Comprehensive Strategies to Protect Drinking Water from Harmful Algal Blooms

Webinar Series #3: Mitigation of Internal Nutrient Loads in Drinking Water Sources

US Army Corps of Engineers®

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Webinar Logistics:

- The meeting will begin at 1200 CDT.
- To access the audio select “Call Me” – this is the preferred option to reduce feedback.
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  - Dial: 1-844-800-2712
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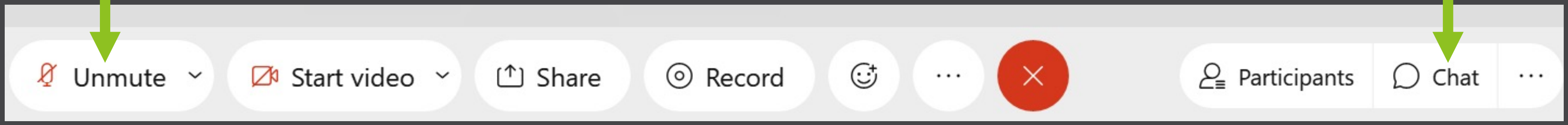
Webinar Instructions

- All lines are muted.
- Submit questions or comments in the Chat Box to "Everyone".
- The webinar is being recorded and will be shared following the meeting.



Webinar Series: Comprehensive Strategies to Protect Drinking Water from Harmful Algal Blooms

American Water Works Association

NALMS
NORTH AMERICAN LAKE MANAGEMENT SOCIETY™

APMS
The Aquatic Plant Management Society

1st Presentation

Dr. Bob Kortmann earned his BS in Environmental Science at Rutgers, then a Masters in Botany at UConn. He then earned his Ph.D. in Applied Limnology and Ecosystem Ecology in an interdisciplinary program in the Biological Sciences, Natural Resources, and Engineering Schools at the University of Connecticut.

He has worked on lakes and water supply reservoirs nationwide and as far away as Sao Paulo, Brazil. He invented several naturalistic lake restoration technologies, was awarded four US Patents, and was awarded the Technology Innovator Award by EPA Region 1 for inventing Layer Aeration.

Dr. Kortmann and Ecosystem Consulting Service recently joined GZA GeoEnvironmental, Inc. to continue to manage and restore lakes and water supply reservoirs, and improve raw water quality and water treatment efficiency.

SUMMER SERIES 2021

COMPREHENSIVE STRATEGIES TO PROTECT DRINKING WATER FROM HARMFUL ALGAL BLOOMS

Artificial Circulation, Hypolimnetic and Layer Aeration, Oxygenation, and other techniques to control Internal Loading and Cyanobacteria in Water Supply Systems

Robert (Bob) Kortmann, Ph.D.
Senior Consultant – Applied Limnologist
GZA GeoEnvironmental, Inc.

Known for excellence.
Built on trust.

NALMS

APMS
The Aquatic Plant Management Society

American Water Works Association

How does Internal Loading Work?

How and When does it Stimulate Cyanobacteria Blooms?

What can be done to Control Internal Loading?

- **Various Circulation, Aeration, and Oxygenation Methods**
- **Emerging Technologies**
- **Methods Specific to Source Water Reservoir Systems**

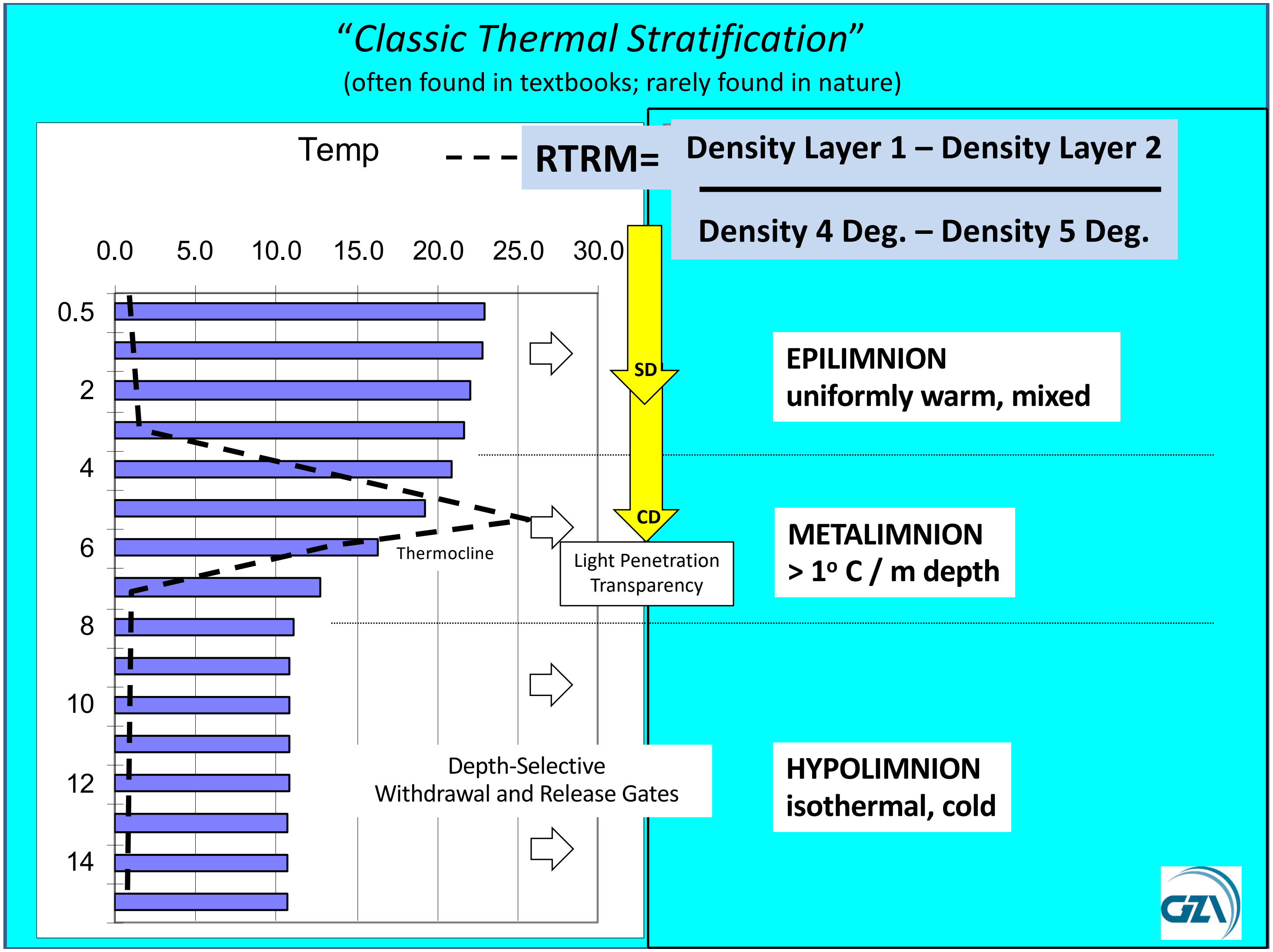
Quantifying Thermal Stratification Structure

