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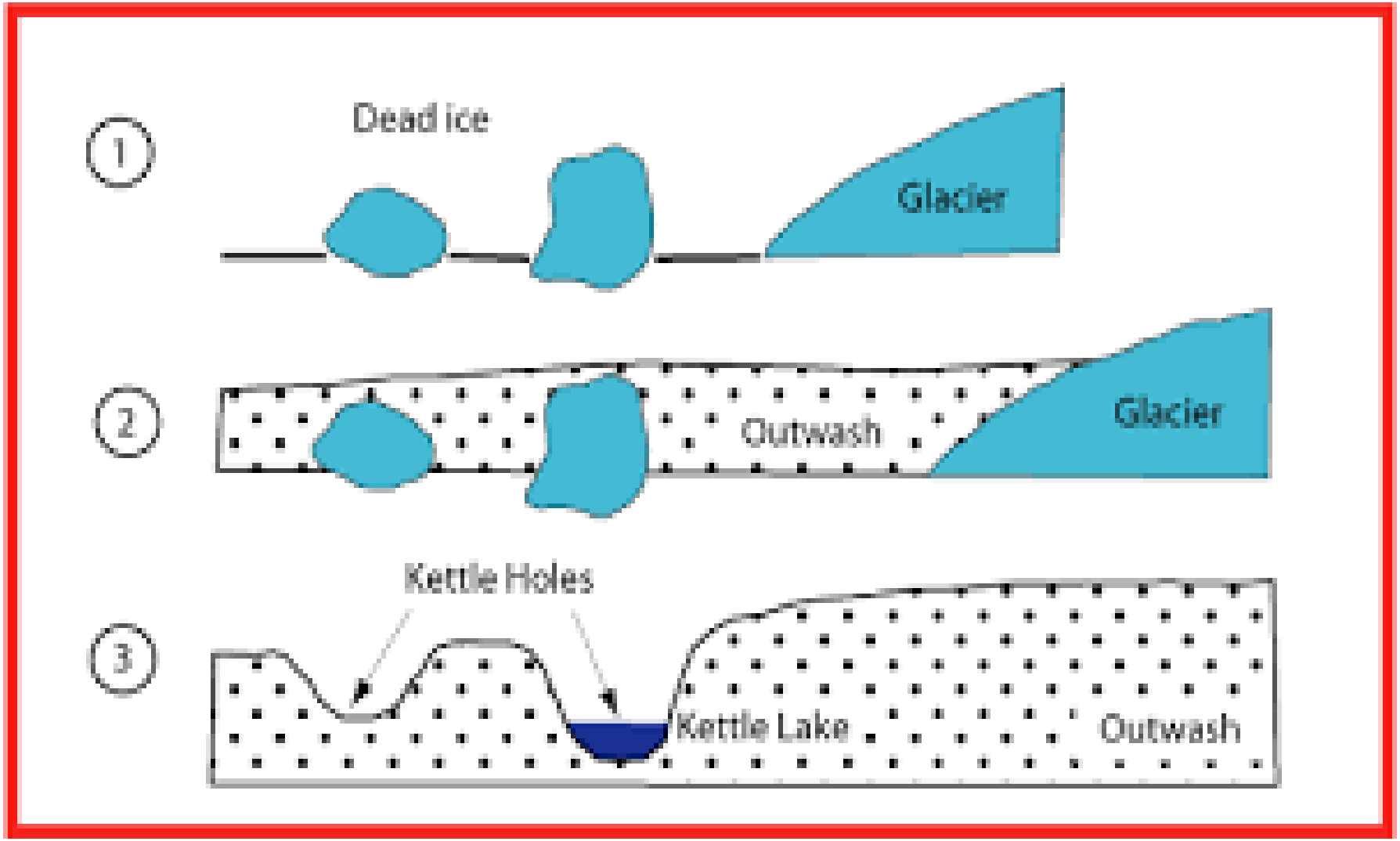
Outline of talk

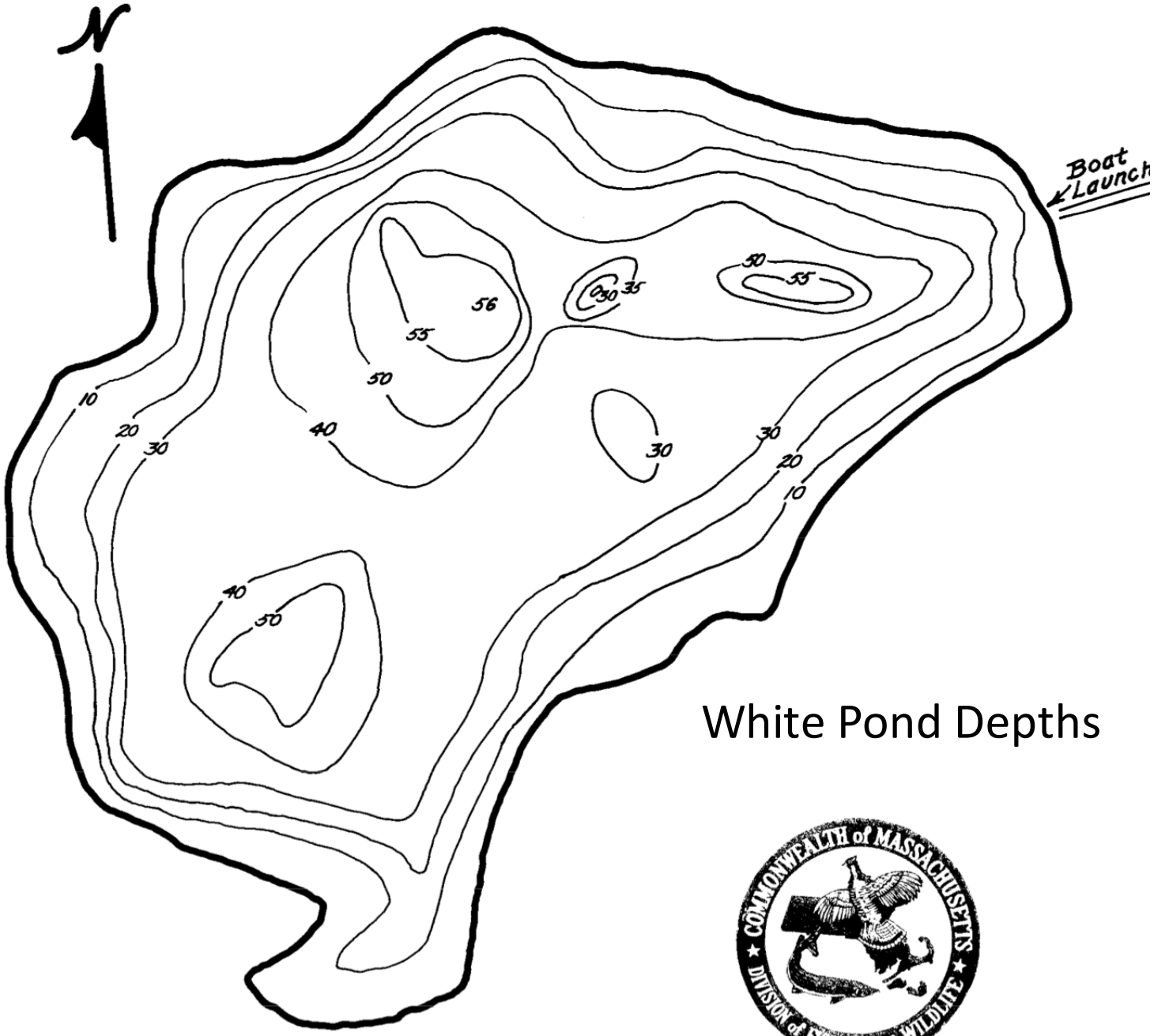
1. Kettle lakes
2. Why phosphorus? Problems
3. Temperature profiles
4. Relevance to phosphorus/ internal loading
5. Management strategies for White Pond

