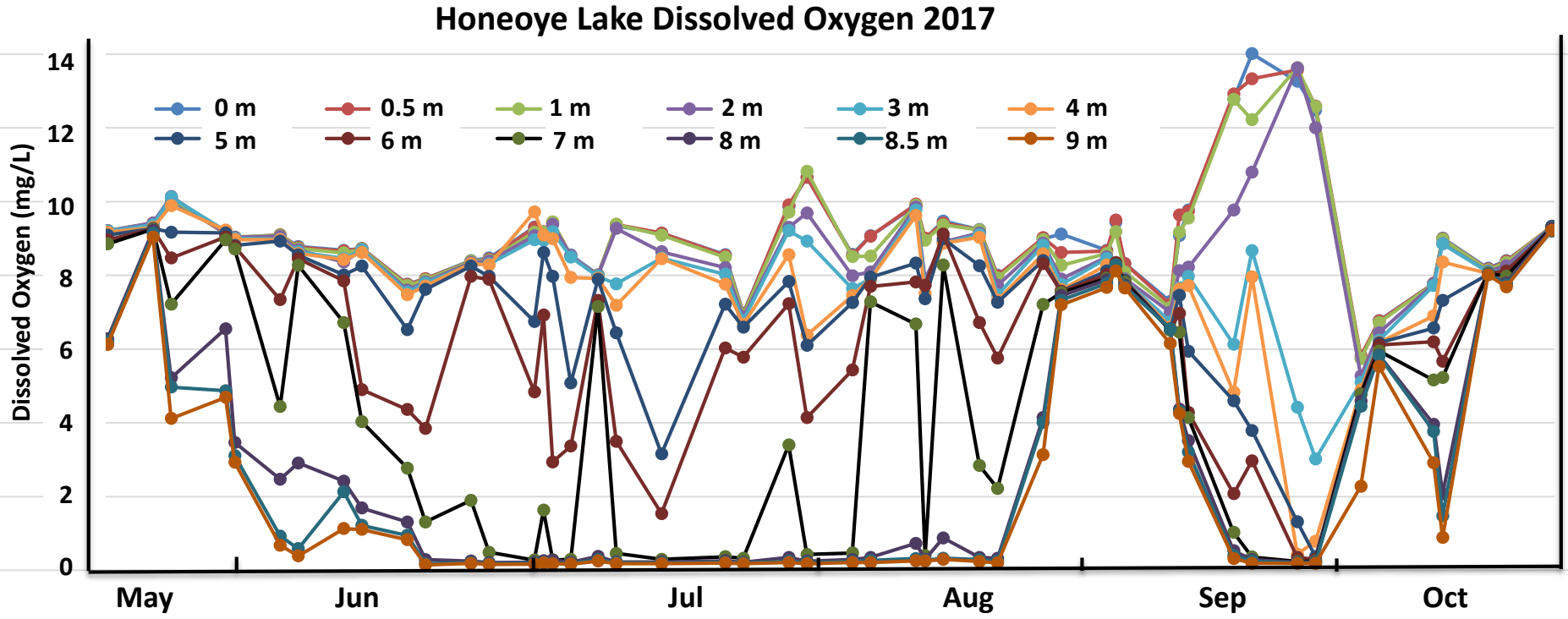


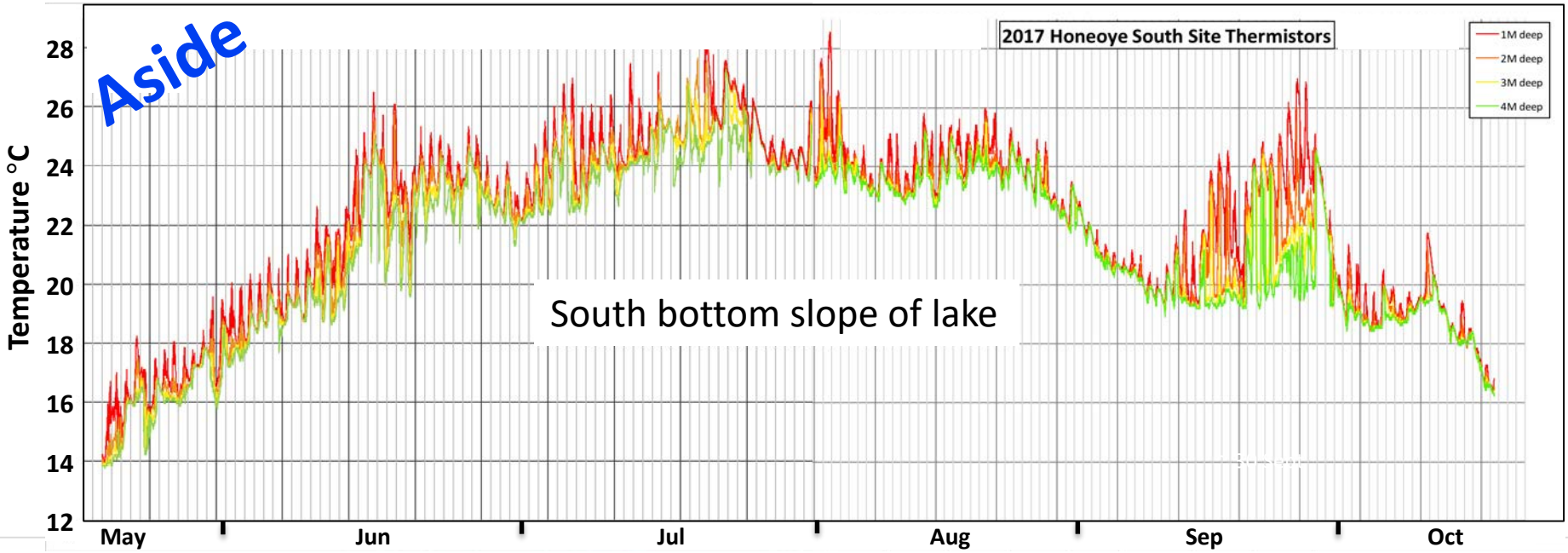
Redrawn from Goldman et al. 1979

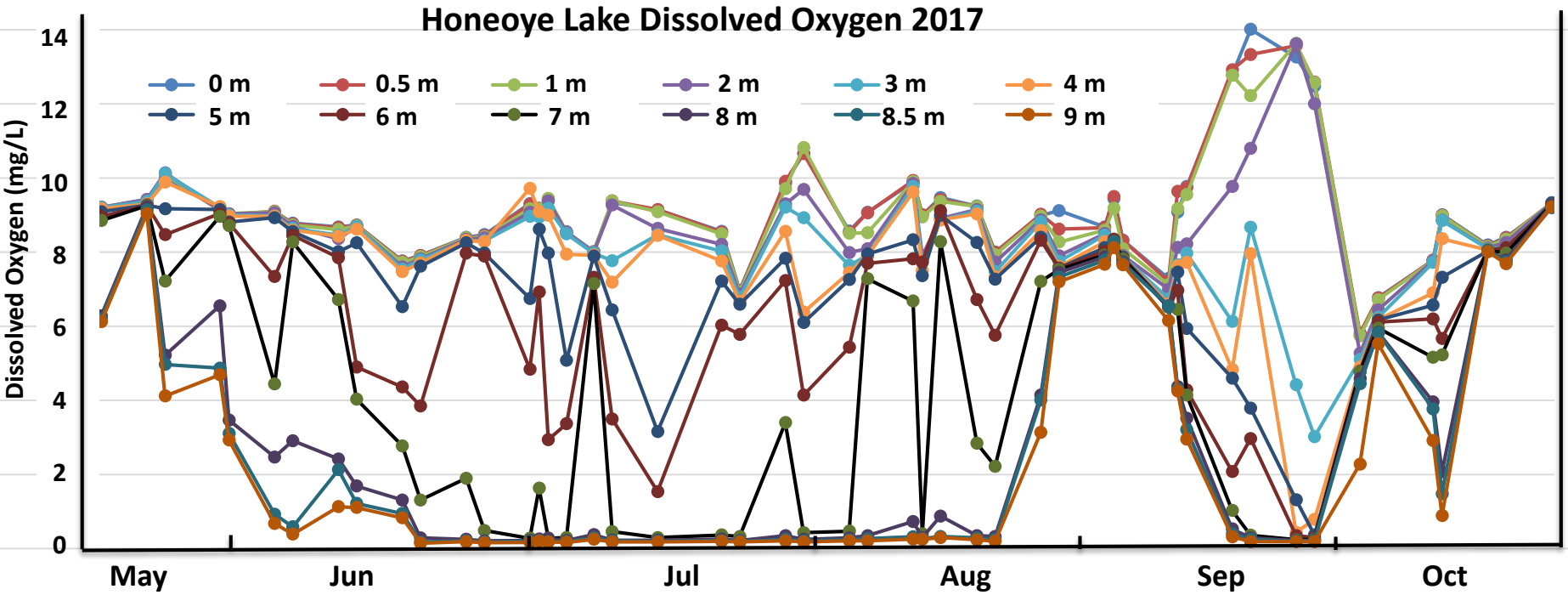

O_2
Diffusion from air keeps oxygen high
Decomposition on lake bottom
uses up oxygen
O_2


