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SUPPRESSION OF HARMFUL ALGAE BLOOMS IN RESERVOIRS: LESSONS LEARNED FROM PROJECTS

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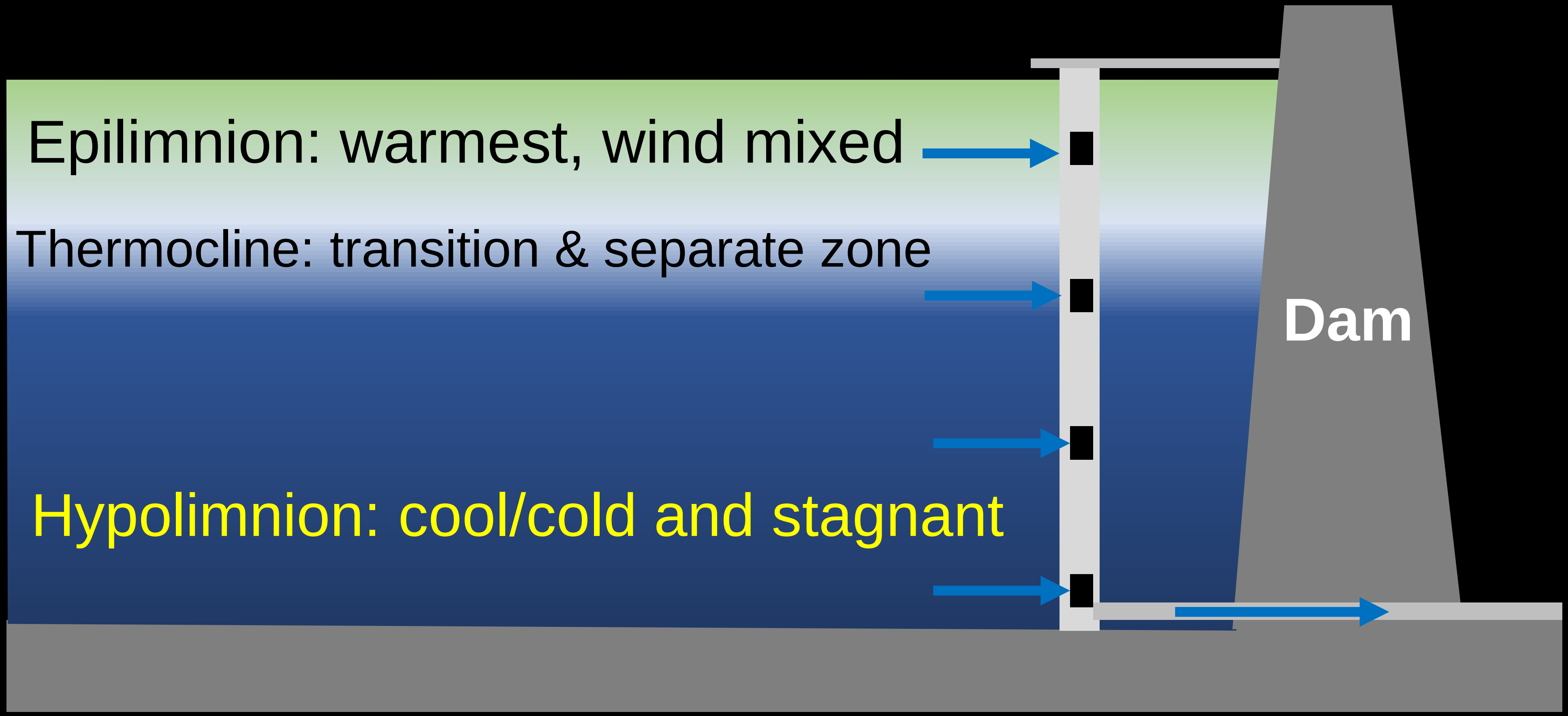
September 19, 2019

JACOBS

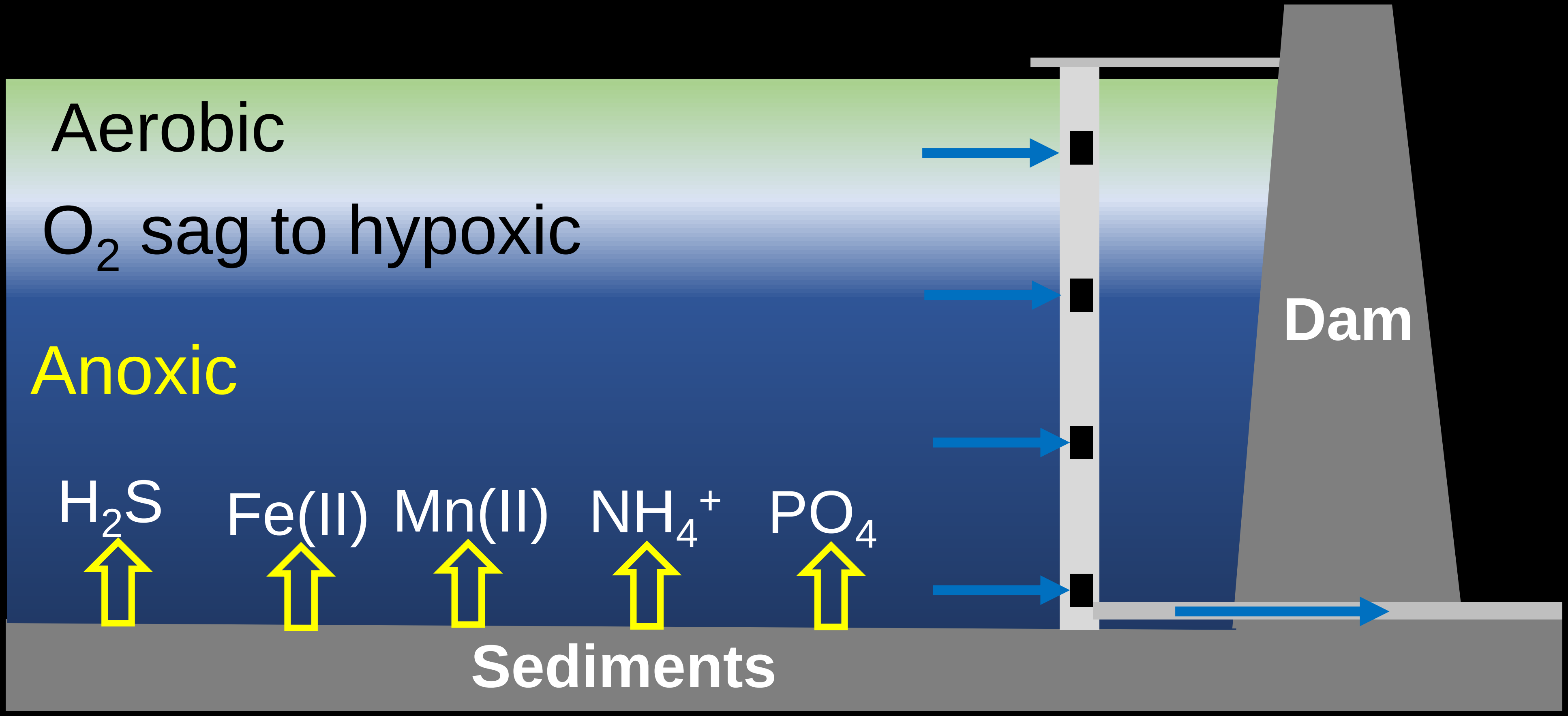
Agenda

- Basic concepts
- **Case studies:**
  - Hypolimnetic oxygenation
  - Destratification aeration
  - Geochemical augmentation