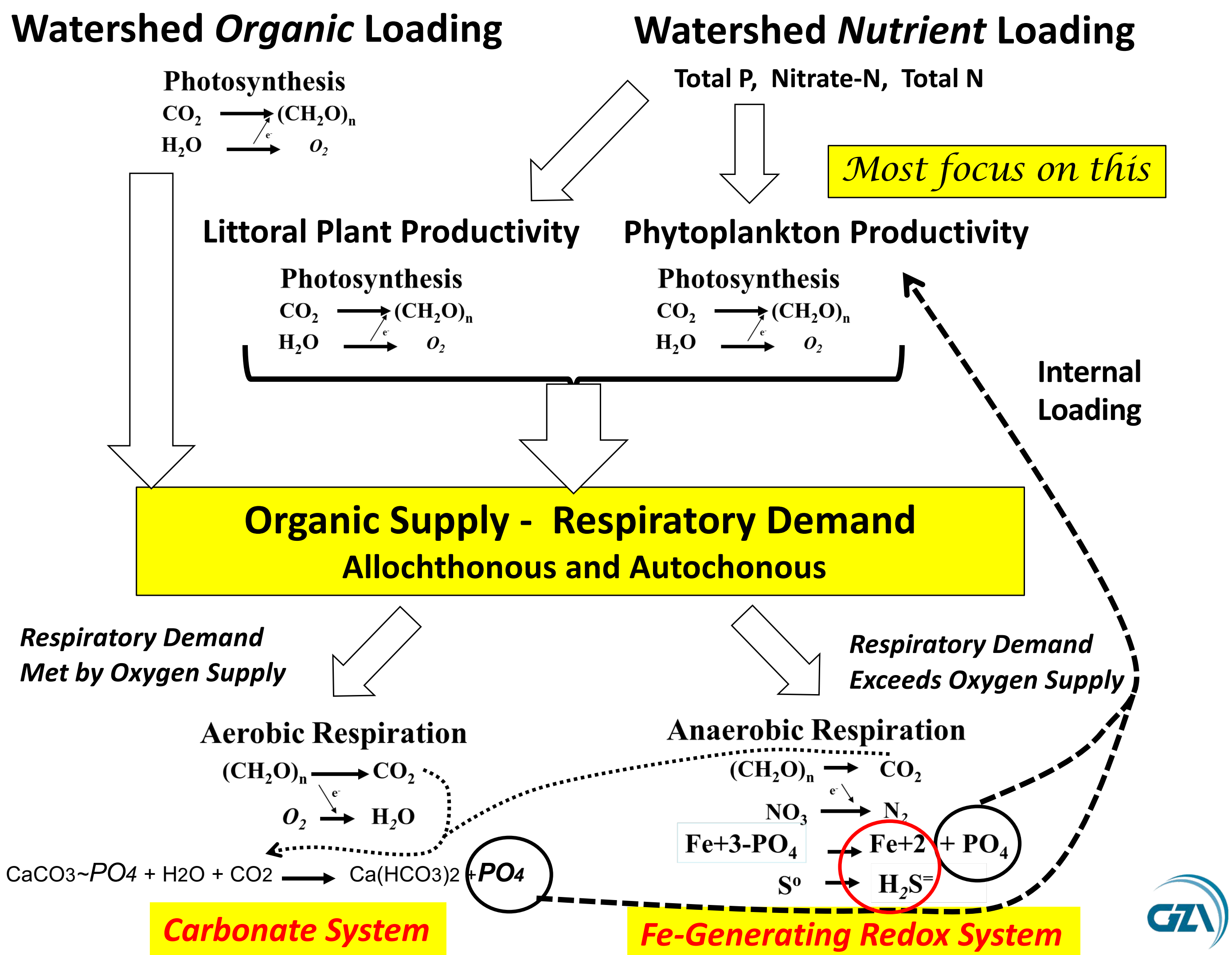
Relative Thermal Resistance to Mixing; RTRM

Anoxia Doesn't Cause Internal Nutrient Loading!

Subsequent Anaerobic Respiration Does.

(We need to examine the anaerobic respiration that happens after Oxygen Depletion!)


"Classic Thermal Stratification"
(often found in textbooks; rarely found in nature)
Temp
RTRM=
Density Layer 1 – Density Layer 2
Density 4 Deg. – Density 5 Deg.
0.0 5.0 10.0 15.0 20.0 25.0 30.0
0.5
2
4
6
8
10
12
14
SD
CD
Thermocline
Light Penetration
Transparency
Depth-Selective
Withdrawal and Release Gates
EPILIMNION
uniformly warm, mixed
METALIMNION
> 1° C / m depth
HYPOLIMNION
isothermal, cold



Watershed Organic Loading
Watershed Nutrient Loading
Total P, Nitrate-N, Total N
Most focus on this
Photosynthesis
$CO_2 \rightarrow (CH_2O)_n$
$H_2O \rightarrow O_2$
Littoral Plant Productivity
Phytoplankton Productivity
Internal Loading
Organic Supply - Respiratory Demand
Allochthonous and Autochonous
Respiratory Demand Met by Oxygen Supply
Respiratory Demand Exceeds Oxygen Supply
Aerobic Respiration
$(CH_2O)_n \rightarrow CO_2$
$O_2 \rightarrow H_2O$
Anaerobic Respiration
$NO_3 \rightarrow N_2$
$Fe+3\text{-}PO_4 \rightarrow Fe+2 + PO_4$
$S^o \rightarrow H_2S^=$
CaCO3~PO4 + H2O + CO2 → Ca(HCO3)2 + PO4
Carbonate System
Fe-Generating Redox System

Photosynthesis happens in the Watershed Too!

(Don’t ignore the allocthonous contribution to Organic Supply and Respiratory Demand, especially in reservoirs!)

If respiration is carried by Oxygen or Nitrate very little sediment flux of Phosphorus!