Honeoye Lake Dissolved Oxygen 2017
Dissolved Oxygen (mg/L)
0 m
0.5 m
1 m
2 m
3 m
4 m
5 m
6 m
7 m
8 m
8.5 m
9 m
16
14
12
10
8
6
4
2
0
May
Jun
Jul
Aug
Sep
Oct

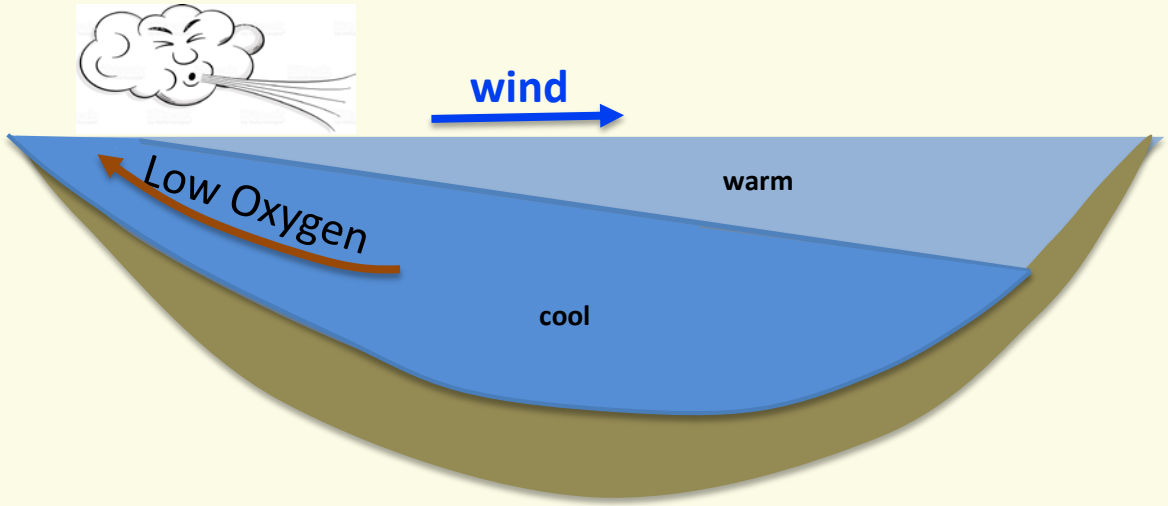

Aside
2017
Temperature °C
28
26
24
22
20
18
16
14
12
May
Jun
Jul
Aug
Sep
Oct
1M deep
2M deep
3M deep
4M deep
5M deep
6M deep
7M deep
8M deep


Honeoye Lake Dissolved Oxygen 2017
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
0 m
0.5 m
1 m
2 m
3 m
4 m
5 m
6 m
7 m
8 m
8.5 m
9 m
May
Jun
Jul
Aug
Sep
Oct