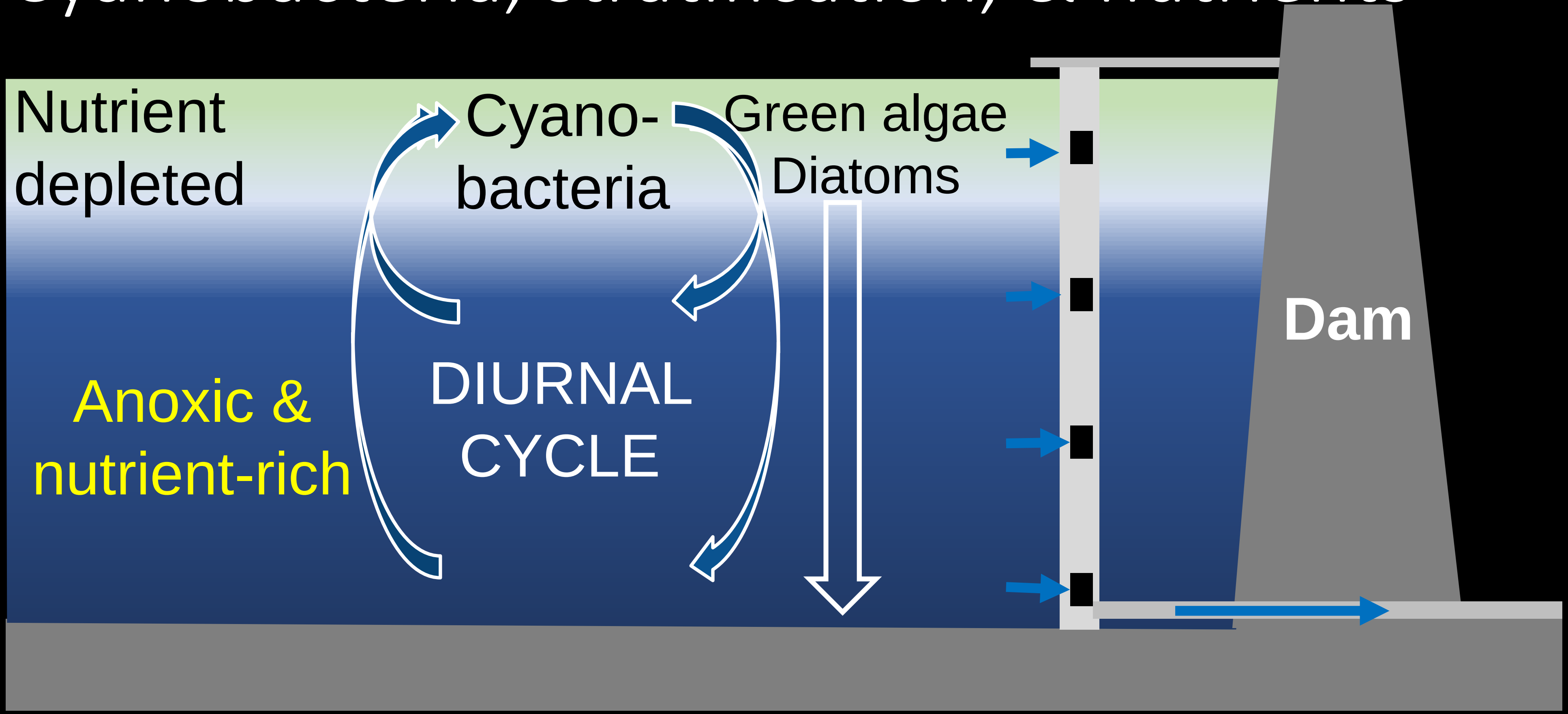
Density stratification



Stratification, anoxia, & nutrients

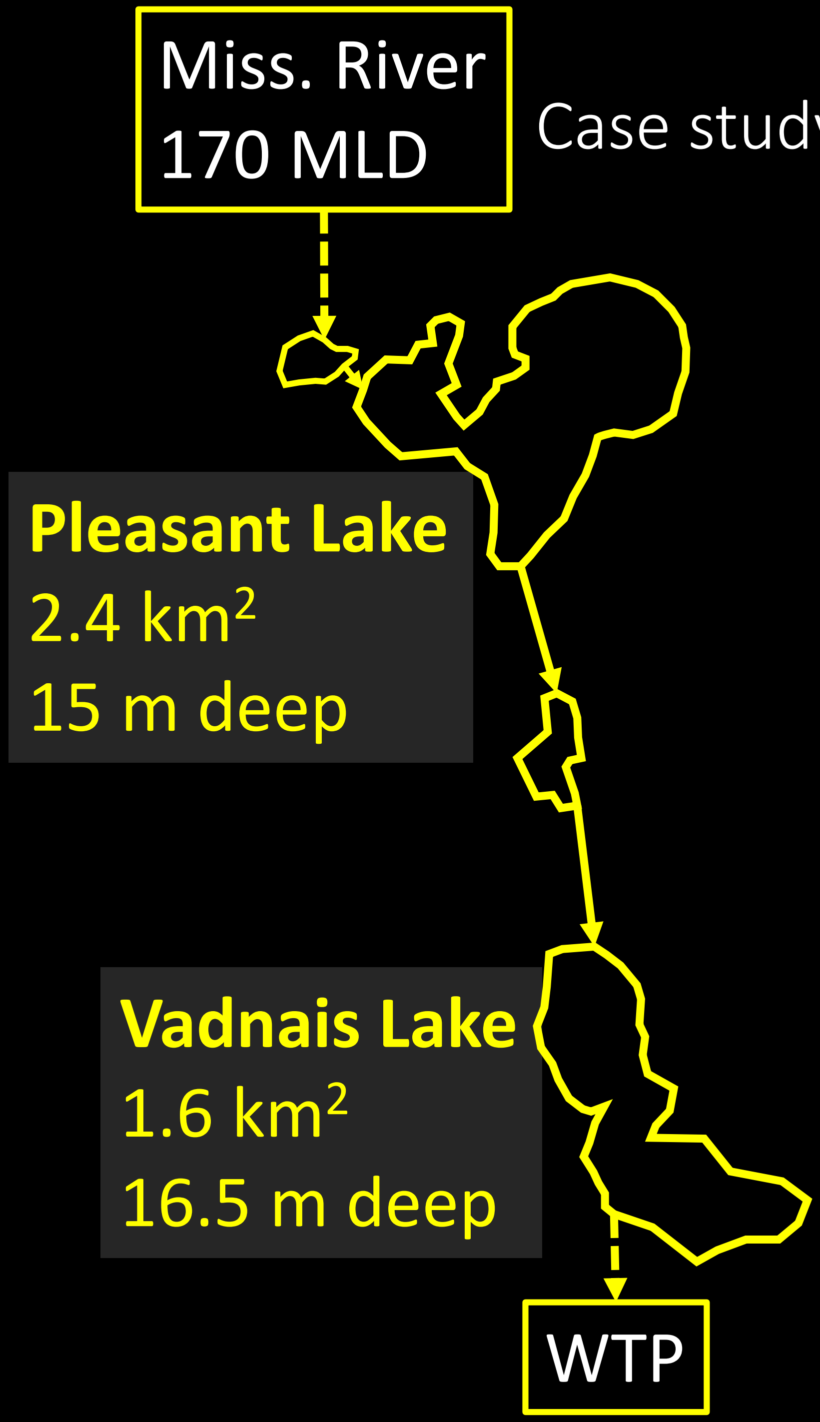


Cyanobacteria, stratification, & nutrients



1) Destroy anoxia to sequester nutrients in sediments to limit HAB growth, OR
2) Disrupt buoyancy (increase vertical diffusivity) regulation, OR
3) Create phosphate-scavenging aqueous geochemistry to limit HAB growth

Case study 1: Saint Paul Regional Water Services, Minnesota, USA



Side stream reservoirs, poor water quality

Hypolimnetic *aeration (HA)*:

Pleasant: 1994 - 2006

Vadnais: 1987 - 2010

Hypolimnetic *oxygenation (HO)*:

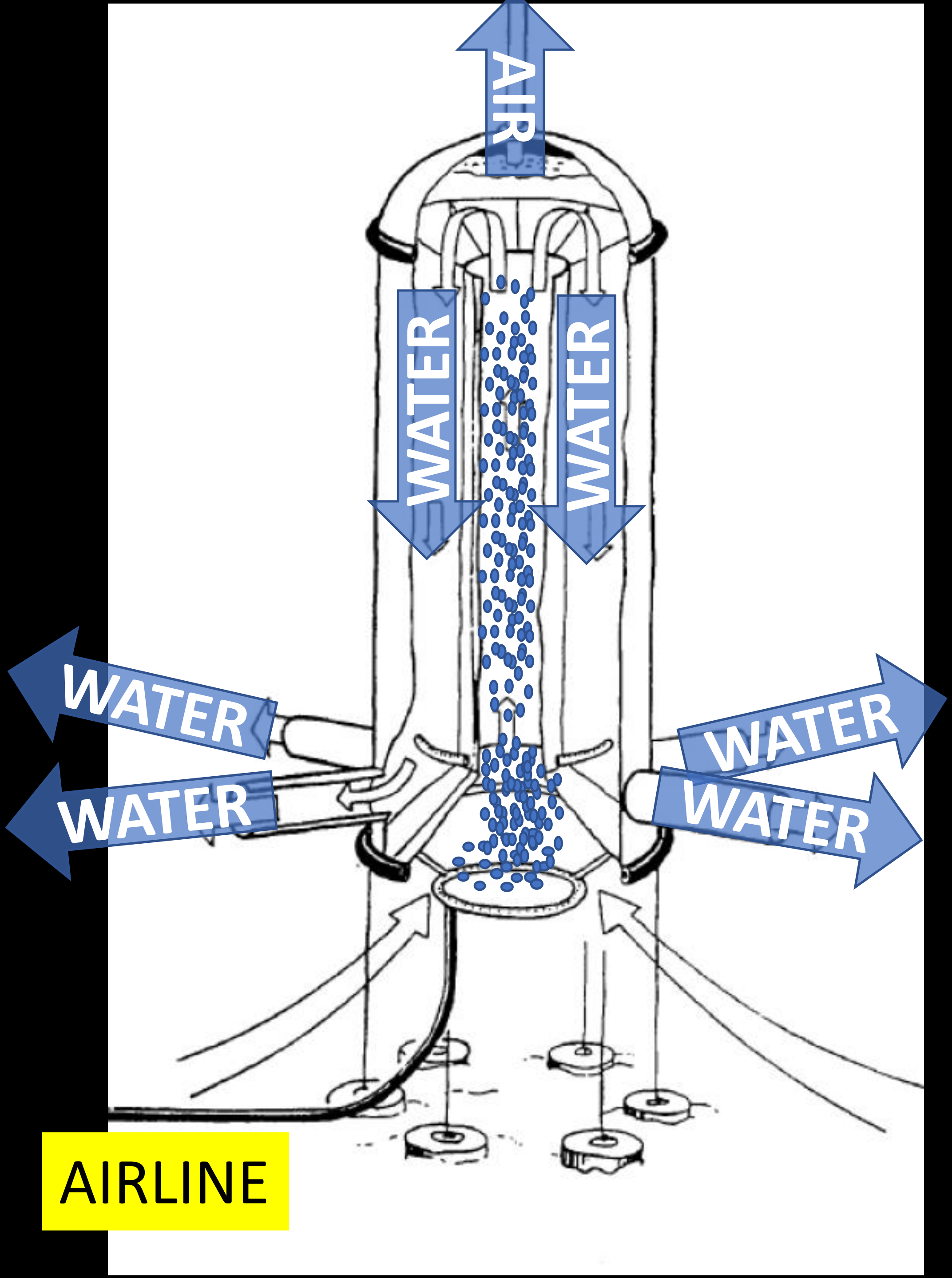
Pleasant: 2013 - Present

Vadnais: 2011 - Present

Ferric injection at Miss. pump station and Vadnais Lake

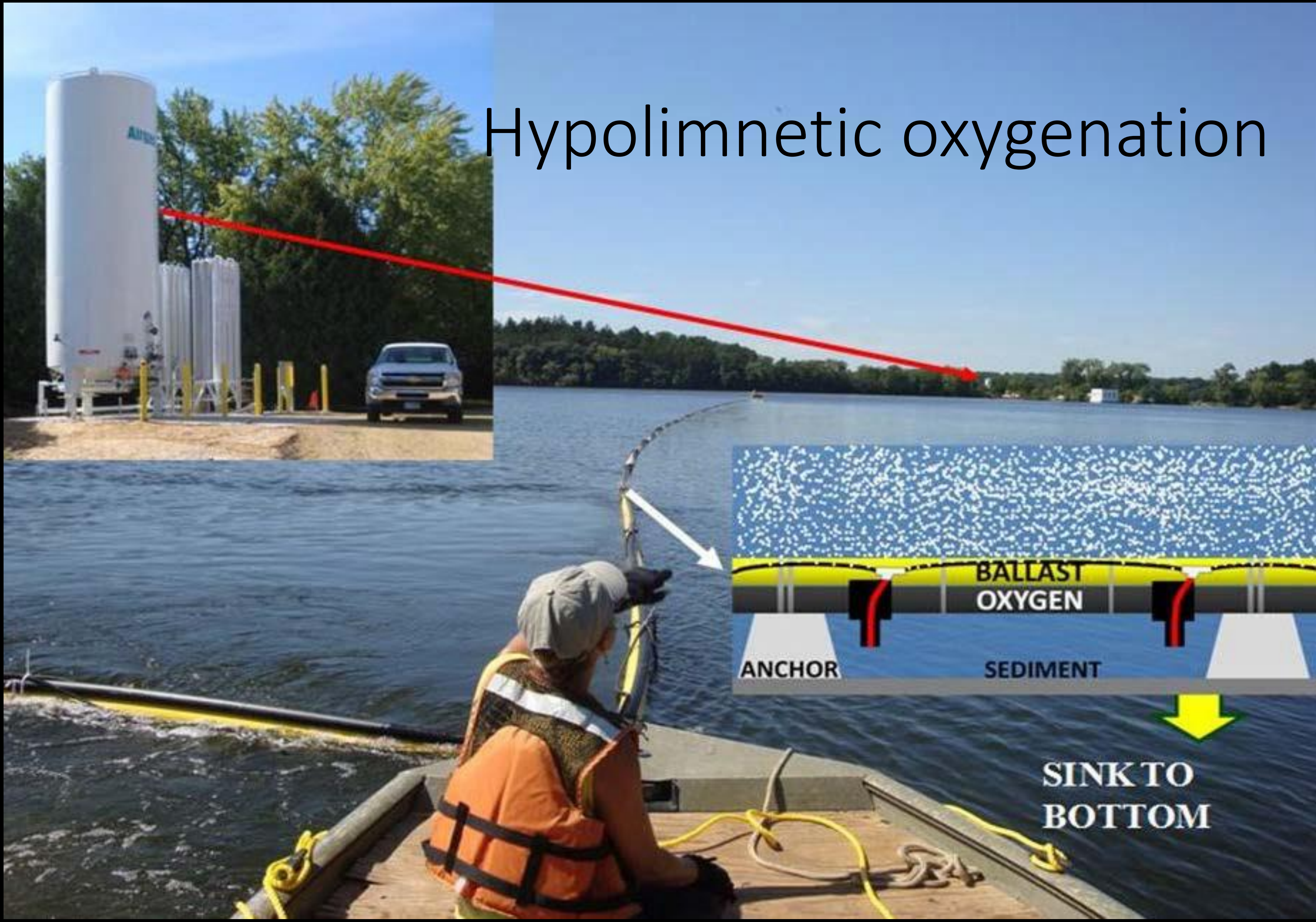
Partial-lift (submerged) hypolimnetic aeration