Formation of kettle lakes



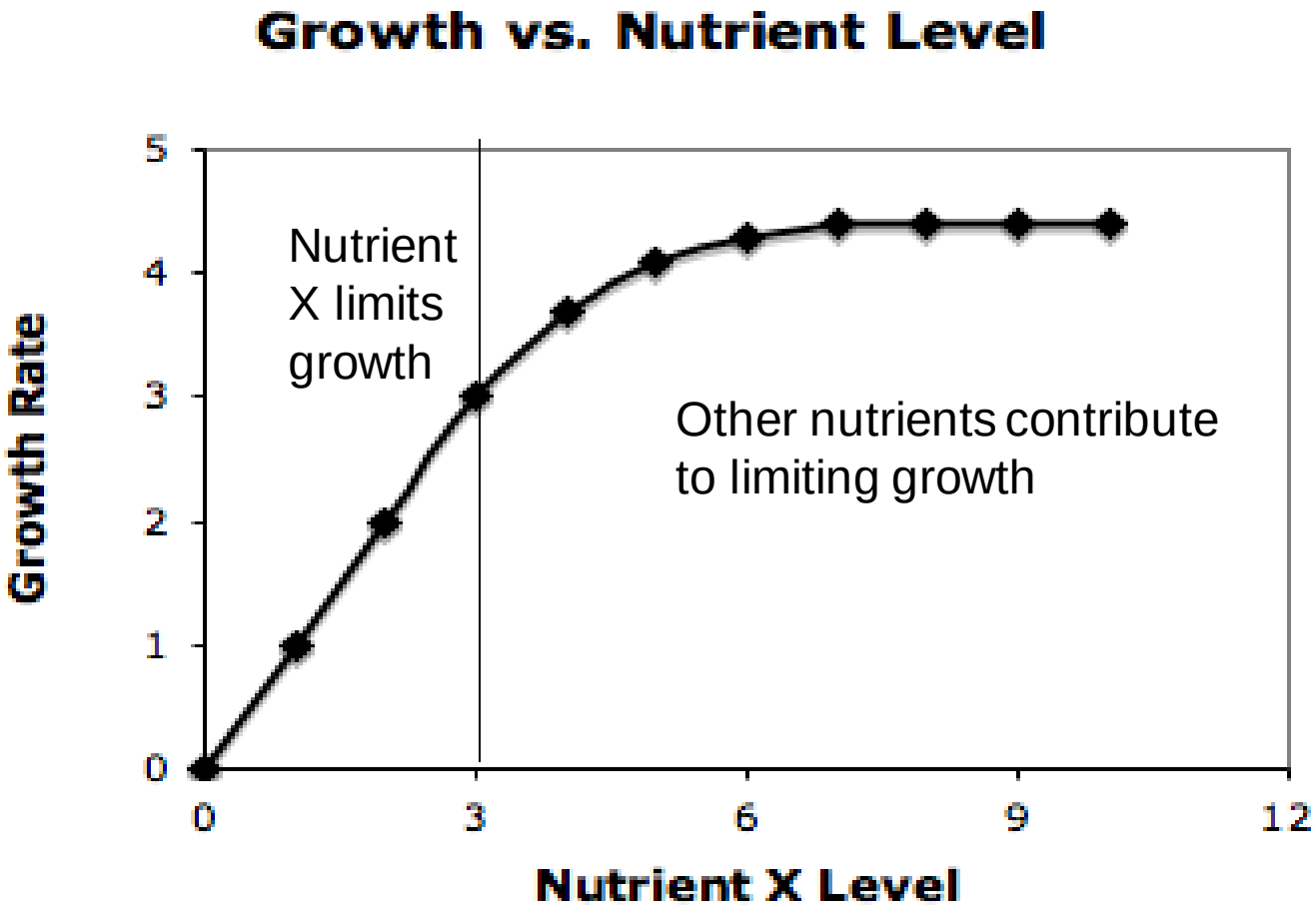
Characteristics of most kettle lakes

- Roundish shape
- Mostly flat (-ish) bottom with steep shorelines
- Surrounded by highly permeable soils
- Groundwater a major water source
- Long retention times (i.e. low flushing rates)