Anaerobic Respiration

Low Internal Loading

$$(CH_2O)_n \rightarrow CO_2$$

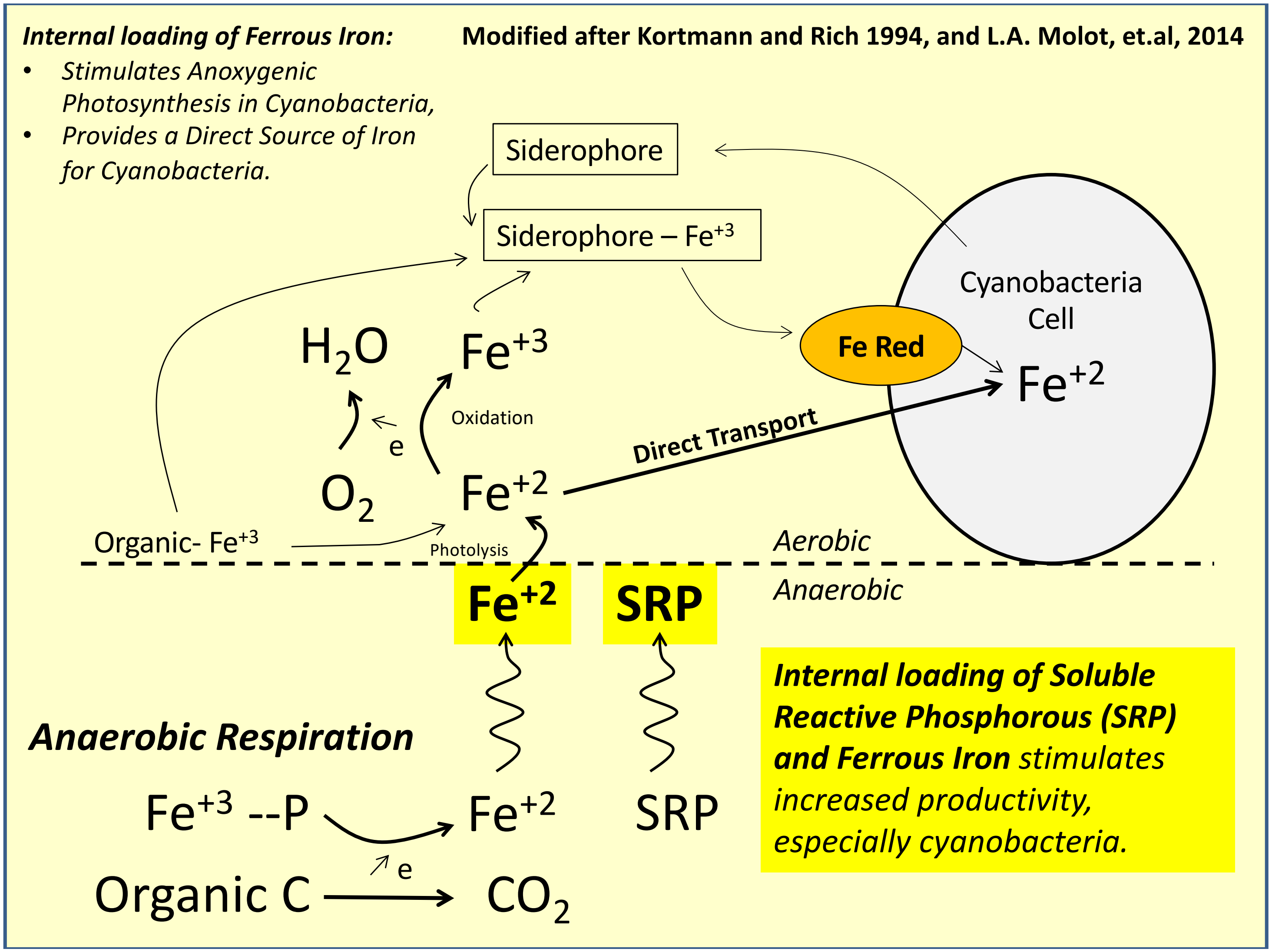
$$NO_3 \xrightarrow{e^-} N_2$$

$$Fe{+}3\text{-}PO_4 \rightarrow \boxed{Fe{+}2} + PO_4$$

$$S^o \rightarrow \boxed{H_2S^=}$$

High Internal Loading

If Anaerobic Respiration goes to Sulfur Reduction, Iron can be permanently deposited as Ferrous Sulfide and Sediment P-Binding can be Reduced.

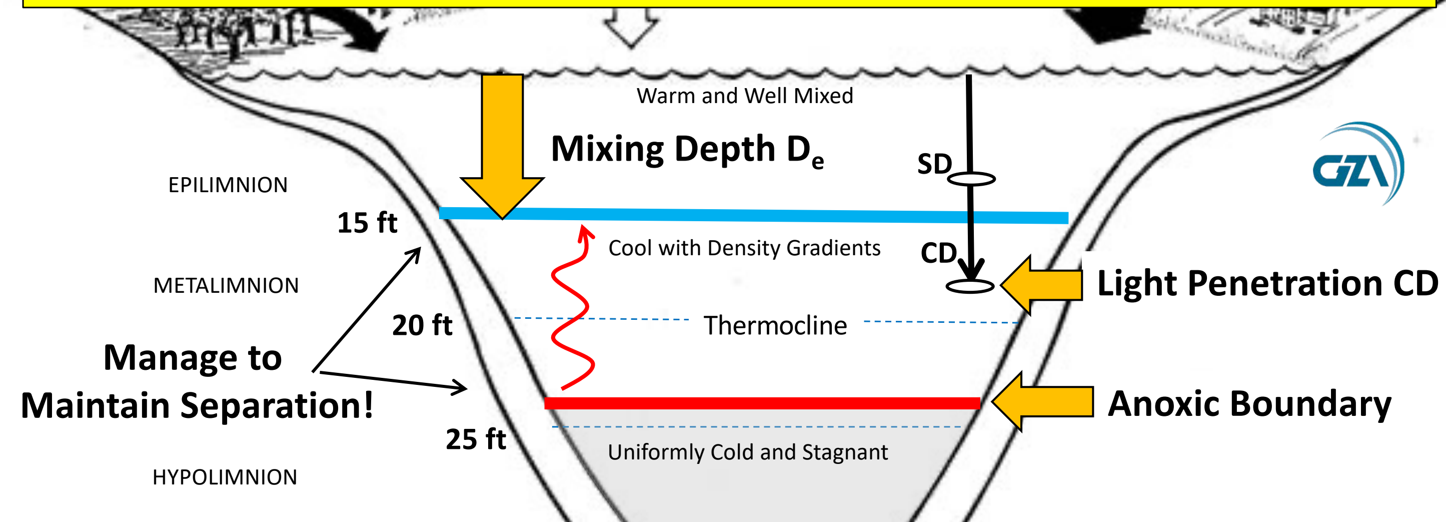


Internal loading of Ferrous Iron:
Stimulates Anoxygenic Photosynthesis in Cyanobacteria,
Provides a Direct Source of Iron for Cyanobacteria.
Modified after Kortmann and Rich 1994, and L.A. Molot, et.al, 2014
Siderophore
Siderophore – Fe^{+3}
Cyanobacteria Cell
Fe Red
Fe^{+2}
H_2O
Fe^{+3}
e
Oxidation
O_2
Fe^{+2}
Direct Transport
Organic- Fe^{+3}
Photolysis
Aerobic
Anaerobic
Fe^{+2}
SRP
Internal loading of Soluble Reactive Phosphorous (SRP) and Ferrous Iron stimulates increased productivity, especially cyanobacteria.
Anaerobic Respiration
Fe^{+3} --P
Fe^{+2}
SRP
e
Organic C
CO_2