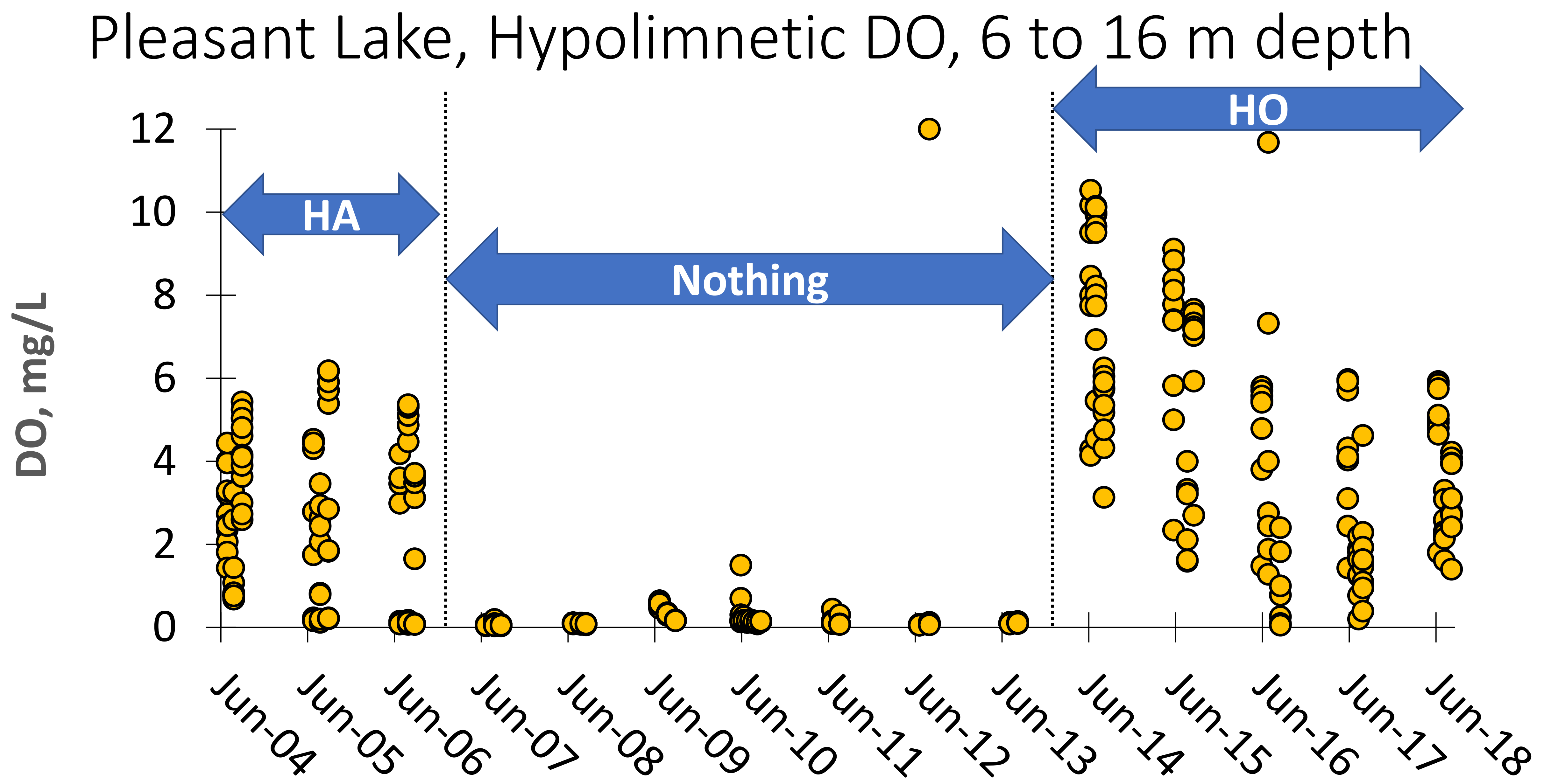
- Preserves thermal stratification
- Partially effective
- Too much turbulence
- Not recommended



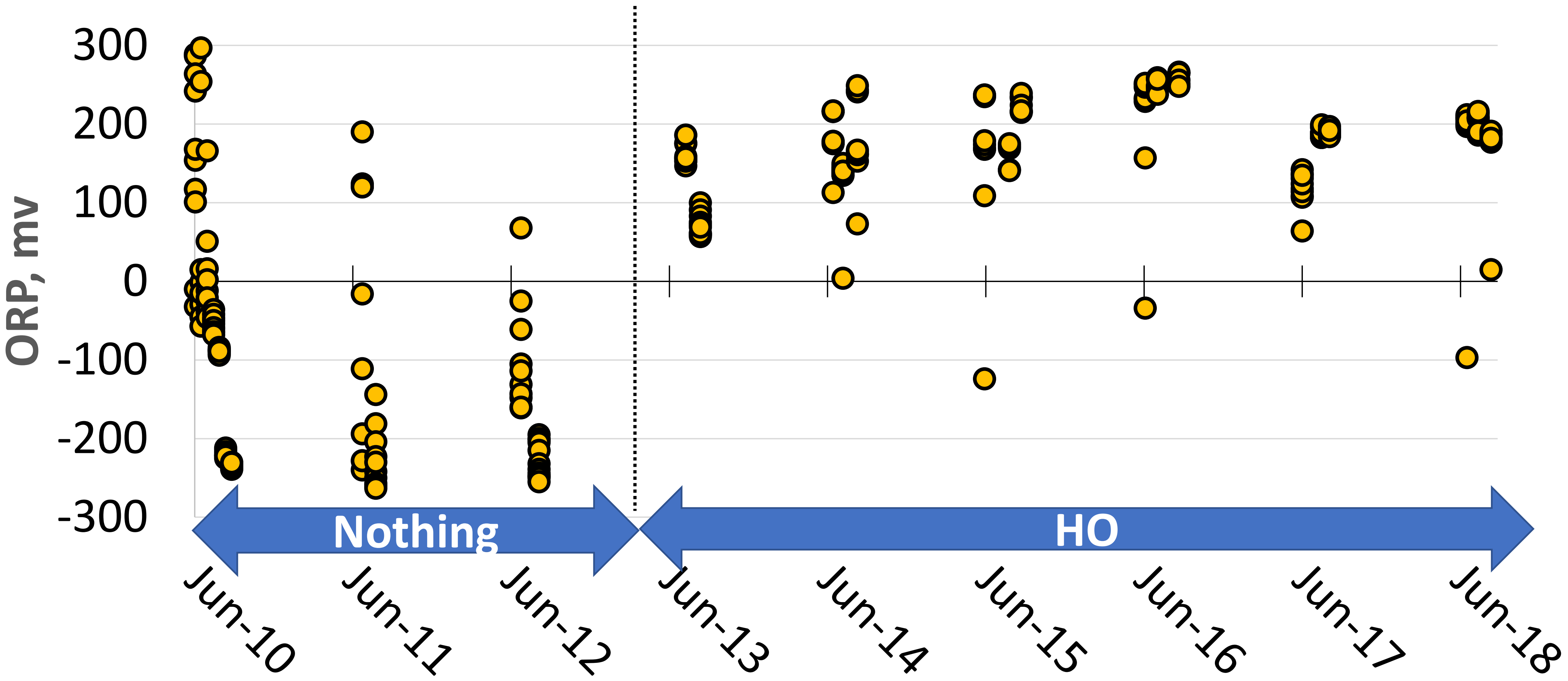
Hypolimnetic oxygenation

- Deep injection of pure O_2
- Typically powered by vaporization pressure of LOx
- Preserve thermal stratification (most of the time)

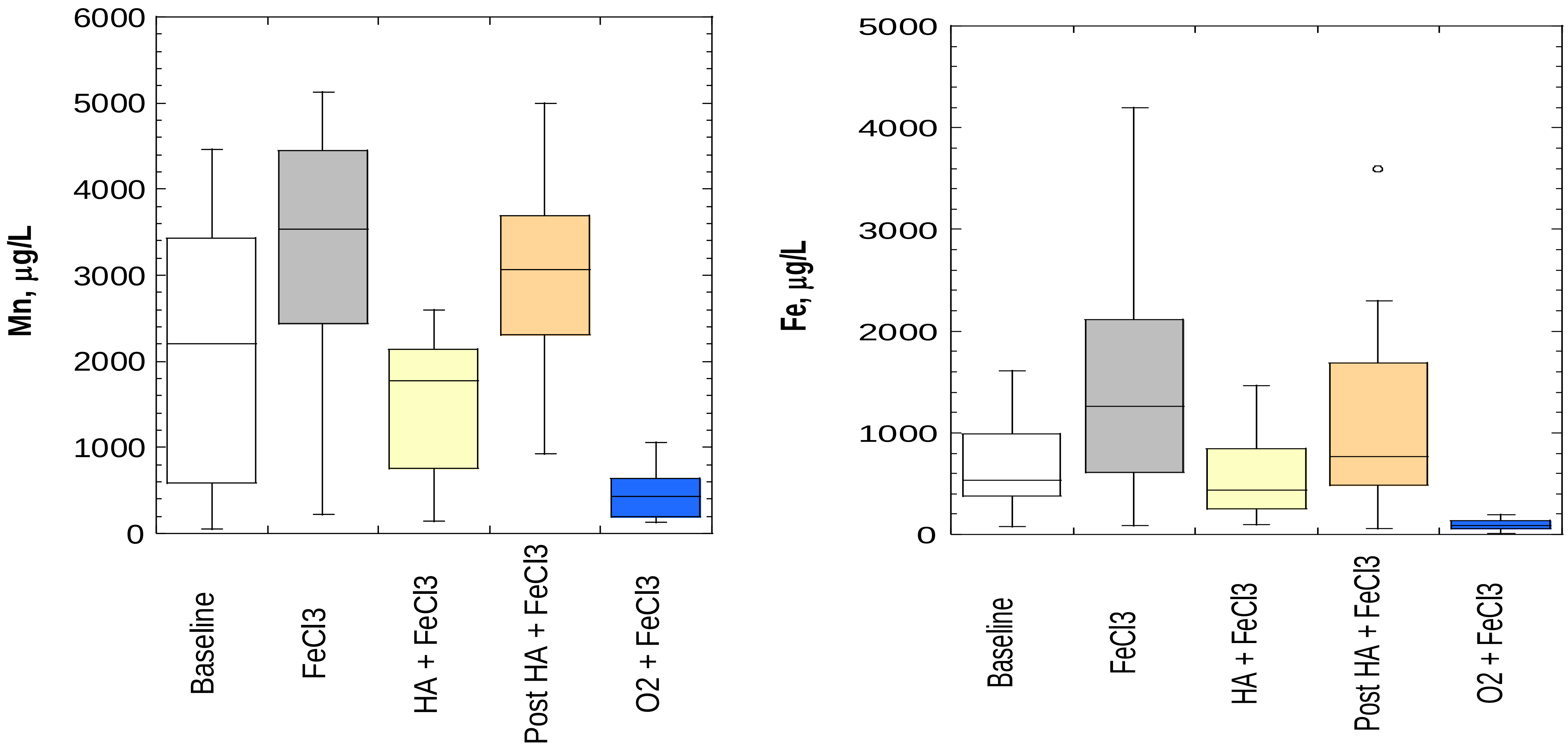



Pleasant Lake, Hypolimnetic DO, 6 to 16 m depth
DO, mg/L
0
2
4
6
8
10
12
HA
Nothing
HO
Jun-04
Jun-05
Jun-06
Jun-07
Jun-08
Jun-09
Jun-10
Jun-11
Jun-12
Jun-13
Jun-14
Jun-15
Jun-16
Jun-17
Jun-18