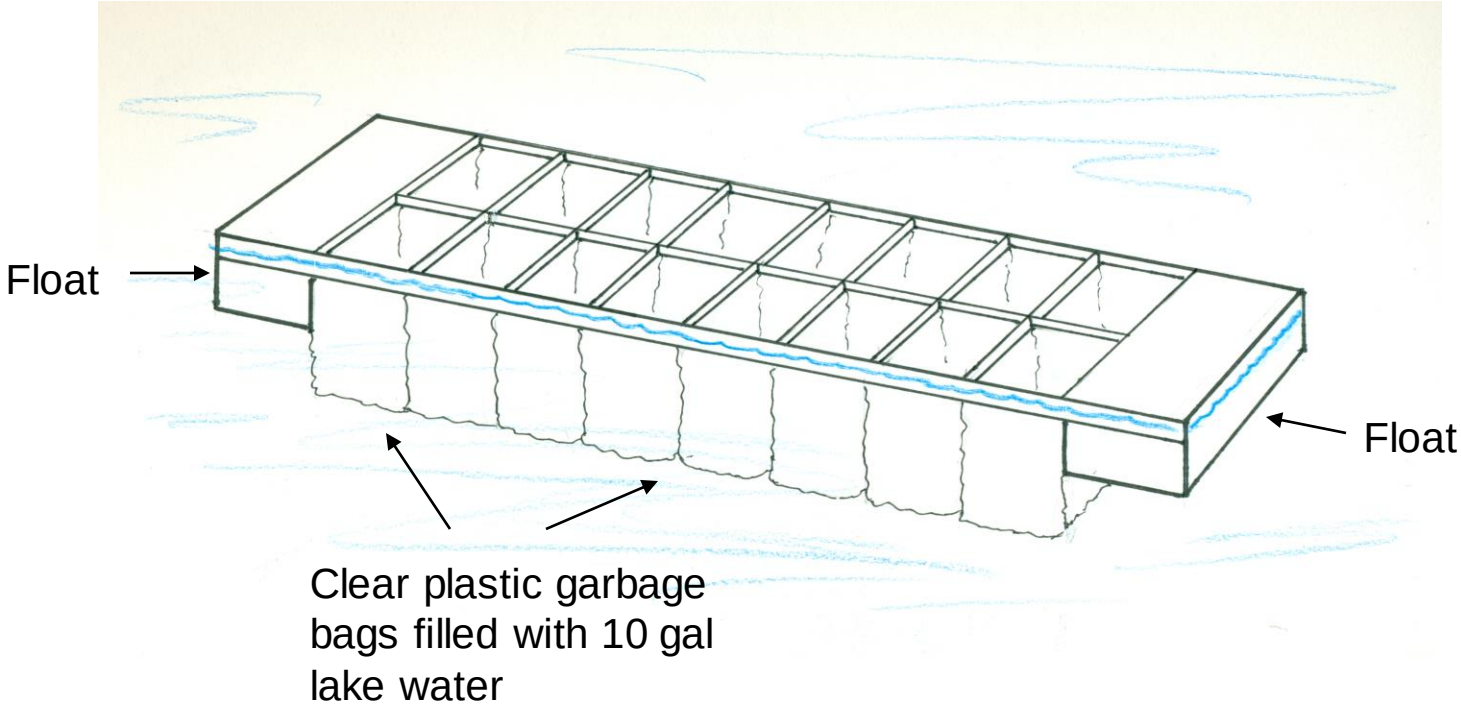
White Pond Depths

What's the fuss about phosphorus?



Therefore "X" is the limiting factor

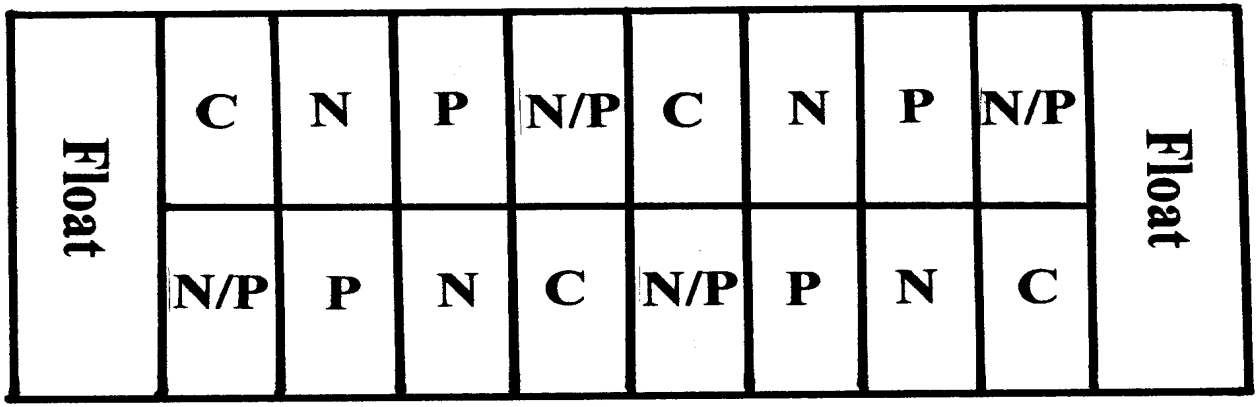
An in-lake experiment to determine the limiting nutrient to algal growth



Possible limiting nutrients:

Phosphorus? Nitrogen?

Put nitrogen (N) and phosphorus (P) in some of the bags, but leave some as added-nutrient-free controls (C).



Limiting nutrient experiment results

(Leave experiment in lake for one week, then measure chlorophyll levels in each bag to estimate algal population size)

Nutrient Added	Chlorophyll (ppb)
None added (control)	6.4
Nitrogen	6.7
Phosphorus	13.5
N & P	15.3

Therefore phosphorus limits (determines) algal growth in the tested lake (and White Pond and most other lakes tested)

EPA data from a study of 99 lakes

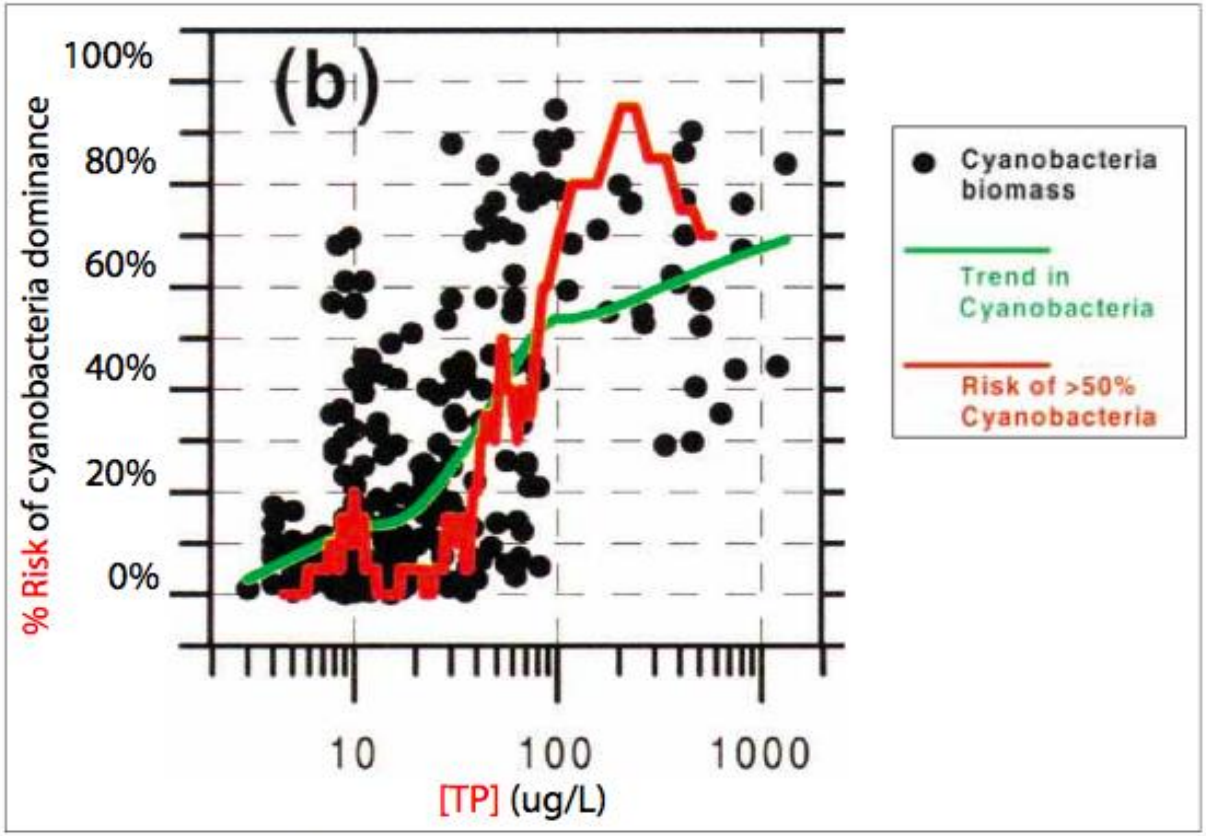


Figure 2. **The probability of cyanobacteria dominance is controlled by phosphorus, but there is much variation. (from Downing et al. 2001)**

Note apparent "tipping point" at about 20-30 ppb total phosphorus (TP).