To Control Internal Loading and Vertical Transport

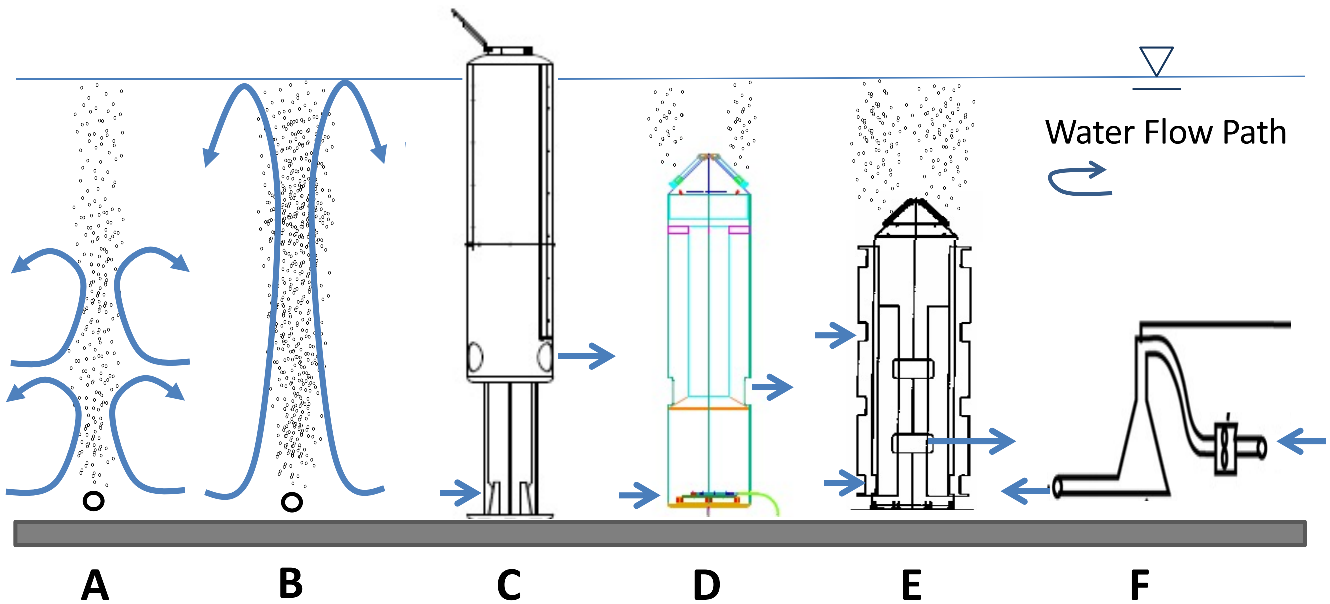
- Maintain an aerobic sediment-water interface
- Maintain separation between Mixing Depth and Anoxic Boundary
- Add Sediment P-Binding Capacity: Al, Fe, Lanthanum, etc.

(Be careful with sulfur loading! $AlSO_4$ $CuSO_4$)



If the RED LINE ascends to the BLUE LINE the stage is set for Cyanobacteria Blooms.

Also: If the BLUE LINE descends to the RED LINE the stage is set for Blooms.
(That happens at turnover and earlier in a number of lakes in 2018 and 2019).



Schematic Diagrams of Aeration and Oxygenation Techniques

A. Line Diffuser with Low Enough Gas Flow to Maintain Stratification
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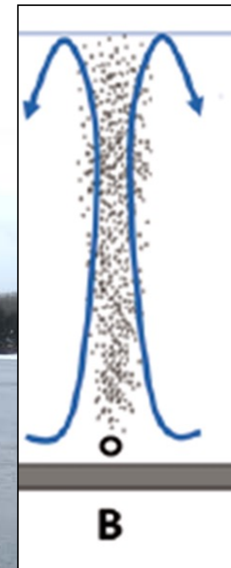
D. Submerged Partial-Lift Hypolimnetic Aeration
E. Depth-Selective Layer Aeration
F. Conical Oxygen Contactor, A.K.A. "Speece Cone".

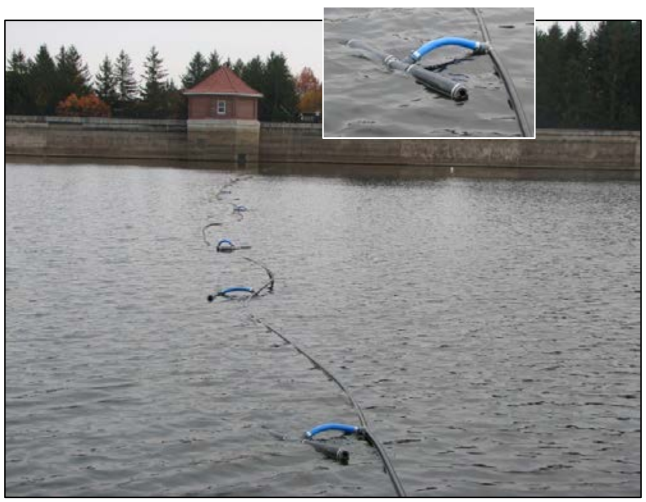
Modified from: Moore, et.al, *Lakeline* 2015

Artificial Circulation

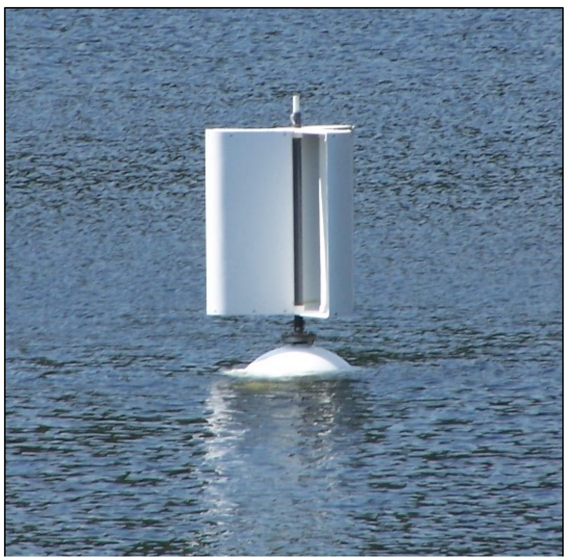
Diffused Air Systems (Many, Line Diffusers, Membrane Diffuser Modules)
Mechanical UpFlow Systems (e.g. SolarBee)
Mechanical DownFlow Systems (WEARS)
Solar or 12 volt Grid-tied Up or DownFlow