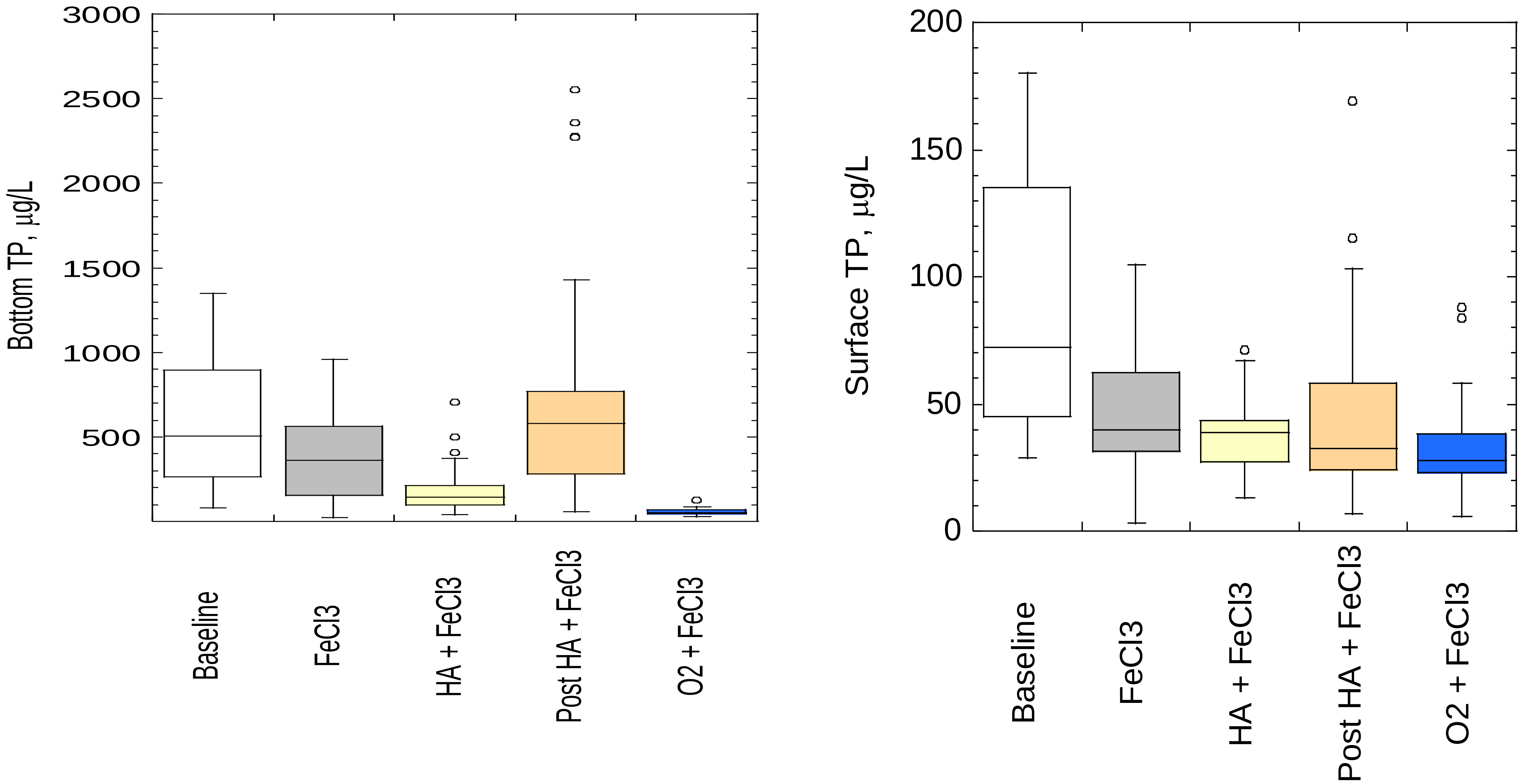
Pleasant Lake, Hypolimnetic Redox



Sulfate reduction at redox < -150 mV (this protocol)

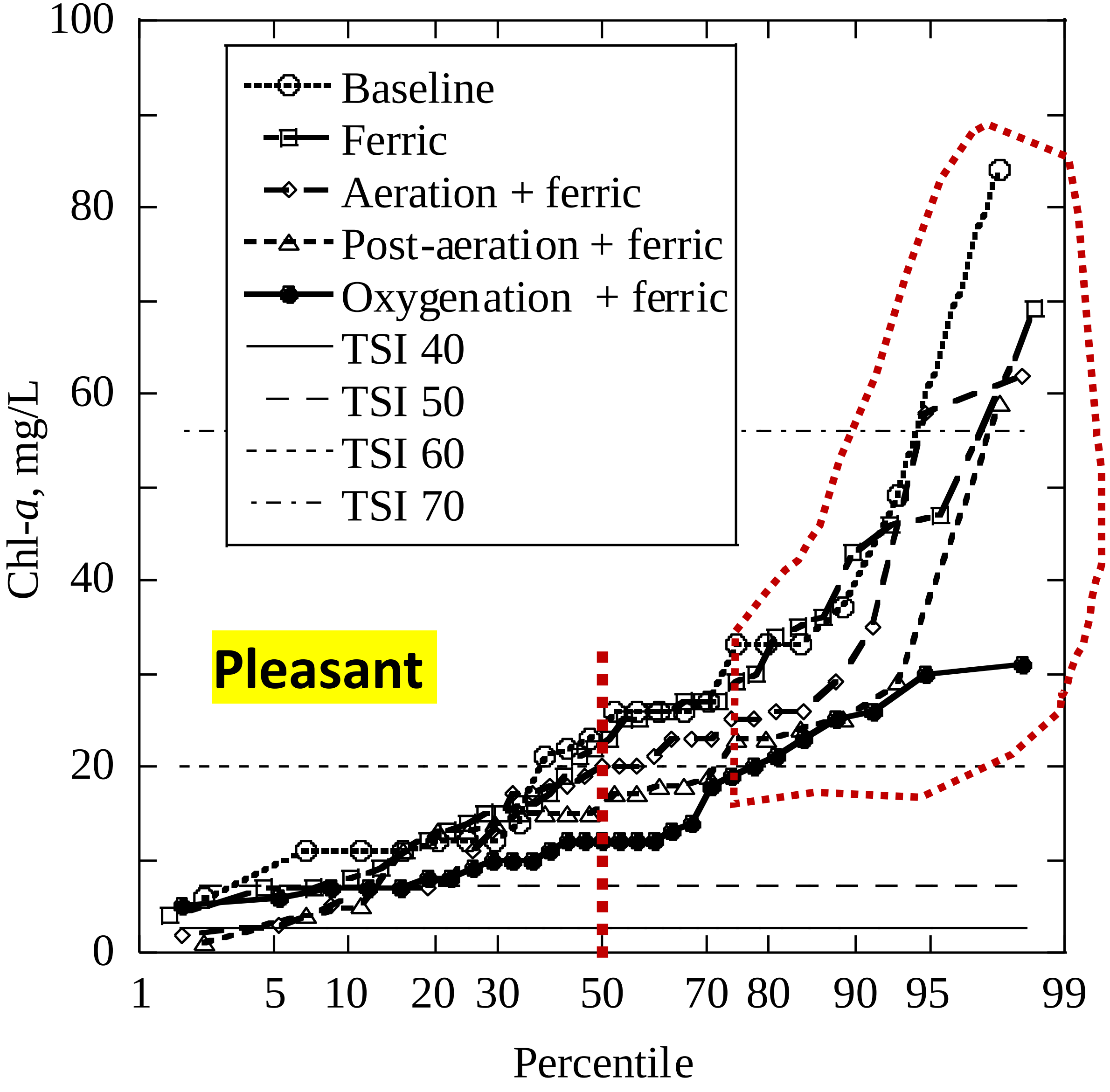


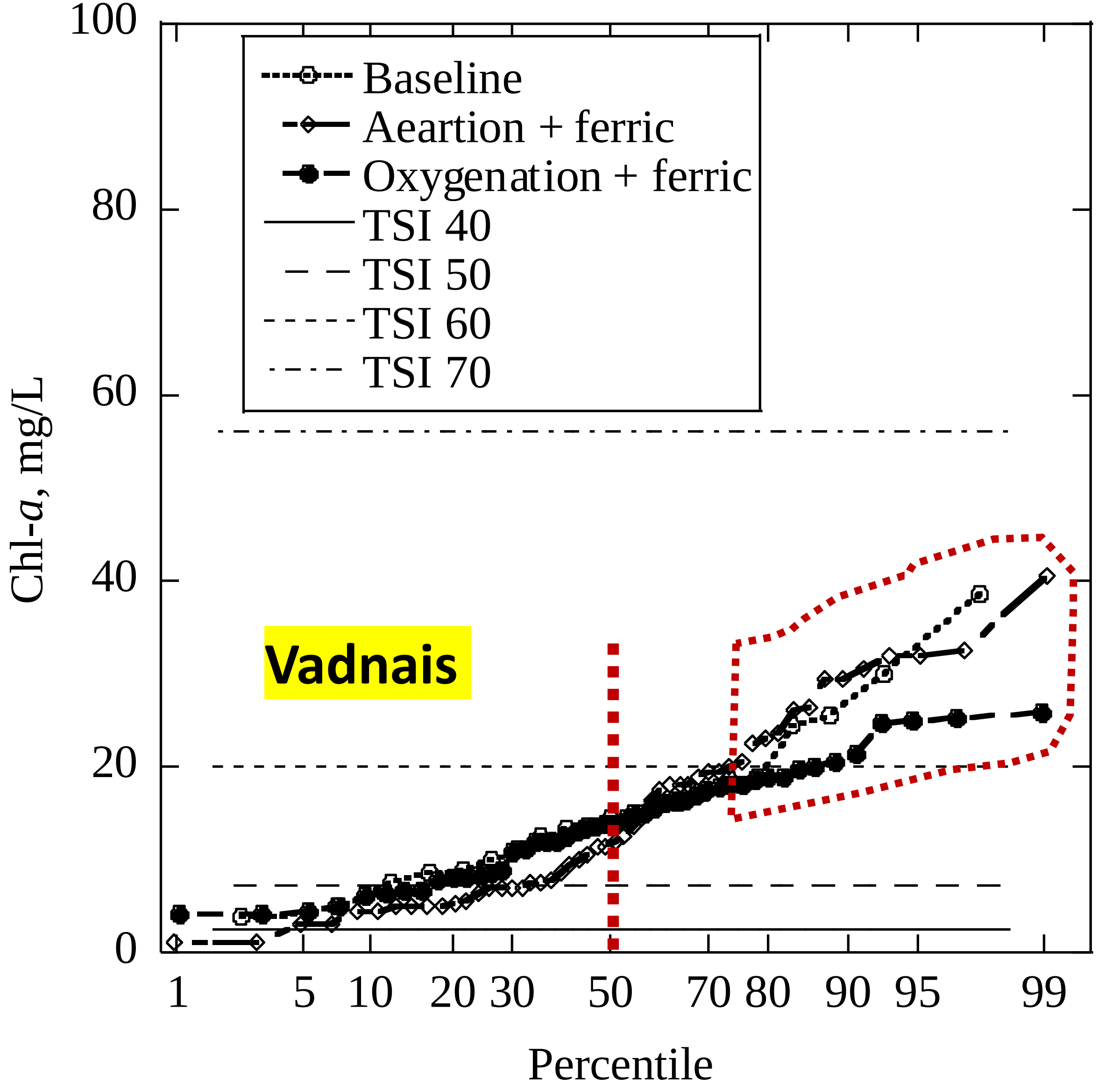
Mn, µg/L
6000
5000
4000
3000
2000
1000
0
Baseline
FeCl3
HA + FeCl3
Post HA + FeCl3
O2 + FeCl3
Fe, µg/L
5000
4000
3000
2000
1000
0
Baseline
FeCl3
HA + FeCl3
Post HA + FeCl3
O2 + FeCl3



Bottom TP, µg/L
3000
2500
2000
1500
1000
500
Baseline
FeCl3
HA + FeCl3
Post HA + FeCl3
O2 + FeCl3
Surface TP, µg/L
200
150
100
50
0
Baseline
FeCl3
HA + FeCl3
Post HA + FeCl3
O2 + FeCl3