This is what you don’t want to happen

(Blue green algae (cyanobacteria) bloom in western basin of Lake Erie 2013)

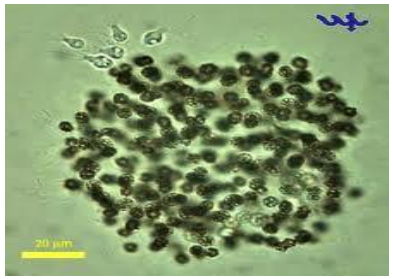
Phosphorus levels in western basin were about 25+/- ppb
(ESS WP report “permissible load” in the 20-30 ppb range???)

Lake Erie west basin

So why be concerned about blue-green algae?

Anabaena

Aphanizomenon



Microcystis

Blooms of some B/G algae can produce toxins:

Microcystin--a liver toxin, can produce nausea

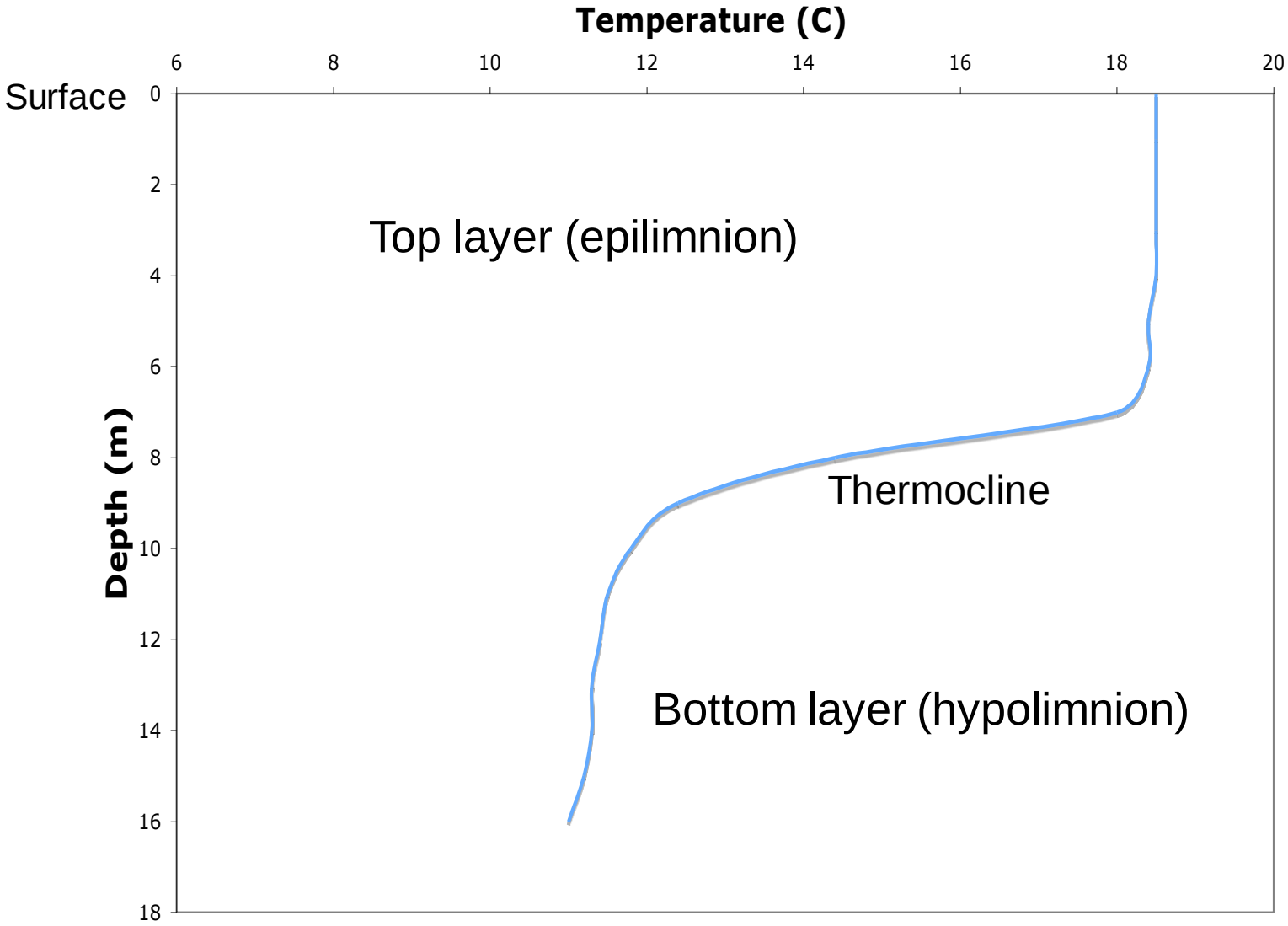
Anatoxin--the "Very fast death factor," a neurotoxin that can cause respiratory paralysis