Diffused Air Circulation



	Artificial Circulation-Diffused Air
Applications	Prevent Stratification; up to ca.8-9m (26-29ft)
Approx. Sizing	0.7-1.3 CFM/Surface Acre
Advantages	No Surface Structures, Relatively Low Cost, System Simplicity, Expands Mixing Depth
Disadvantages	Bottom Warming, Increased Demand, Steep Sediment-Water Conc. Gradient, Nutrient Upwelling
Considerations	Start before stratified, must maintain 2-3 mg/L DO over sediment or net negative effects

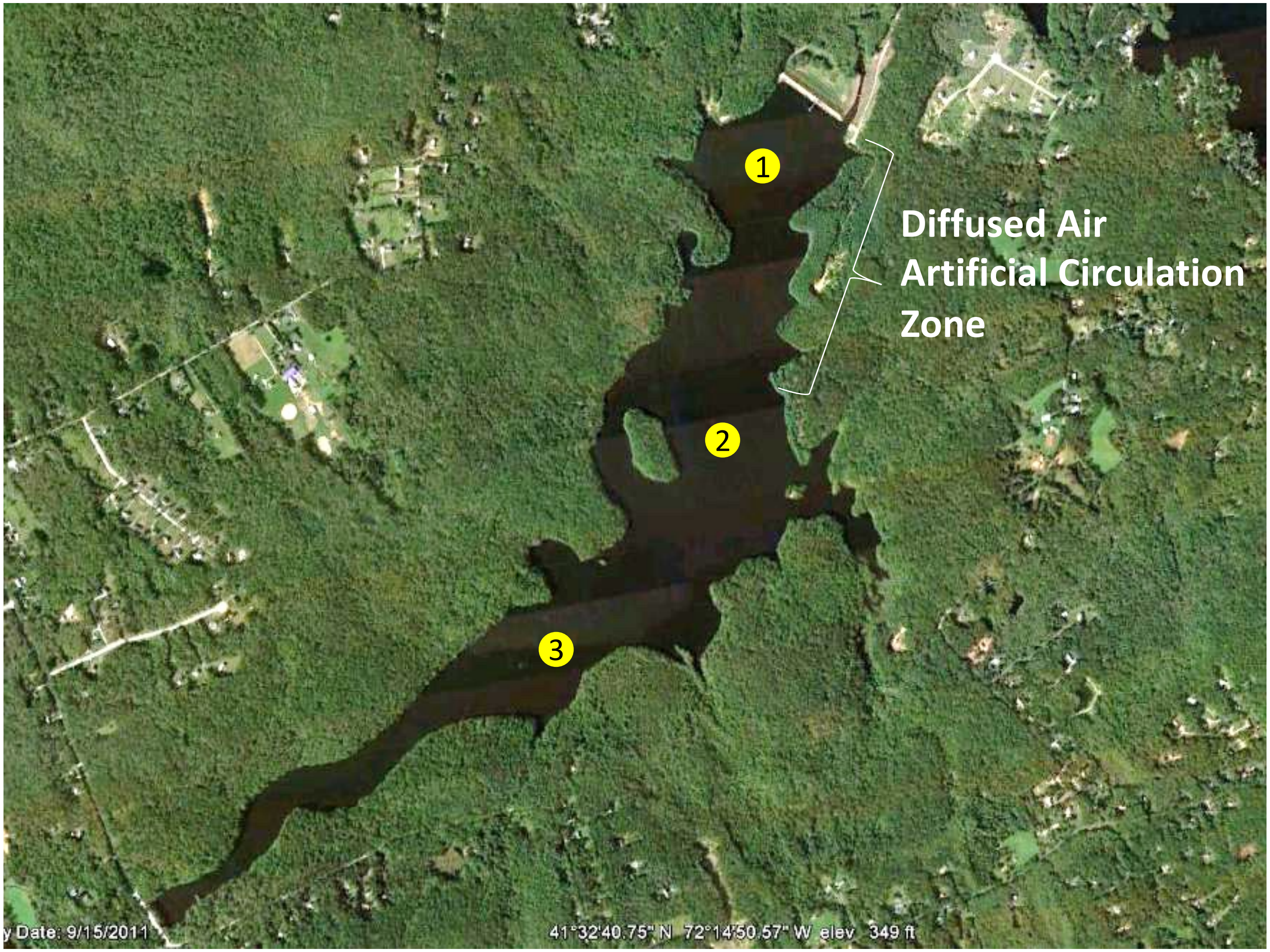


Mechanical Upflow

	Artificial Circulation-Mechanical Up Flow
Applications	Prevent Stratification; up to ca.8-9m (26-29ft)
Approx. Sizing	System and Site Specific
Advantages	Some are Solar or Wind Powered
Disadvantages	Bottom Warming, Increased Demand, Steep Sediment-Water Conc. Gradient, Nutrient Upwelling, In-Water Power, Some Have Surface Structures
Considerations	Start before stratified, must maintain 2-3 mg/L DO over sediment or net negative effects

Mechanical DownFlow

	Artificial Circulation-Mechanical Down Flow
Applications	Manage how stratification develops, Uses Ambient DO Source
Approx. Sizing	System and Site Specific, Can be solar or wind powered or low draw grid power
Advantages	Less risk of Nutrient Upwelling. Pushes Oxygen-Rich Water Down, Can maintain some stratification
Disadvantages	Bottom Warming, Increased Demand, Steep Sediment-Water Conc. Gradient, Nutrient Upwelling, In-Water Power
Considerations	Can perform downward circulation from a depth above compensation depth to use photosynthetic oxygen



1
Diffused Air
Artificial Circulation
Zone
2
3
y Date: 9/15/2011
41°32'40.75" N 72°14'50.57" W elev 349 ft

- temp (deg C)

depth (m)	6/3	7/7	7/29
0.5	20.3	25.4	28.8
1	20.3	25.4	28.4
2	20.2	25.3	28.2
3	20.1	25.2	28.1
4	19.4	25.1	28.0
5	19.0	25.0	27.9
6	18.7	24.8	27.9
7	18.5	24.4	27.6
8	18.3	23.6	27.0
9	17.9	23.2	26.9
10	17.4	22.7	26.3
11	16.6	22.2	25.1
12	16.0	21.4	24.3
13	15.2	20.3	

Mostly Aerobic, struggles some during most rapid heating month

. - DO (mg/L)

depth (m)	6/3	7/7	7/29
0.5	8.56	6.78	6.21
1	8.55	6.76	6.03
2	8.56	6.64	6.00
3	8.57	6.52	5.98
4	8.38	6.40	5.96
5	8.36	6.29	5.96
6	8.31	6.01	5.87
7	8.19	5.36	5.59
8	8.05	4.46	5.13
9	7.77	3.95	4.92
10	7.29	3.26	4.53
11	6.55	2.42	2.97
12	6.23	1.68	1.44
13	5.80	0.88	