Pleasant and Vadnais Algae (Chl-*a*) Results



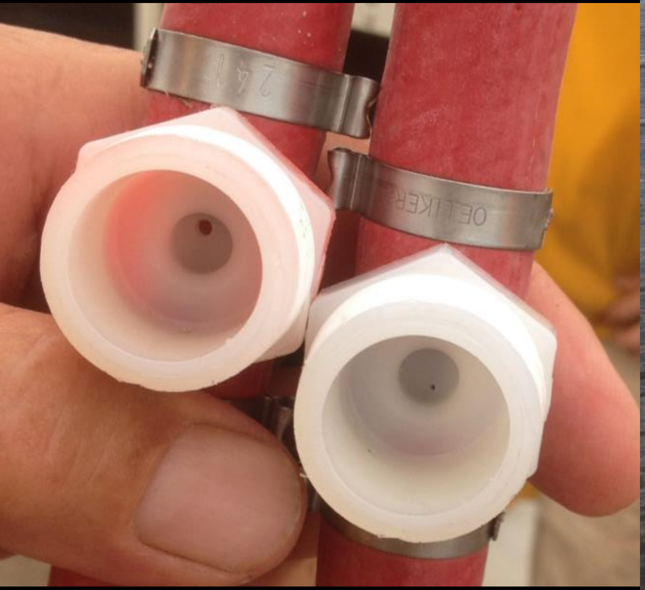


Buoyancy Disruption

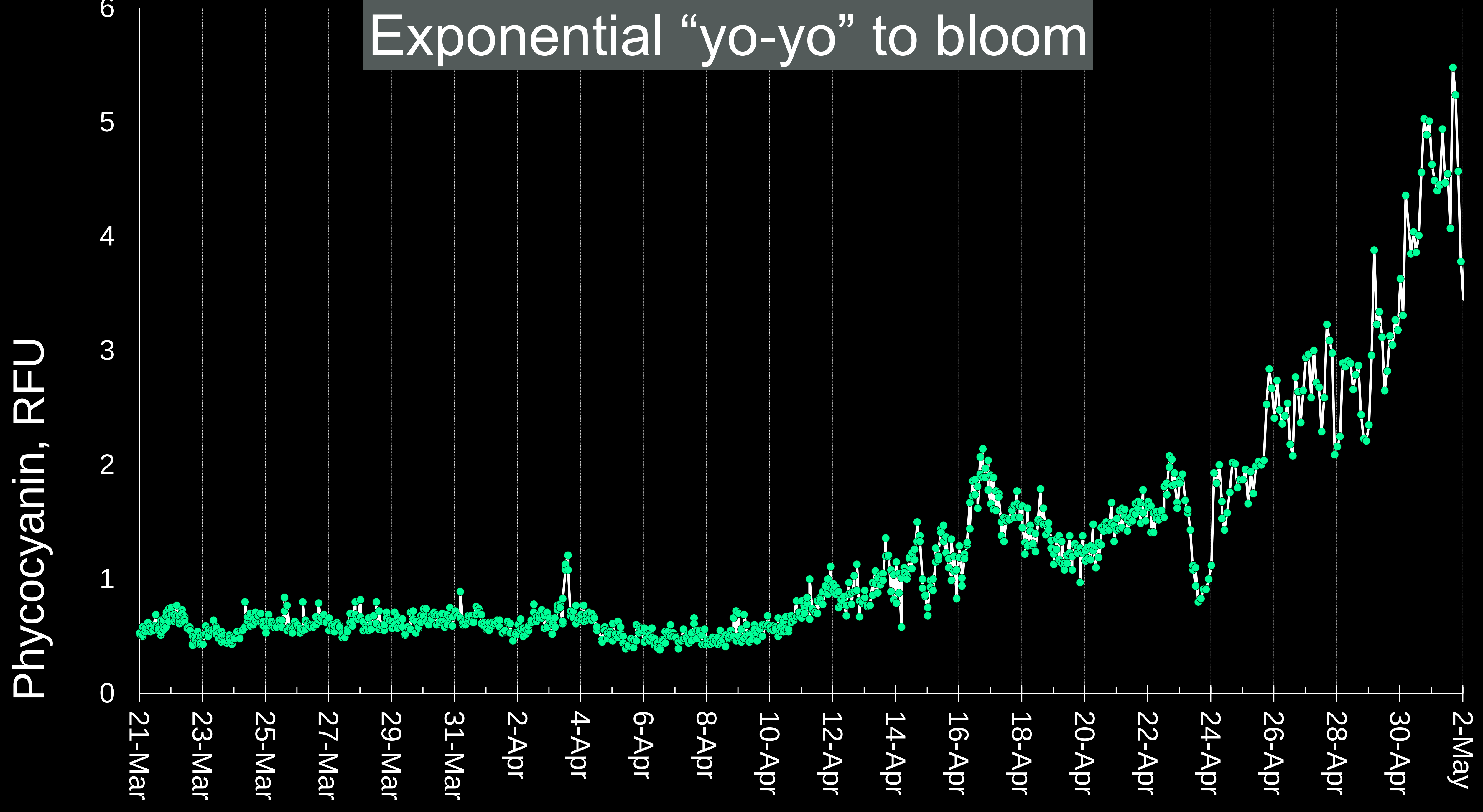
- Sidestream reservoir
  - 63 GL
  - 450 ha
  - 21 m deep
  - TP > 100 µg/L
- Aeration systems:
  - HA
  - Destratification

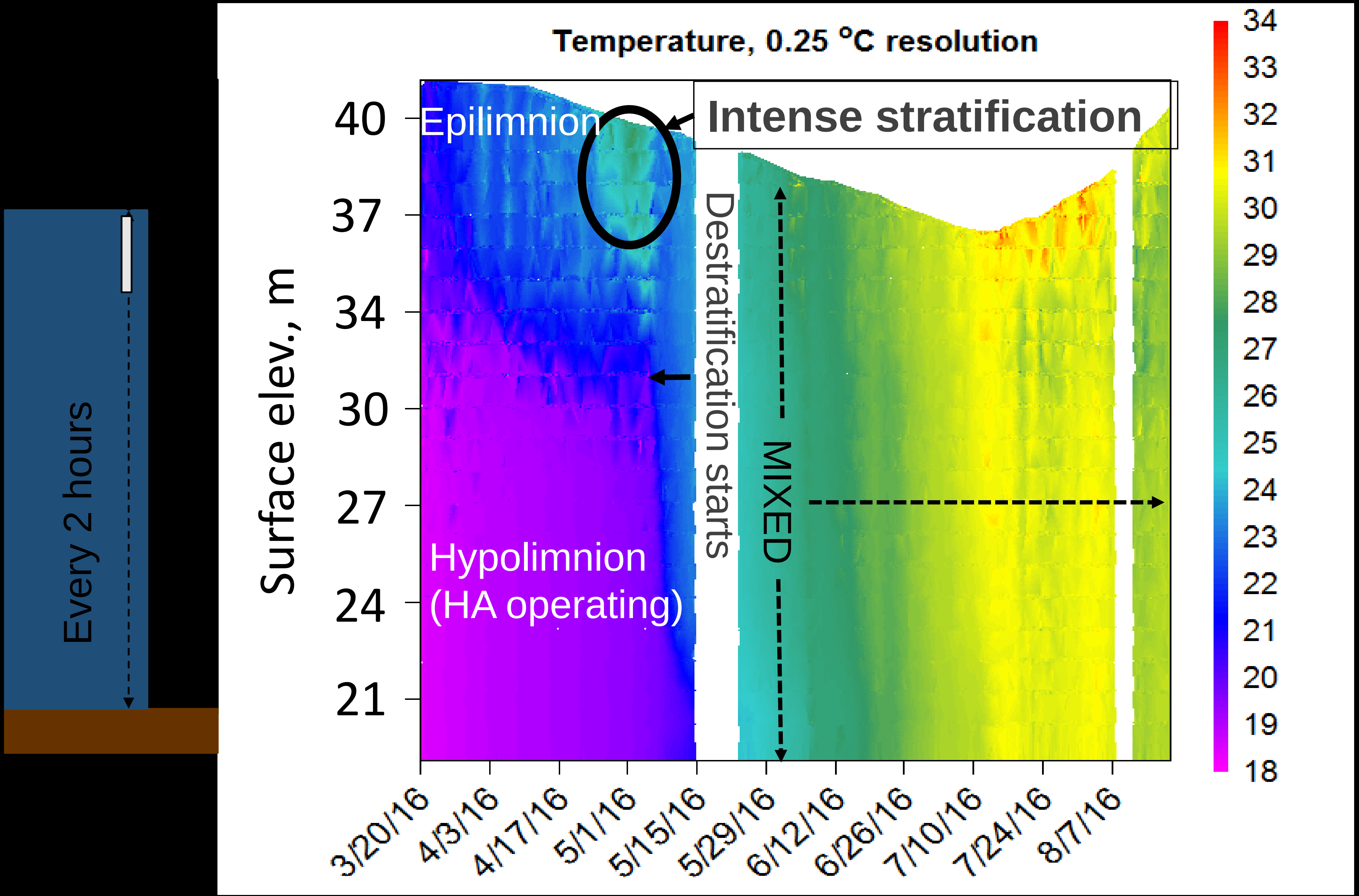
Destratification aeration

- For depths < 14 m
- Or cyanobacteria bloom any depth
- Diffuser same as pure O_2 except for orifice diameter