Cylindrospermopsin--toxic to liver and kidney

BMAA--associated with neurodegenerative disease--jury still out on this

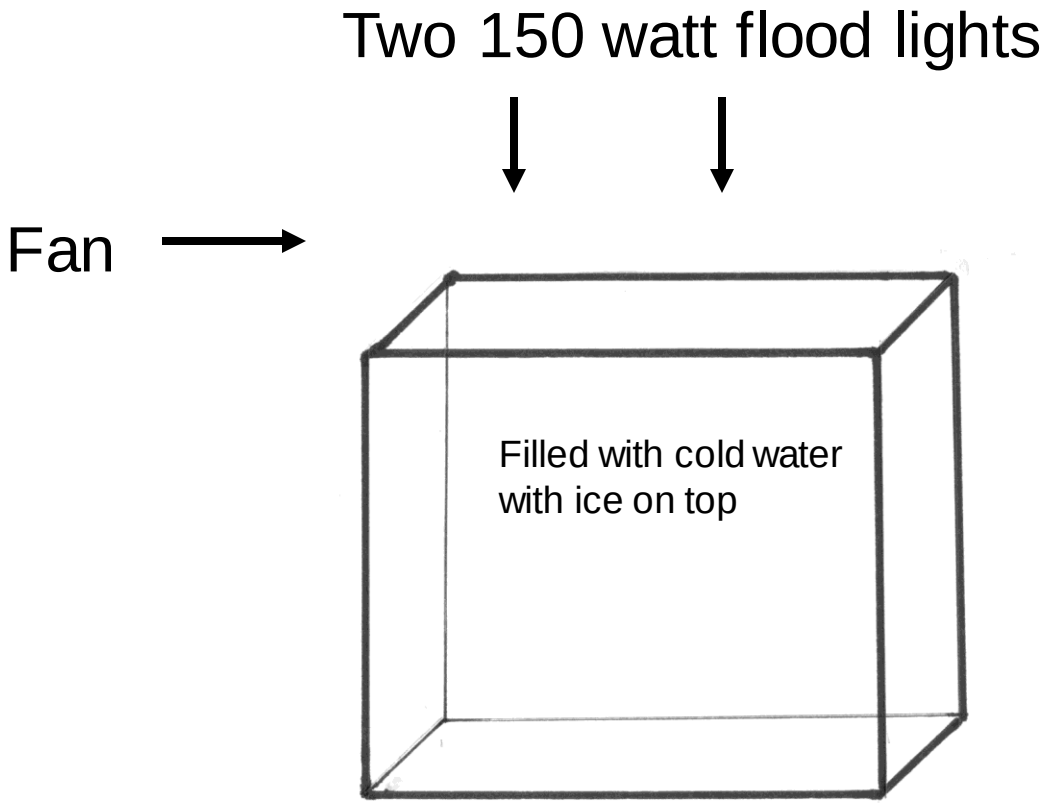
Last summer at least 5 dogs were killed by the Lake Erie B/G bloom, and 50+ people made ill. Toledo's water supply was shut down.

Typical summer lake temperature profile



How does this profile develop?

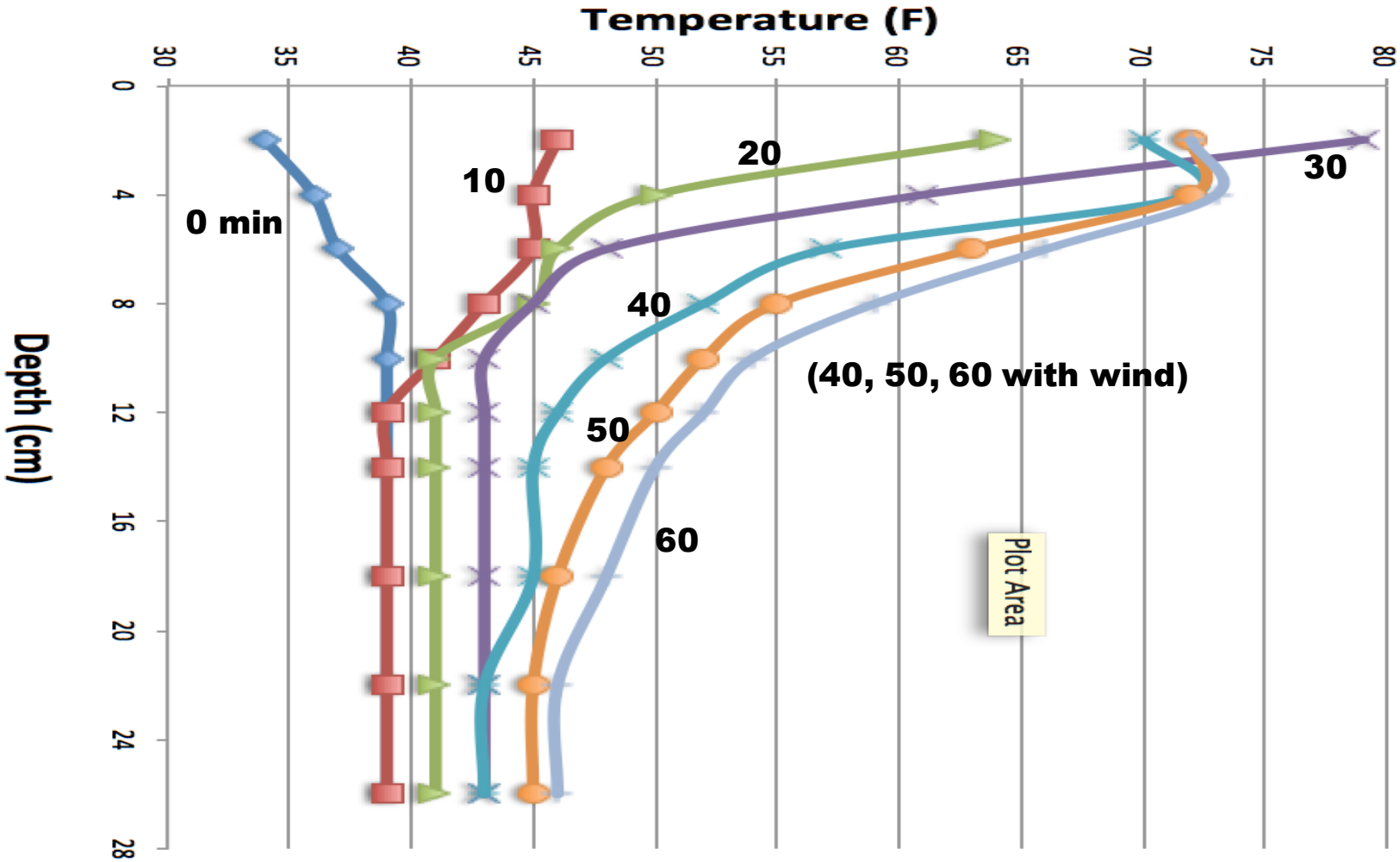
(An in-class micro lake demonstration)