Bottom Warms

- RTRM

depth (m)	6/3	7/7	7/29
0.5	0.0	0.0	0.0
1	0.0	0.0	10.7
2	2.6	6.4	7.1
3	0.0	3.2	7.0
4	20.1	3.2	3.5
5	9.7	3.2	0.0
6	7.2	6.3	3.5
7	2.4	12.4	10.4
8	7.0	21.3	17.1
9	6.9	14.8	3.4
10	11.2	11.7	20.1
11	17.2	17.1	39.0
12	14.3	19.4	25.0
13	13.6	31.8	
ım RTRM:	111.9	150.8	146.9

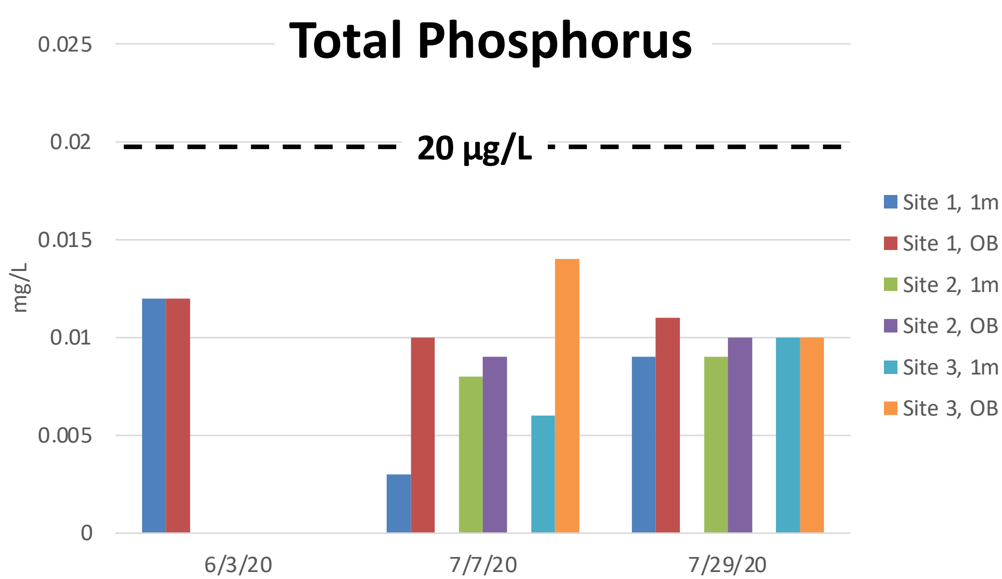
% DO Saturation < 100%

- DO (%Sat)

depth (m)	6/3	7/7	7/29
0.5	97	83	81
1	97	83	79
2	97	81	78
3	97	79	77
4	93	78	77
5	92	76	77
6	91	73	76
7	89	64	72
8	88	53	65
9	84	46	62
10	78	38	57
11	69	28	36
12	65	19	17
13	59	10	

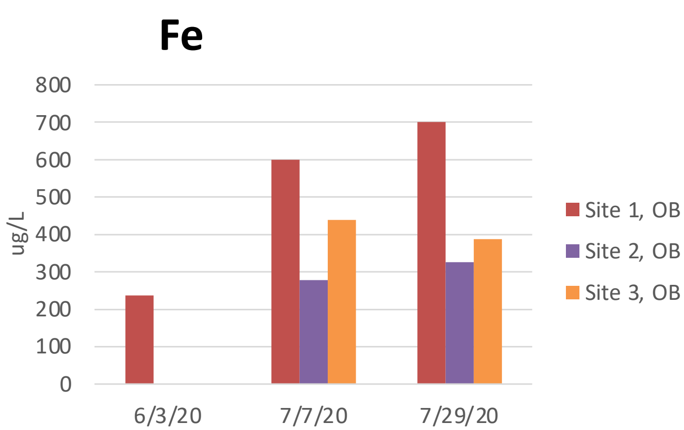
Weak Stratification, most RTRM below 7m

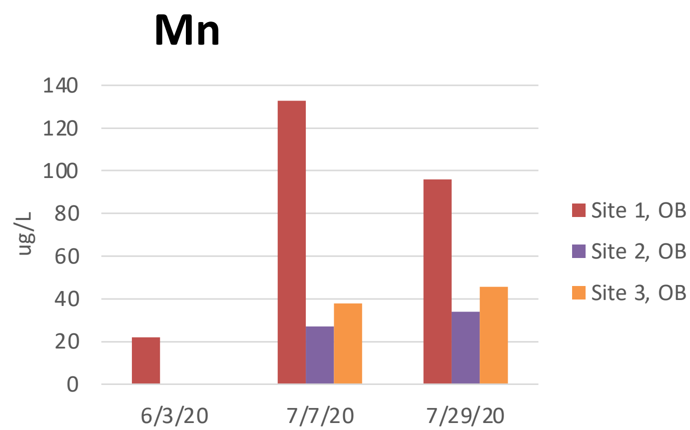
Examining RTRM reveals that about 40% of Stratification Remains



	Site 1			Site 2			Site 3		
	6/3/20	7/7/20	7/29/20	6/3/20	7/7/20	7/29/20	6/3/20	7/7/20	7/29/20
1m	0.012	0.003	0.009		0.008	0.009		0.006	0.01
OB	0.012	0.01	0.011		0.009	0.01		0.014	0.01

Total Phosphorus (TP) tends to limit how much total phytoplanktonic productivity occurs in the water column. Other factors (inorganic N, silica, CO2, Fe) tend to dictate whether the primary productivity is performed by eukaryotic algae or cyanobacteria. Total Phosphorus remained low in all samples, below the 20 µg/L that can sustain increased cyanobacteria densities.