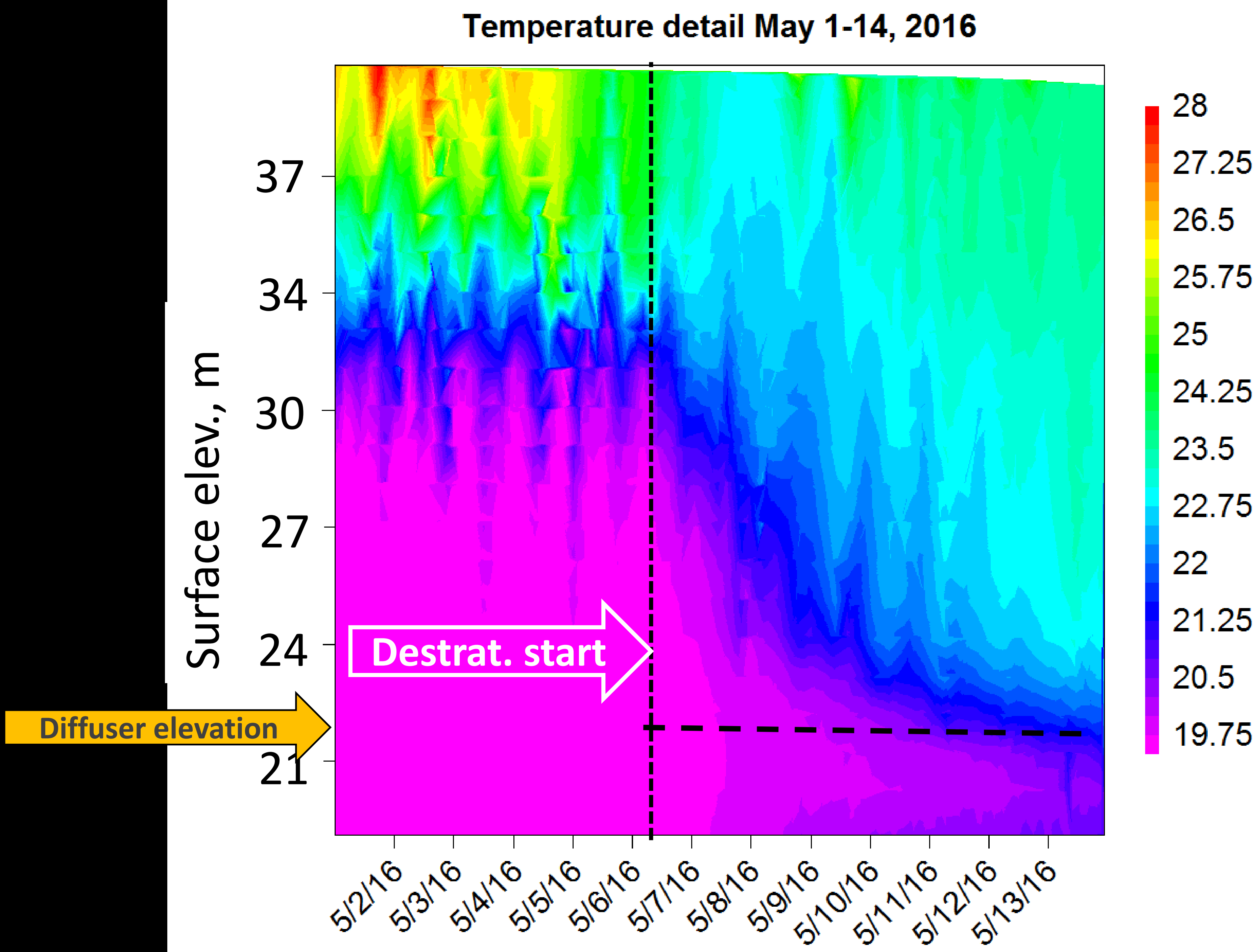


Exponential “yo-yo” to bloom



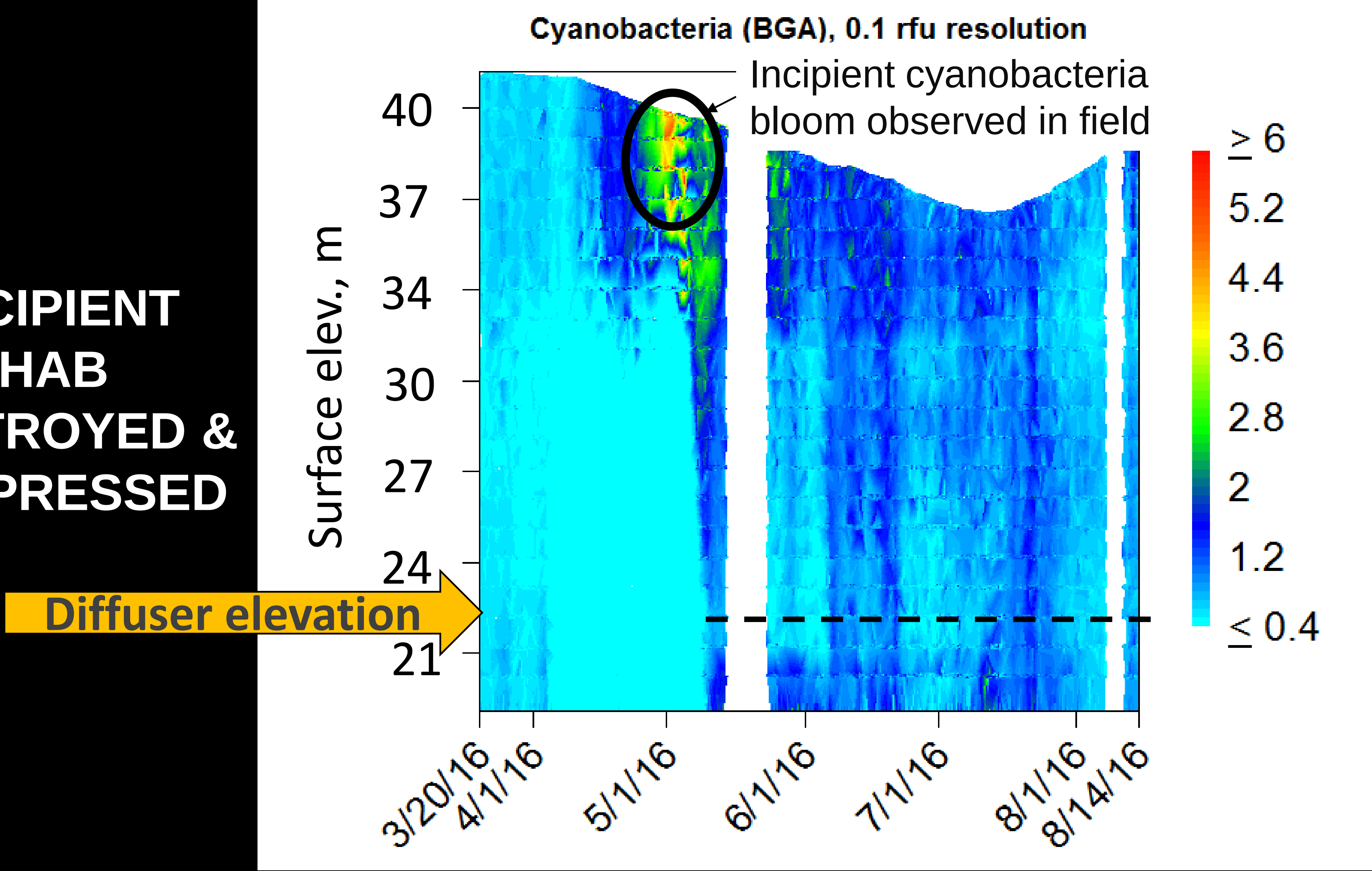


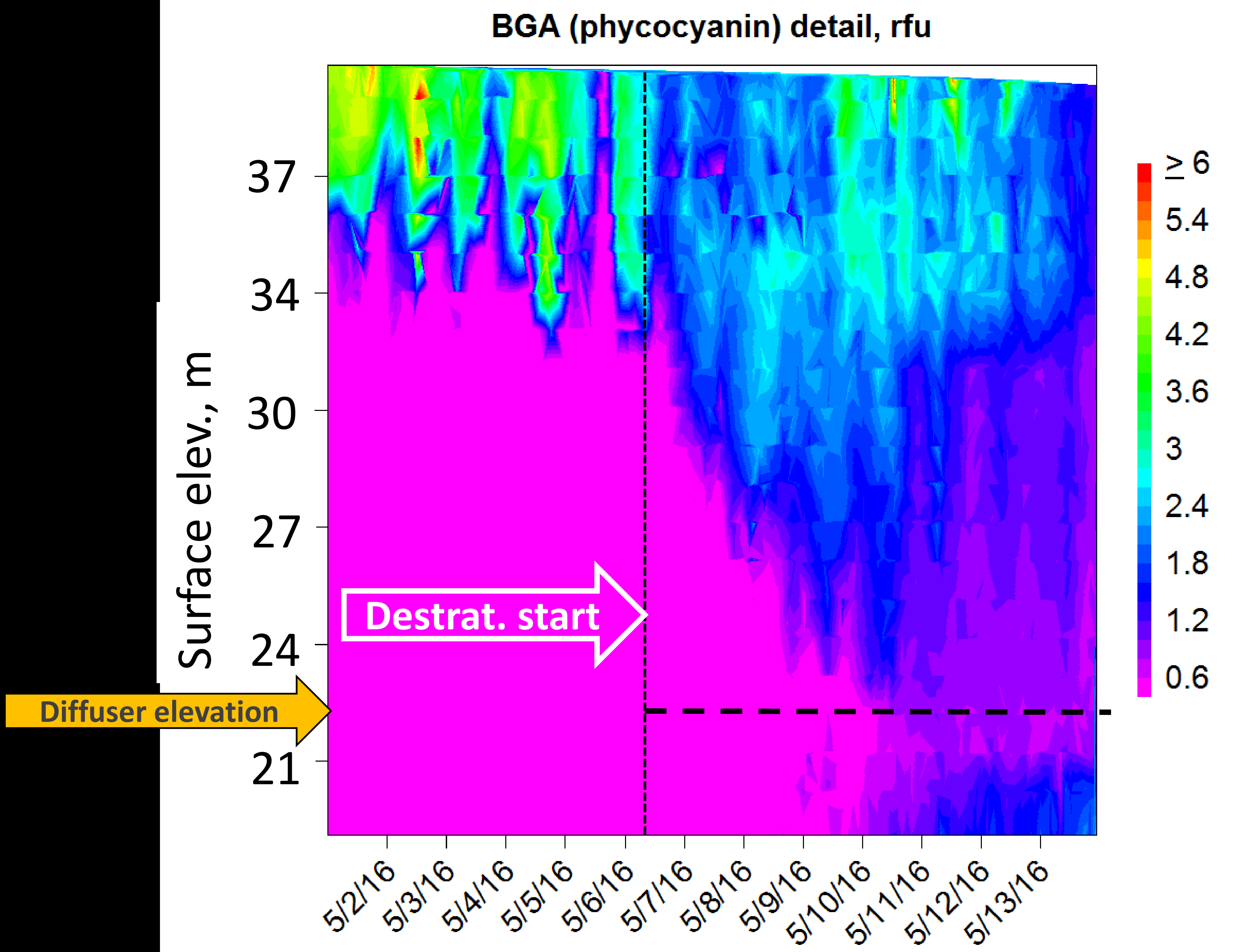
Temperature, 0.25 °C resolution
Intense stratification
Epilimnion
Hypolimnion
(HA operating)
Destratification starts
MIXED
Surface elev., m
Every 2 hours
40
37
34
30
27
24
21
3/20/16
4/3/16
4/17/16
5/1/16
5/15/16
5/29/16
6/12/16
6/26/16
7/10/16
7/24/16
8/7/16
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18



Temperature detail May 1-14, 2016
Surface elev., m
37
34
30
27
24
21
Destrat. start
Diffuser elevation
5/2/16
5/3/16
5/4/16
5/5/16
5/6/16
5/7/16
5/8/16
5/9/16
5/10/16
5/11/16
5/12/16
5/13/16
28
27.25
26.5
25.75
25
24.25
23.5
22.75
22
21.25
20.5
19.75

INCIPIENT HAB DESTROYED & SUPPRESSED





BGA (phycocyanin) detail, rfu
Surface elev., m
37
34
30
27
24
21
Destrat. start
Diffuser elevation
5/2/16
5/3/16
5/4/16
5/5/16
5/6/16
5/7/16
5/8/16
5/9/16
5/10/16
5/11/16
5/12/16
5/13/16
≥ 6
5.4
4.8
4.2
3.6
3
2.4
1.8
1.2
0.6

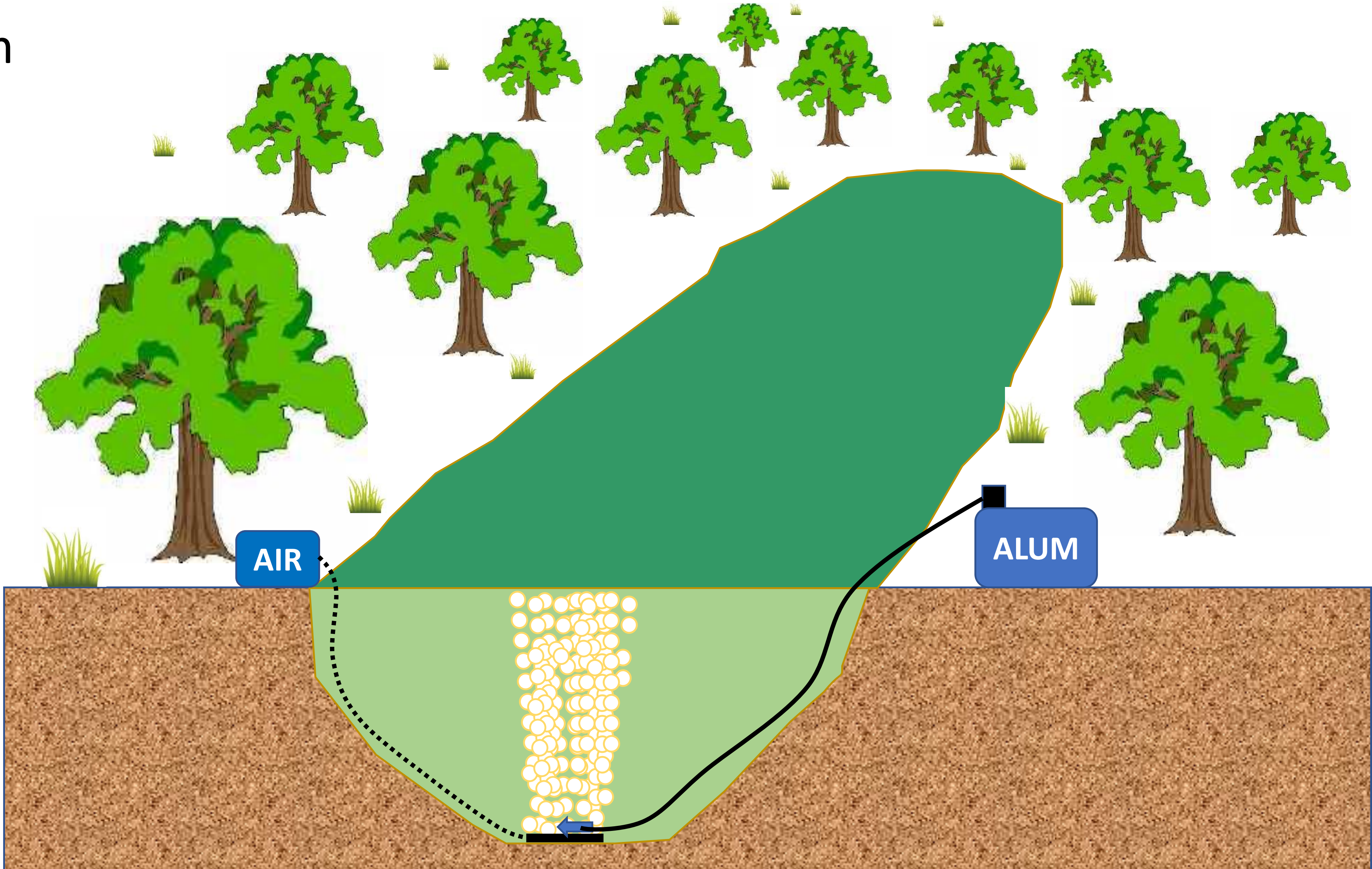
Case study 3:
Veteran’s Lake, Great Bend, Kansas