Data from micro lake experiment

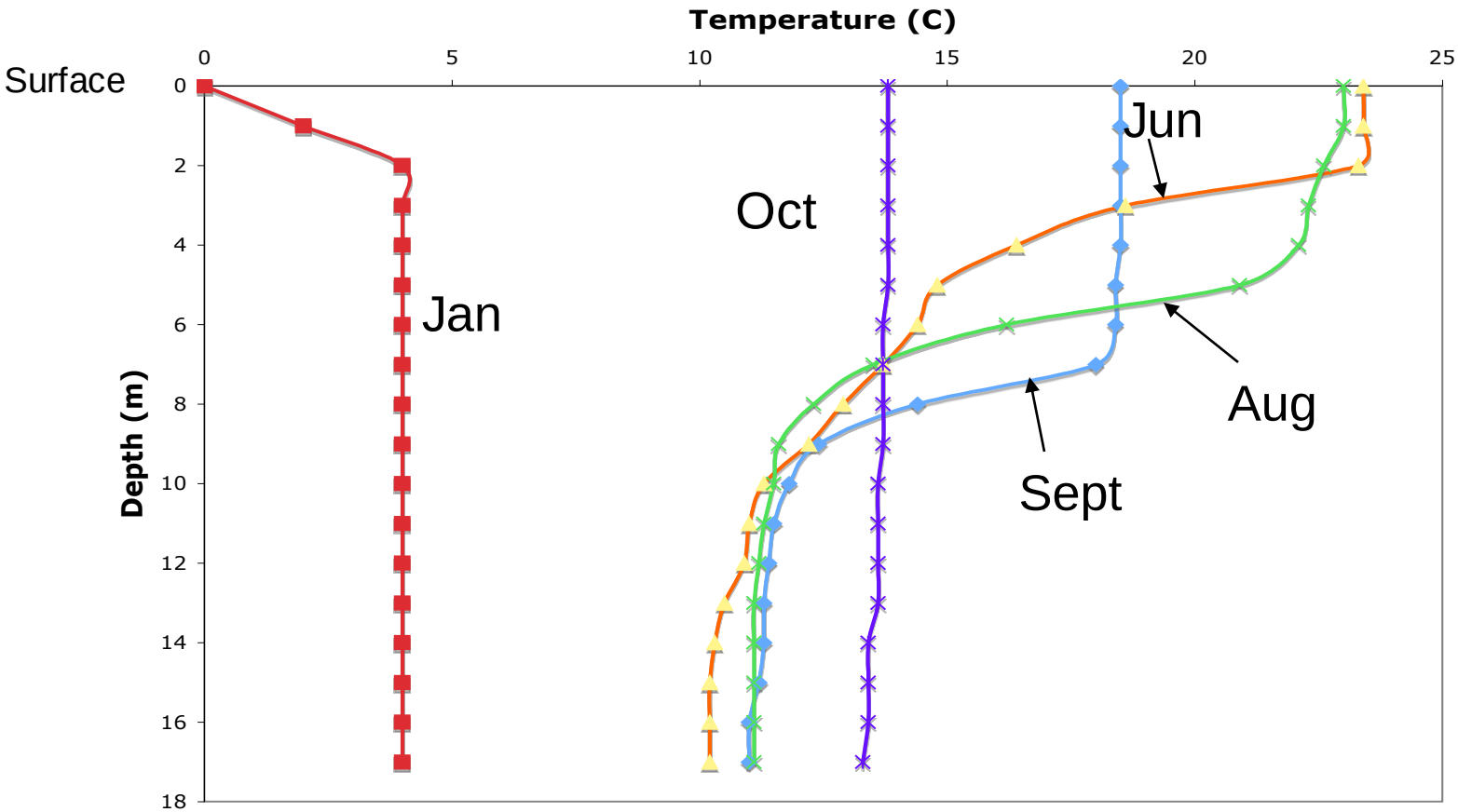
			Micro-lake Temperature Profile (°F)					
Depth		Ice	Light on-->			Wind and Light -->		
(cm)	2	34	46	64	79	70	72	72
	4	36	45	50	61	72	72	73
	6	37	45	46	48	57	63	66
	8	39	43	45	45	52	55	59
	10	39	41	41	45	48	52	54
	12	39	39	41	43	46	50	52
	14	39	39	41	43	45	48	50
	18	39	39	41	43	45	46	48
	22	39	39	41	43	43	45	46
	26	39	39	41	43	43	45	46
		0	10	20	30	40	50	60
				Time (minutes)				

Mini Lake Temperature Profiles



Seasonal water temperature profiles

(Sacandaga Lake data)



Note that the lower level remains about the same temperature for the entire summer until fall turnover

Spring and fall turnovers

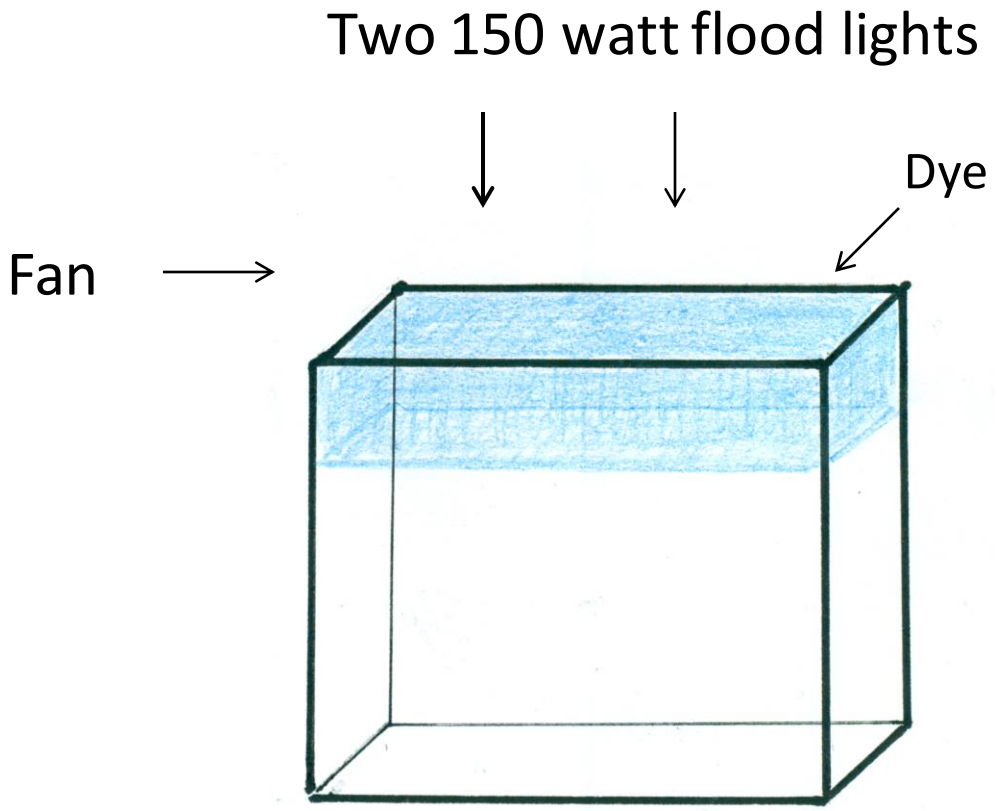
Very important to lakes. When the lakes are isothermal (having the same temperature through their depth profiles), wind will mix the lakes entirely. This happens in the spring after ice melt and in the fall as the upper layer cools until it matches the lower layer. During these mixing periods, water chemistry (e.g. phosphorus and dissolved oxygen levels) are constant throughout the lake.

As the upper water warms in the spring sun, eventually a thermocline will form. In the fall, the isothermal water will continue to cool until the bottom layer reaches 4° C (39° F) and the upper layer cools further until it eventually freezes.

What do you think will be the effect of climate change on this cycle?