Deep River Fe (ug/L)

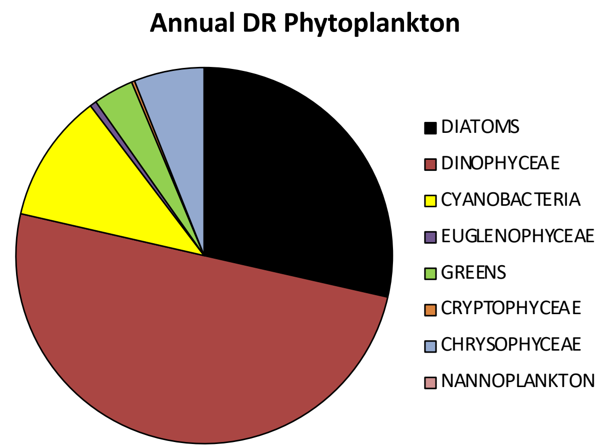
	Site 1			Site 2			Site 3		
	6/3/20	7/7/20	7/29/20	6/3/20	7/7/20	7/29/20	6/3/20	7/7/20	7/29/20
1m									
OB	236.6	599.8	701.1		277.2	325.9		439.4	388.3

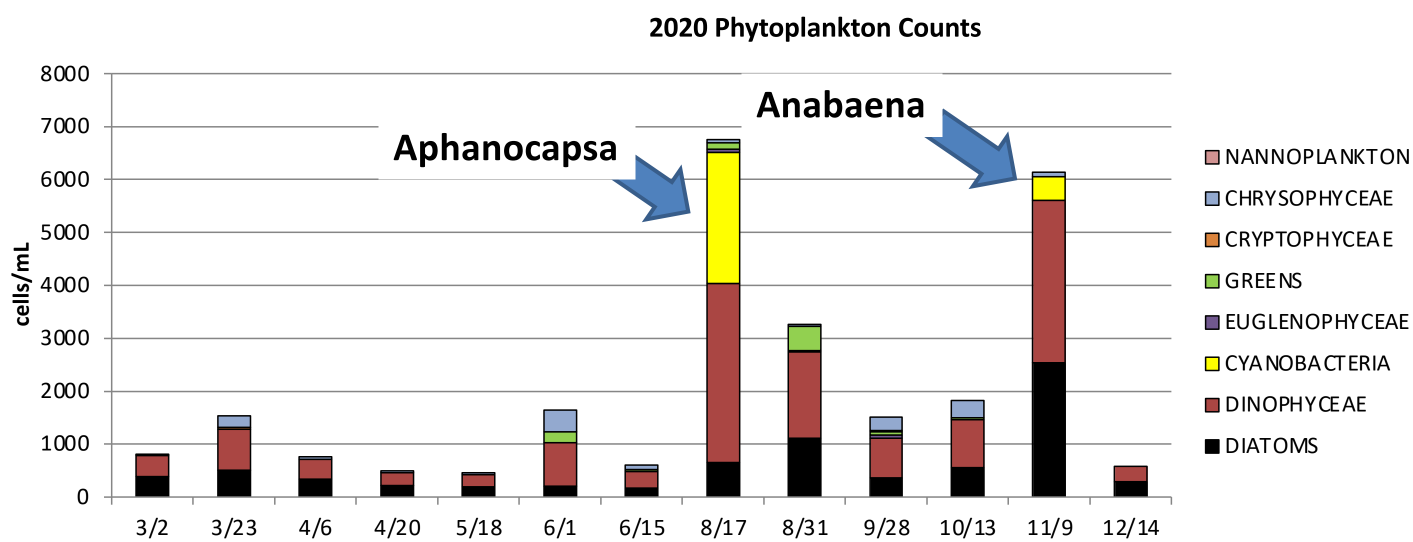
Deep River Mn (ug/L)

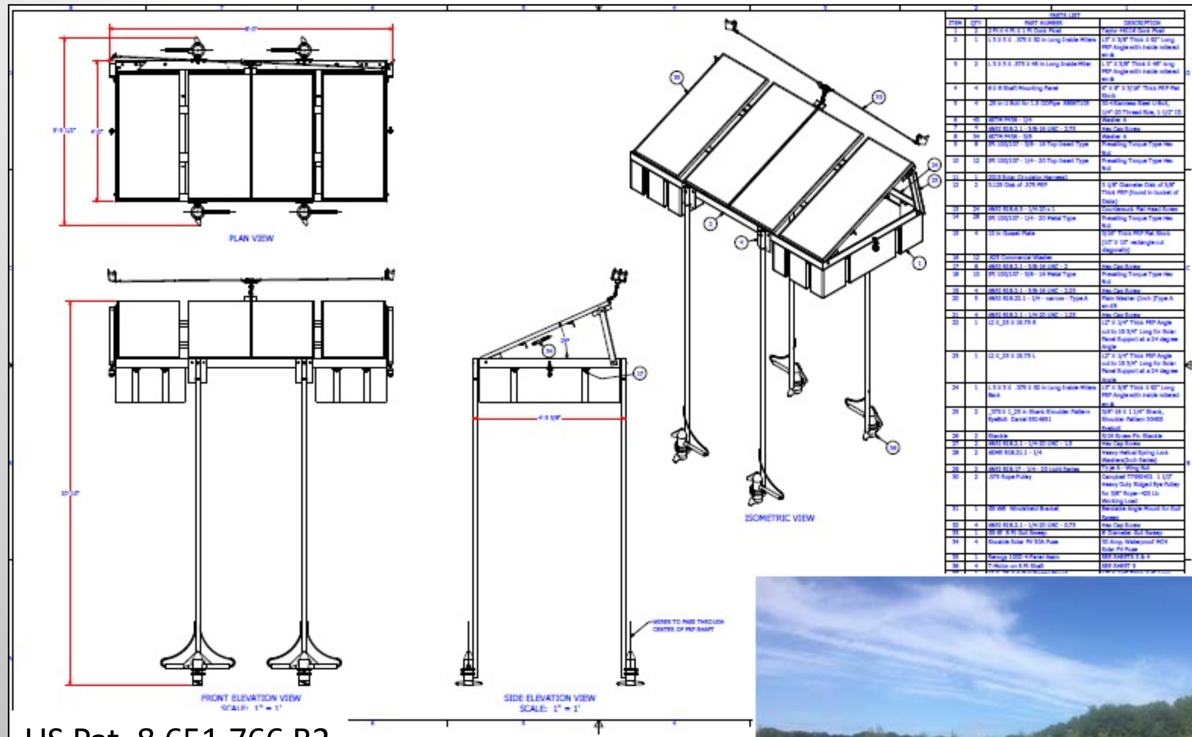
	Site 1			Site 2			Site 3		
	6/3/20	7/7/20	7/29/20	6/3/20	7/7/20	7/29/20	6/3/20	7/7/20	7/29/20
1m									
OB	21.99	132.8	96.06		27.09	33.99		37.82	45.71

Total Fe increased to approximately 0.7 mg/L in the deepest over-bottom water at Site 1. Total Mn increased to approximately 0.13 mg/L at Site 1. Again, Site 1 is deeper than Sites 2 & 3, and has lower DO concentrations at the bottom. Therefore, it makes sense that Fe and Mn accumulation is higher at Site 1.

Other than a modest increase in August and again in November, cyanobacteria cell densities remained low. Continued phytoplankton monitoring is recommended in order to identify a developing cyanobacteria population early, before a taste and odor episode occurs. **Dinoflagellates and diatoms are the dominant phytoplankton most of the time**; Greens and cyanobacteria become more abundant in June through August when temperature increases surface to bottom.