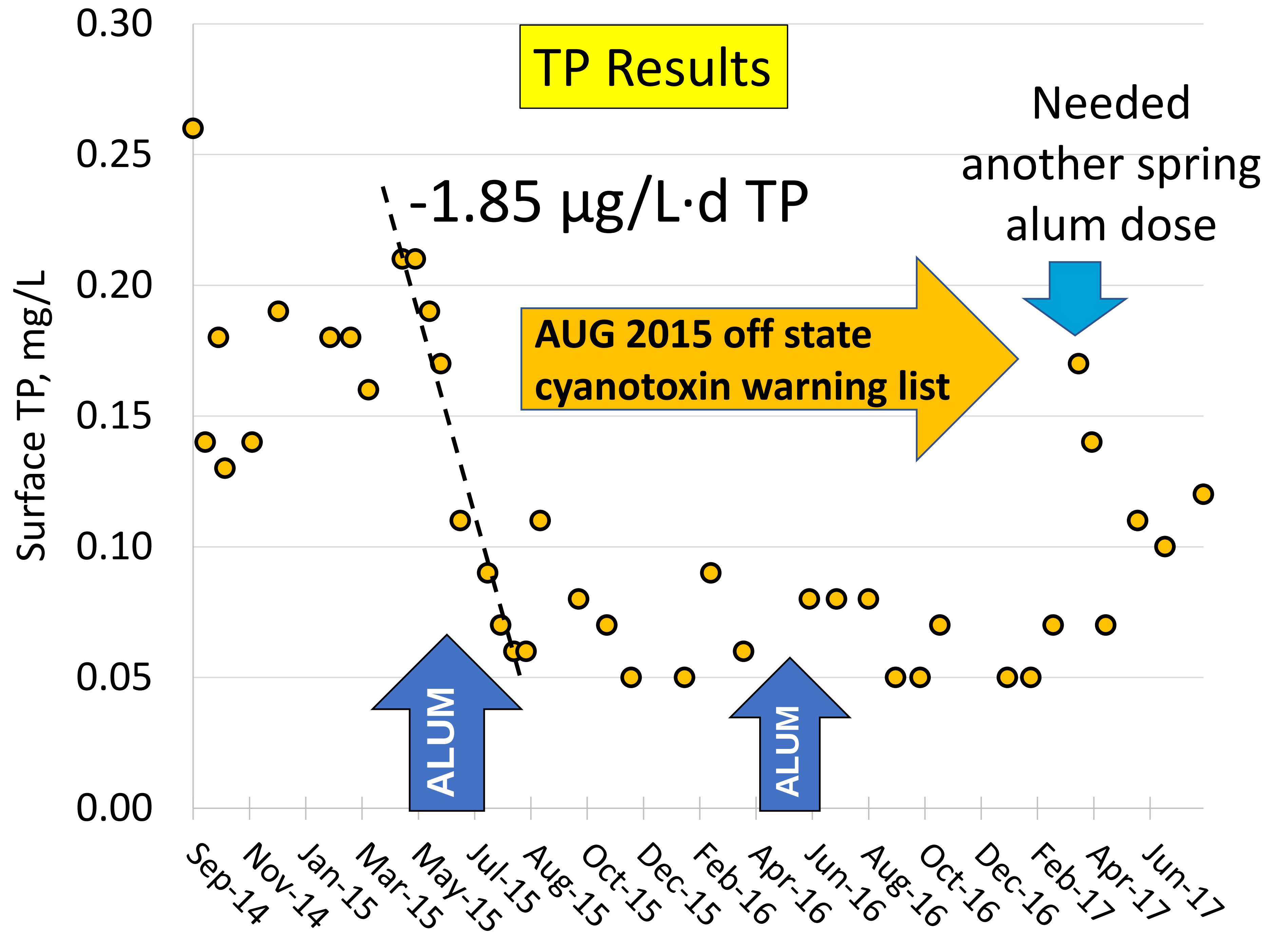
- Urban lake
- Stormwater fed
- 5.6 ha
- 2.4 m deep
- Heavy HAB

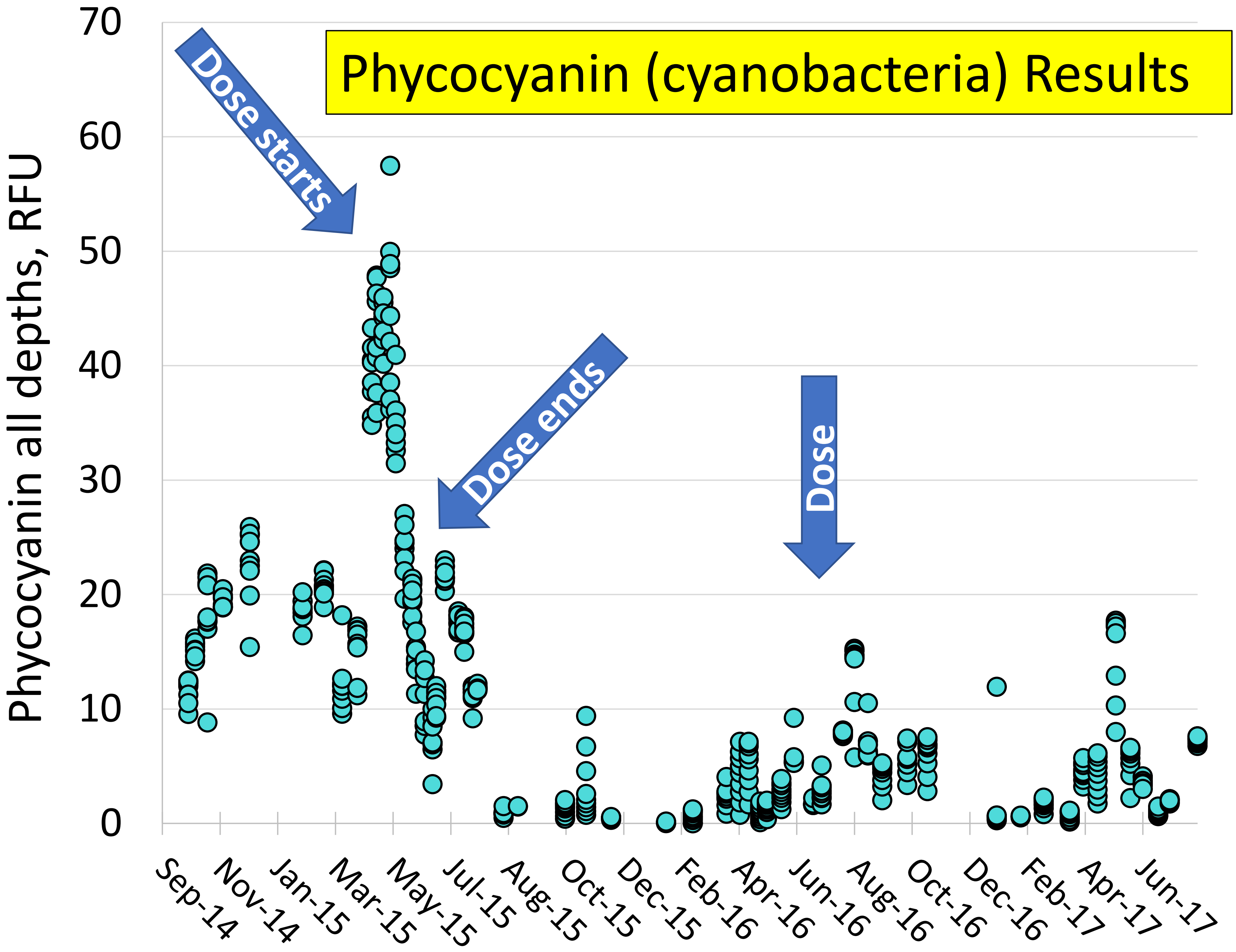
http://www.greatbendpost.com/

Geochemical augmentation

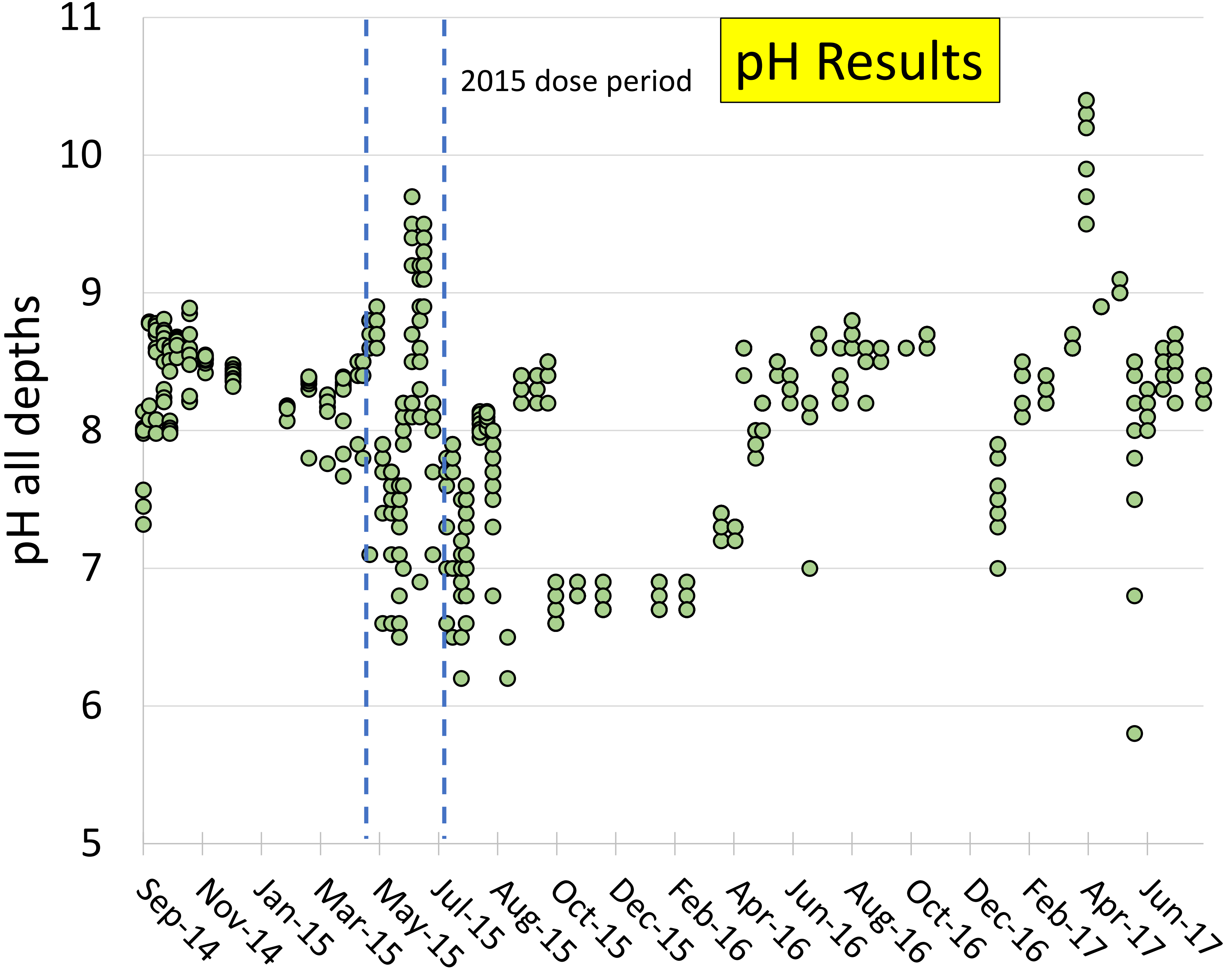
- Inject ***soluble*** alum dose over months (3 in case study)
- Create Al-PO_4 scavenging geochemistry in lake
- Simple infrastructure