Back to the in-class mini lake:

If you add a few drops of blue dye into the top layer:



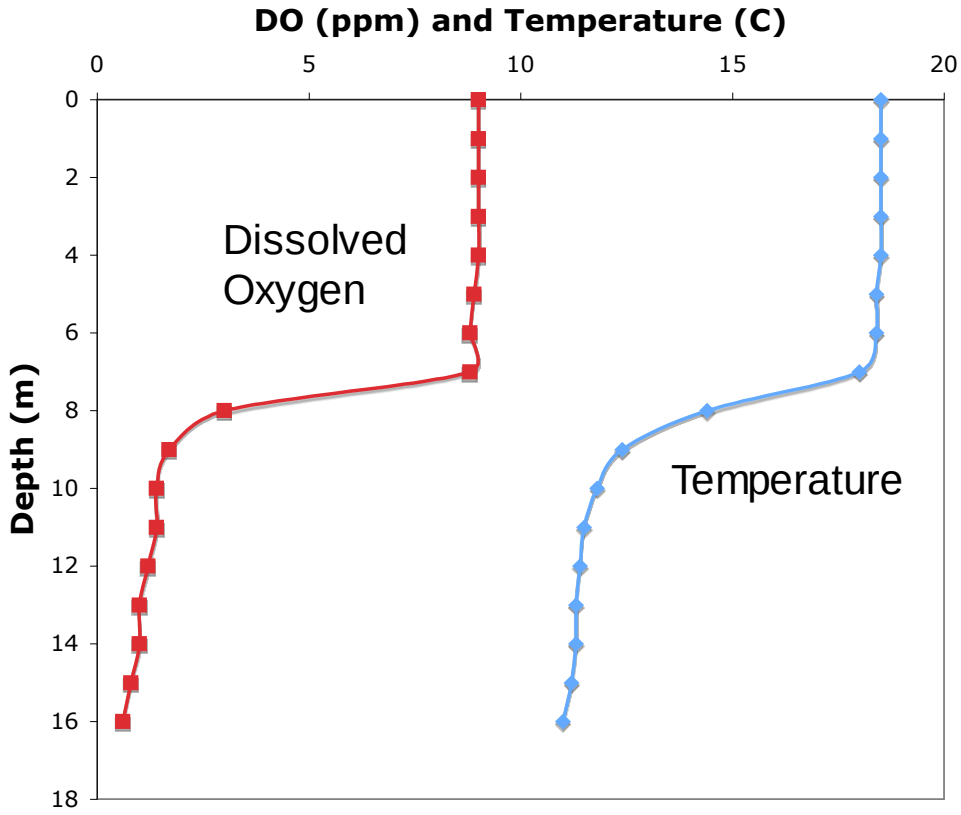
The dye will stay in the top layer

The two layers will NOT MIX until fall turnover

How does this relate to dissolved oxygen?

- Oxygen can enter a lake through diffusion at the lake surface.
- Algae can produce oxygen through photosynthesis (PS), but only where light intensity is high enough (the top).
- All living organisms in the lake require oxygen to live. (except a few weird ones)
- When algae drop to depths where they can no longer carry out PS, they die and the bacteria that decompose them take up more oxygen.
- Also bacteria and fungi digest the organic compounds in the sediment, further reducing oxygen levels in the bottom layer of the lake.
- The result is that the upper lake layer can maintain a high level of oxygen through diffusion and algal PS, whereas the lower level is always depleting the water of oxygen as the growing season progresses. This is true in White Pond.

The thermocline forms a resistance to the mixing of the upper lake layer with the lower layer (Sacandaga lake data from late August)



So how does all this relate to phosphorus?

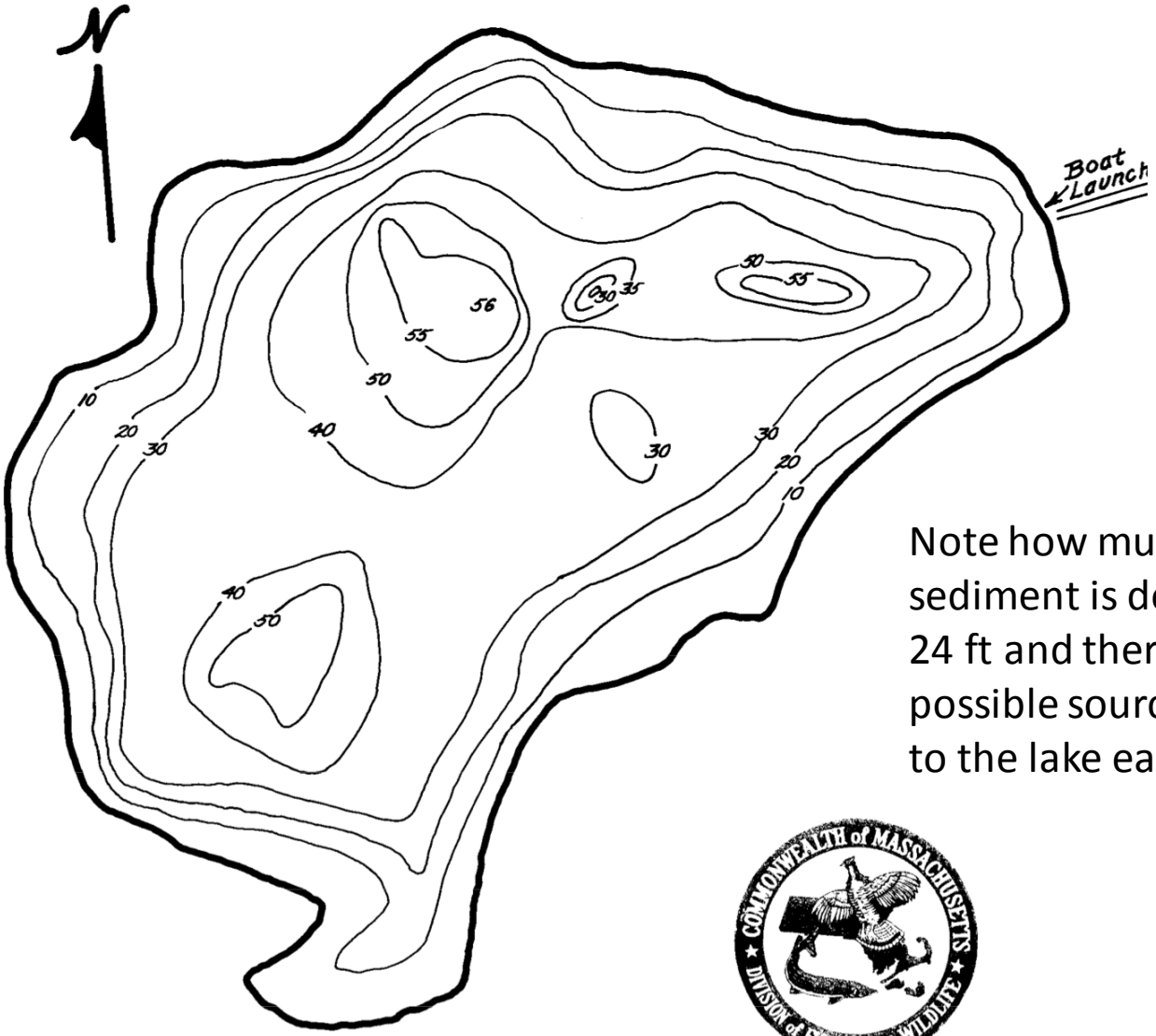
- There is a large store of phosphorus locked up in organic lake sediments
- When oxygen is present, phosphorus is held tightly in a ferric phosphate molecule that is insoluble in water
- Under low oxygen conditions, the ferric phosphate is changed into ferrous phosphate, a water soluble molecule that is released from the sediments into the water column

High oxygen Low oxygen

$FePO_4 \leftarrow \rightarrow Fe_3(PO_4)_2$ (soluble in water)

- White Pond's thermocline is typically about 24 ft deep, so large portions of its bottom sediments are anoxic for a large part of the summer and therefore the sediments can be a major source of phosphorus to the lake. (Think of the effect of climate change)

Remember this?