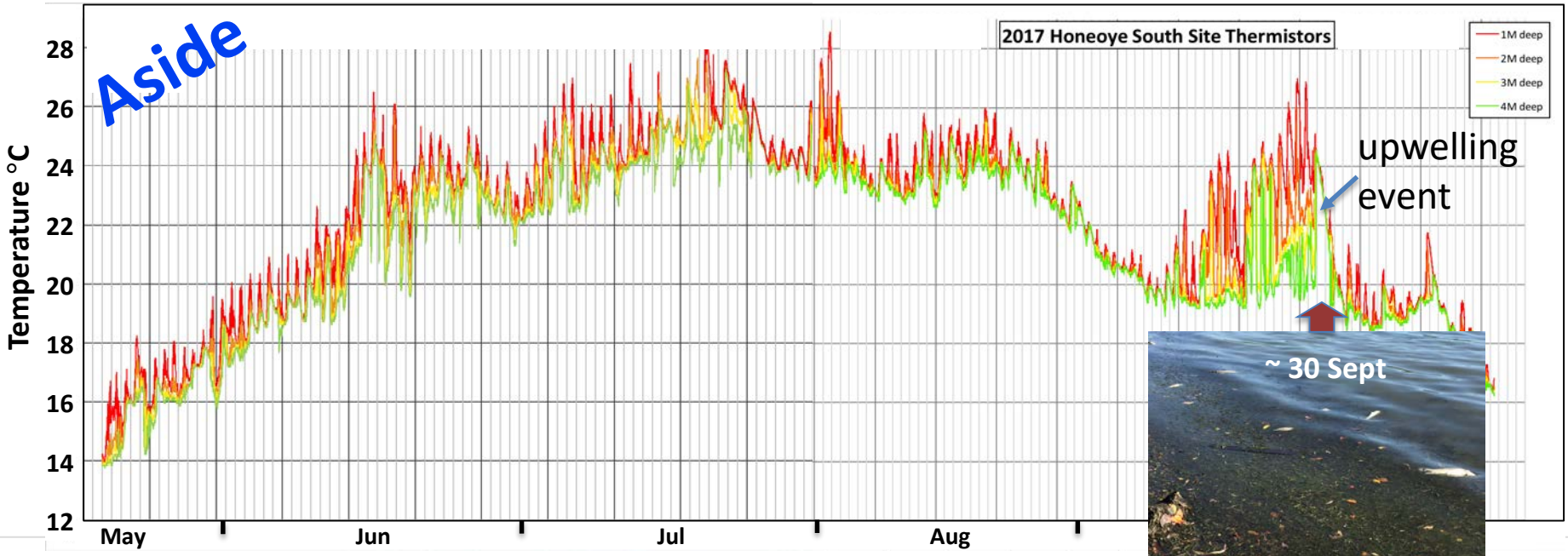

Aside
2017 Honeoye South Site Thermistors
1M deep
2M deep
3M deep
4M deep
Temperature °C
28
26
24
22
20
18
16
14
12
South bottom slope of lake
May
Jun
Jul
Aug
Sep
Oct

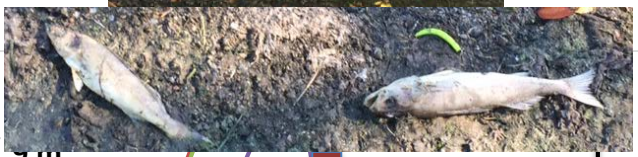

Honeoye Lake Dissolved Oxygen 2017
0 m
0.5 m
1 m
2 m
3 m
4 m
5 m
6 m
7 m
8 m
8.5 m
9 m
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
May
Jun
Jul
Aug
Sep
Oct

Internal waves along the thermocline



Aside


2017 Honeoye South Site Thermistors
1M deep
2M deep
3M deep
4M deep
Temperature °C
28
26
24
22
20
18
16
14
12
May
Jun
Jul
Aug
upwelling
event
~ 30 Sept



Honeoye Lake Dissolved Oxygen 2017
0 m
0.5 m
1 m
2 m
3 m
5 m
6 m
7 m
8 m
8.5 m
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
May
Jun
Jul
Aug
Sep
Oct
fish kill