TP Results
-1.85 µg/L·d TP
Needed another spring alum dose
AUG 2015 off state cyanotoxin warning list
ALUM
ALUM
Surface TP, mg/L
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Sep-14
Nov-14
Jan-15
Mar-15
May-15
Jul-15
Aug-15
Oct-15
Dec-15
Feb-16
Apr-16
Jun-16
Aug-16
Oct-16
Dec-16
Feb-17
Apr-17
Jun-17

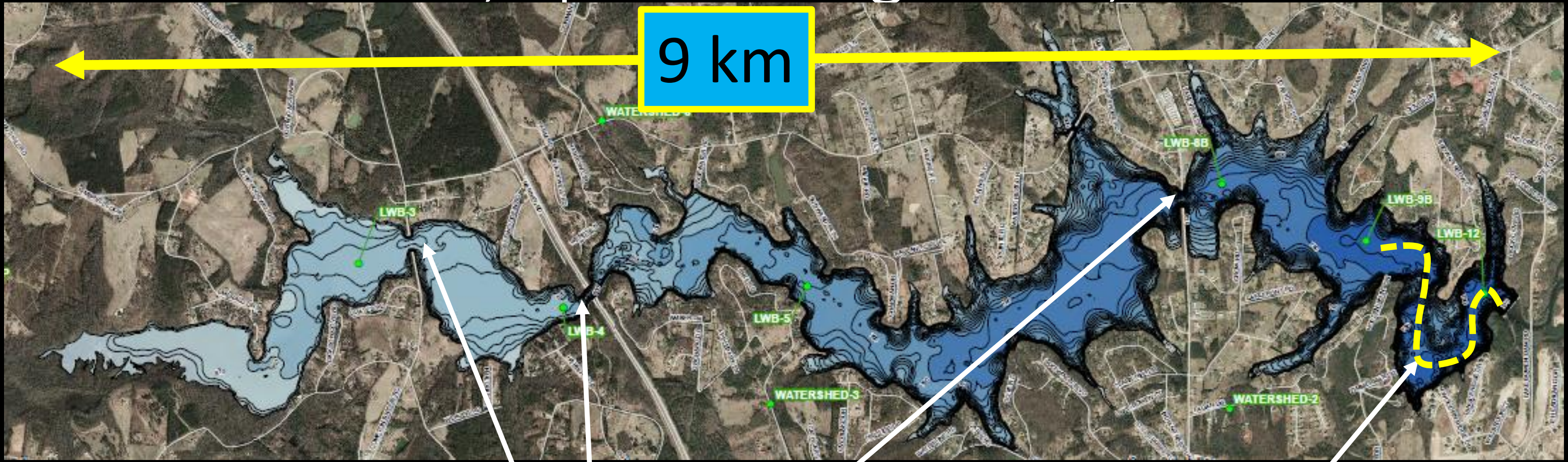


Phycocyanin (cyanobacteria) Results
Dose starts
Dose ends
Dose
Phycocyanin all depths, RFU
70
60
50
40
30
20
10
0
Sep-14
Nov-14
Jan-15
Mar-15
May-15
Jul-15
Aug-15
Oct-15
Dec-15
Feb-16
Apr-16
Jun-16
Aug-16
Oct-16
Dec-16
Feb-17
Apr-17
Jun-17



pH Results
2015 dose period
pH all depths
11
10
9
8
7
6
5
Sep-14
Nov-14
Jan-15
Mar-15
May-15
Jul-15
Aug-15
Oct-15
Dec-15
Feb-16
Apr-16
Jun-16
Aug-16
Oct-16
Dec-16
Feb-17
Apr-17
Jun-17

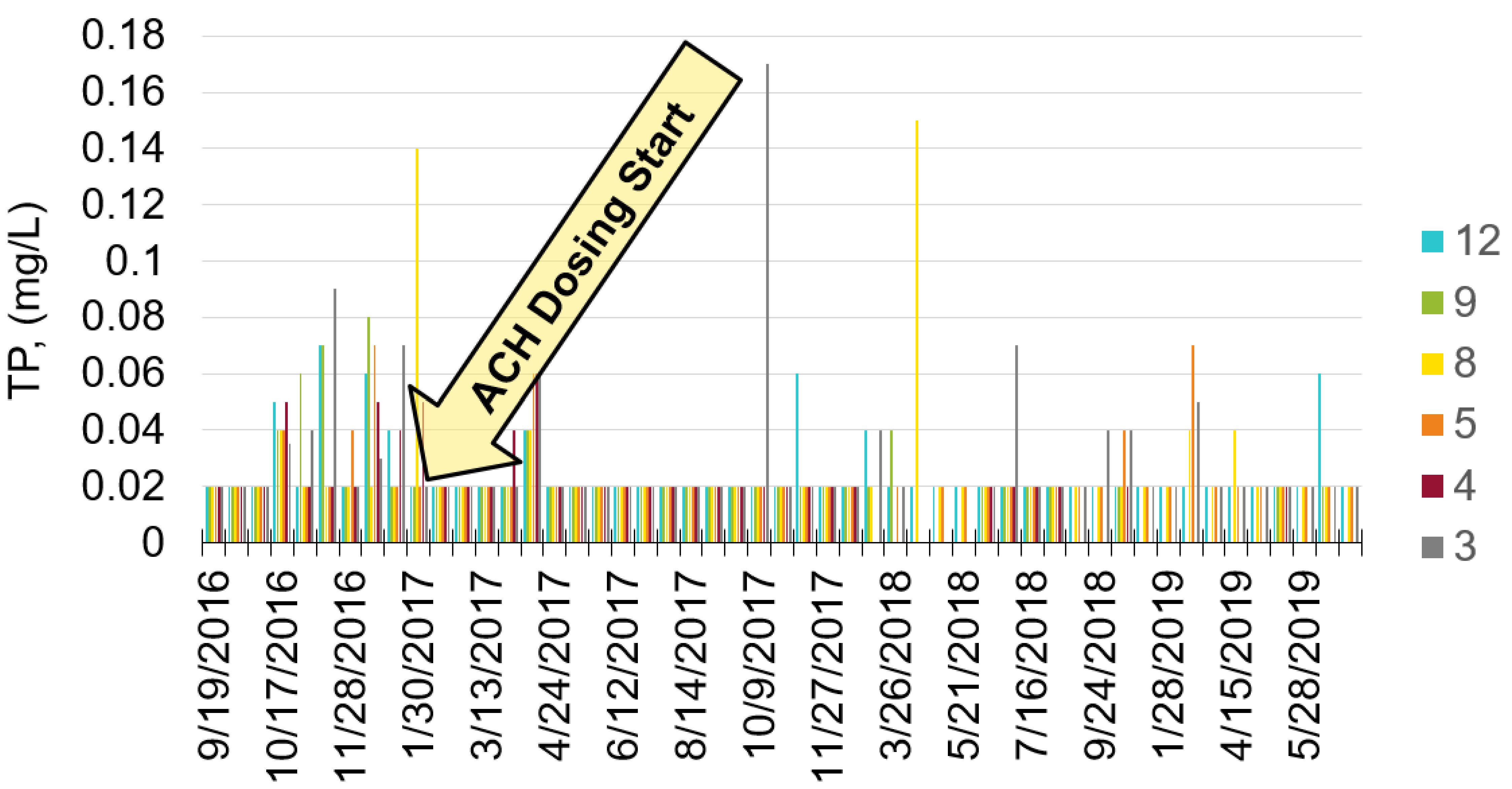
Case Study 4:
Lake Bowen Reservoir, Spartanburg Water, South Carolina



$O_2 + FeCl_3$

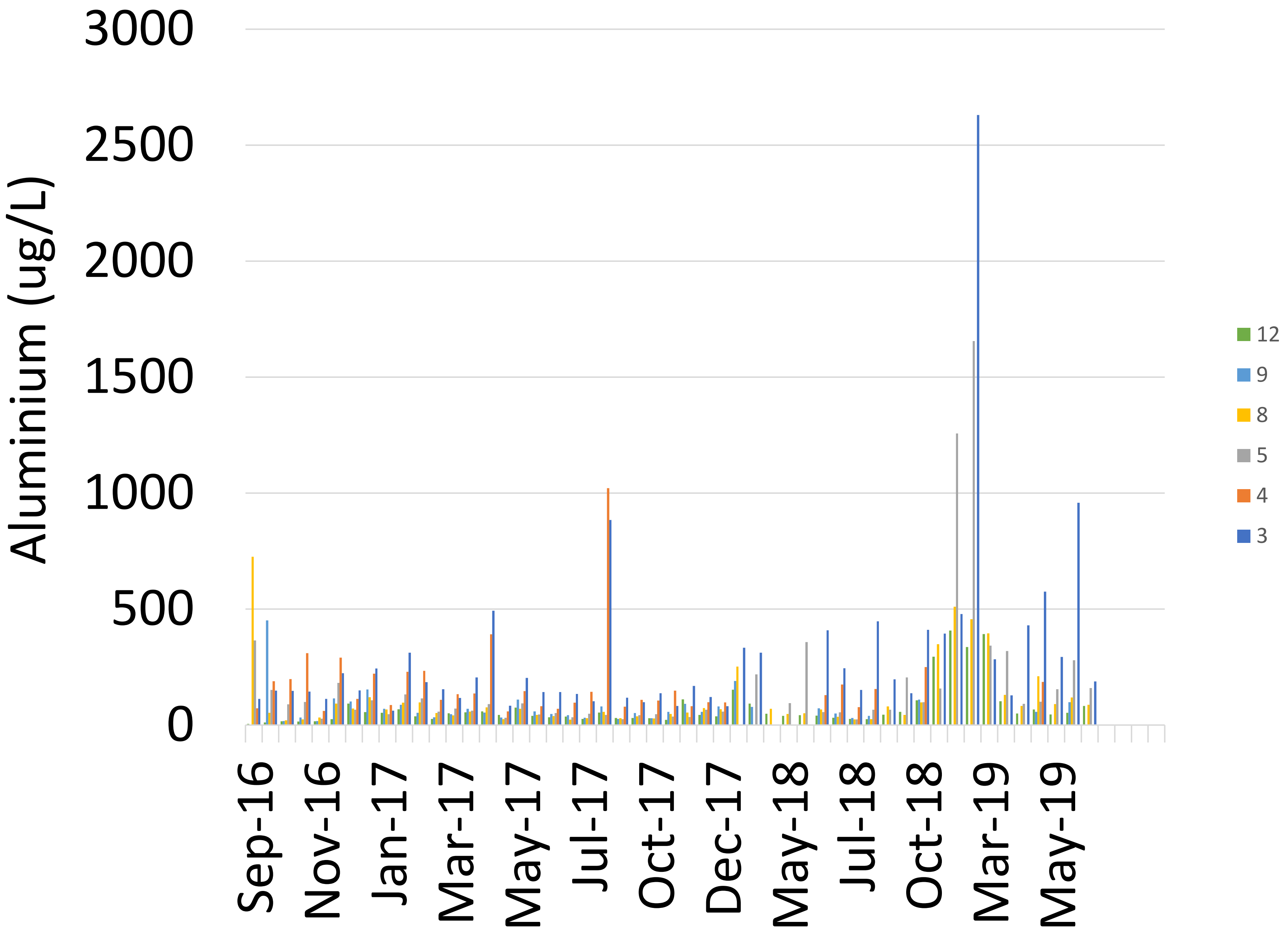
ACH continuous injection at narrows

Surface TP results



Aluminum results

- US EPA 2018 model
  - pH, DOC, hardness inputs
  - 4-day rolling average Al Conc.
- About 1500 µg/L chronic toxicity threshold in Lake Bowen



Conclusions

- Key HAB drivers subject to ecologically engineered controls
- **Nutrient denial**:
  - Hypolimnetic oxygenation superior to aeration/mixing to keep PO_4 bound to ferric iron in sediments
  - Geochemical augmentation (continuous dose, < chronic toxicity):
    - Ferric iron: requires O_2 injection, best for deeper water
    - Aluminum salts: best for shallow water
- **Buoyancy disruption**: Effective, but probably requires a critical depth (> 10 m?) to mix cyanobacteria out of light

Questions?

September 19, 2019

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