Note how much of the sediment is deeper than 24 ft and therefore a possible source of phosphorus to the lake each summer

Phosphorus levels in some Cape Cod kettle lakes

(from Wagner: Algae Control on Cape Cod , undated report)

- Phosphorus load includes major internal load

	Hydrologic Load		Phosphorus Load		
Pond	Precip	Grdwtr	Internal	Surf Flow	Grdwtr
	(%)	(%)	(%)	(%)	(%)
Hamblin	11	87	67	9	11
Long	51	44	64	17.3	9.4
Mystic	18	80	46	15	21
Lovers	39	55	43	27	12
Stillwater	13	25	55	32	5
Great	14	83	26	8	45
Herring	43.5	56.5	40	1	46
Lovells	43	53	62	4	16
Cliff	71	23	67	5	6

Note that most of the water entering these lakes is from ground water--no streams

Note that most of the phosphorus entering the lakes is from internal loading--from the low-O_2 sediments

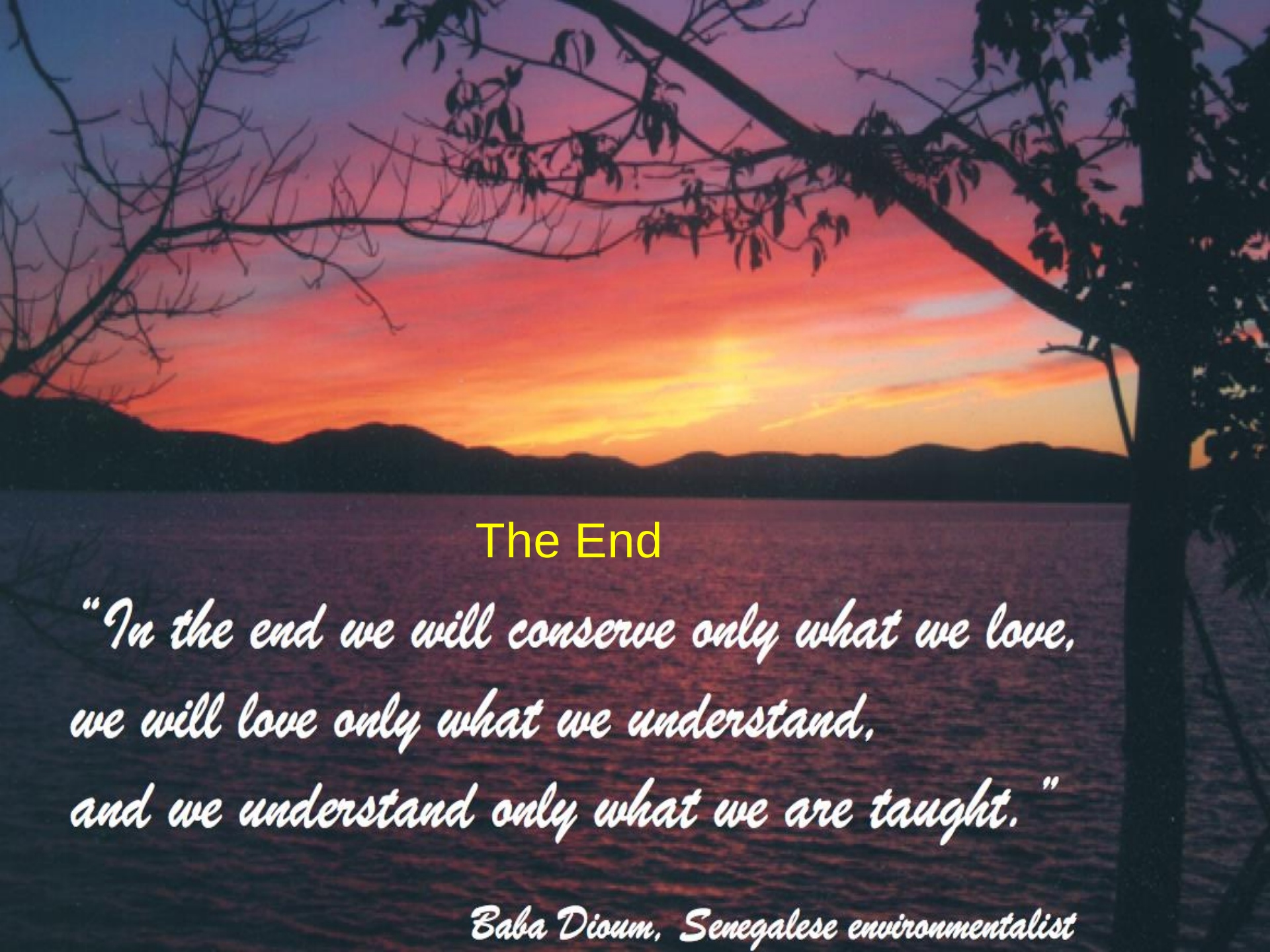
Possible solutions

1. Control surface runoff (high P levels but low volume) ESS report-71% P input
2. Ground water P control ESS report-15%
3. Aeration of hypolimnion (bottom lake layer)
4. Phosphorus sequestration (alum)
5. Biomanipulation???? Anyone looked at the fish? (e.g. Otsego Lake, NY)

Alum treatment effects on some Cape Cod kettle lakes

	Surface Total P		Bottom Total P	
Pond	Pre-trtmt	Post-trtmt	Pre-trtmt	Post-trtmt
	µg/L	µg/L	µg/L	µg/L
Hamblin	42	10	454	46
Long	30	16	163	62
Mystic	35	10 - 19	555	65
Lovers	32	13	116	22
Stillwater	28	9	290	30
Great	21	<10	29	<10
Herring	27	12	1537	37
Lovells	61	12	167	35

Alum treatment can be temporarily (15+/- yrs) successful in some lakes, but can create problems (e.g. if pH not controlled).


The End
"In the end we will conserve only what we love,
we will love only what we understand,
and we understand only what we are taught."
Baba Dioum, Senegalese environmentalist