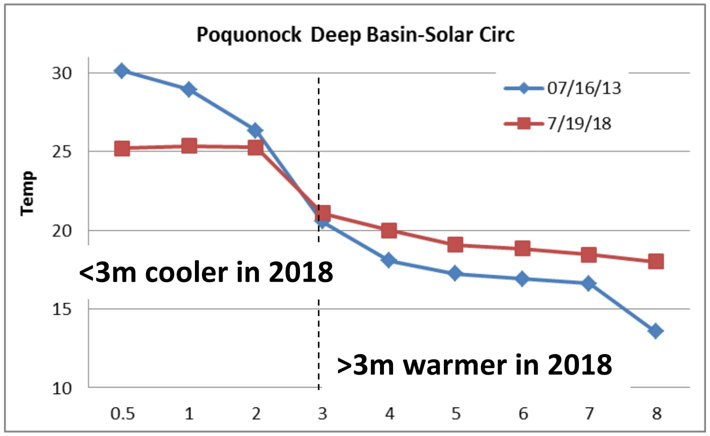


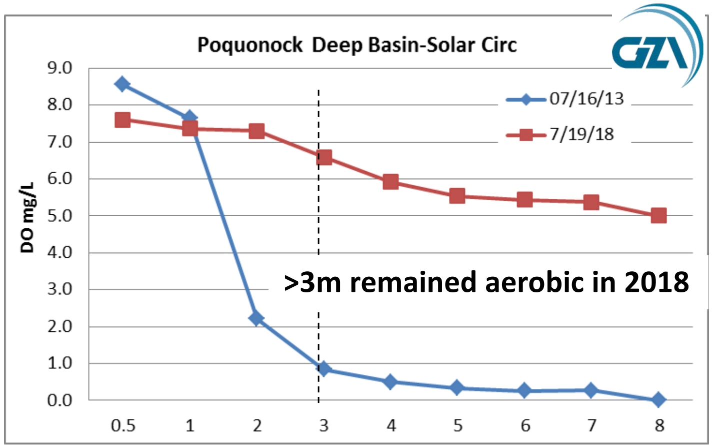


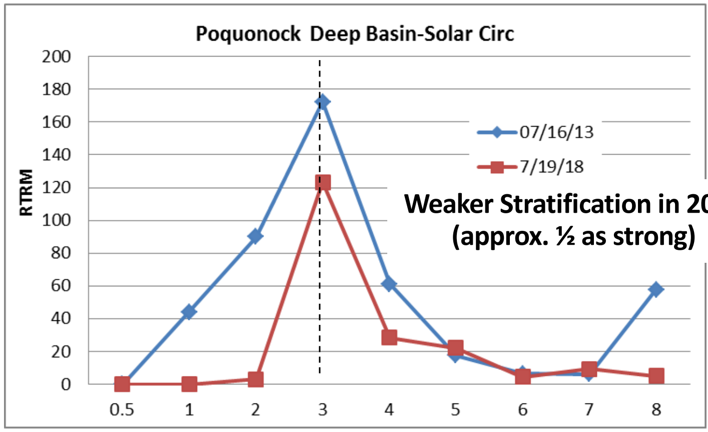
US Pat. 8,651,766 B2

Solar Powered Circulation Apparatus

- DownFlow Artificial Circulation
- Layer Circulation / Aeration



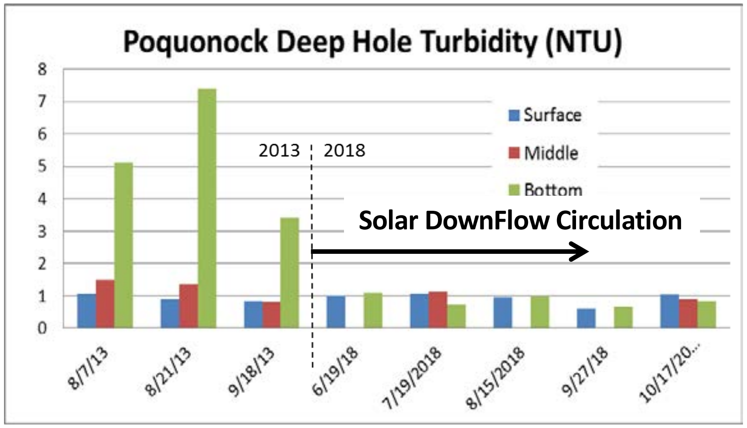


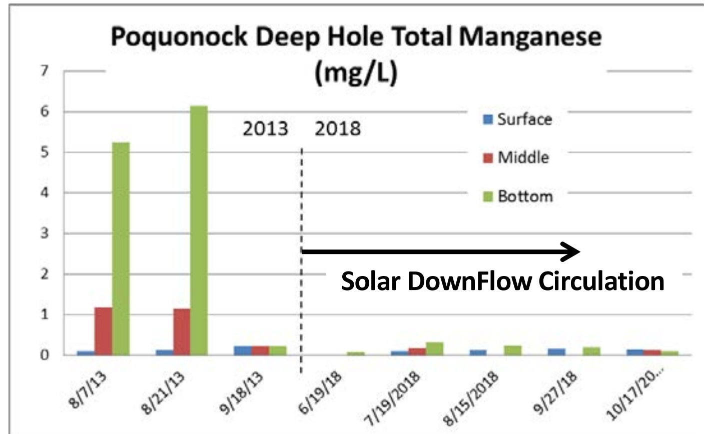


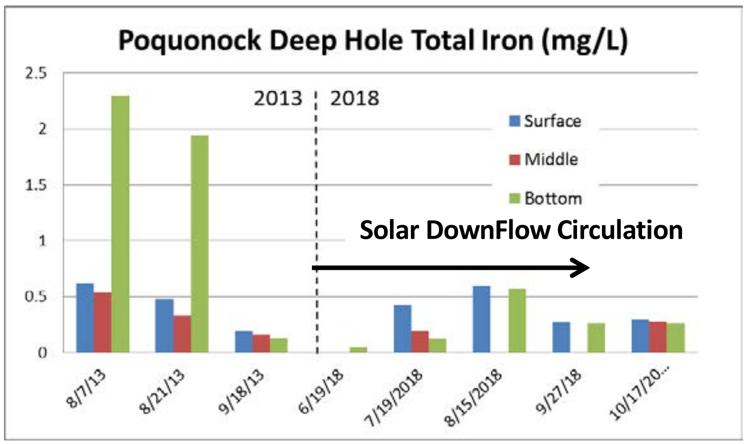
US Pat 8,651,766

Emerging Technology: Solar Powered Aeration or Circulation
(Self Contained or Land-Based Solar)

It is better to Push Oxygen-Rich Water Down than to Pump Nutrient-Rich Water up!







Much lower Deep Iron and Manganese Concentrations and Turbidity

Hypolimnetic Aeration (Full-Lift, Partial Lift)

Lake Prince Reservoir, Norfolk VA

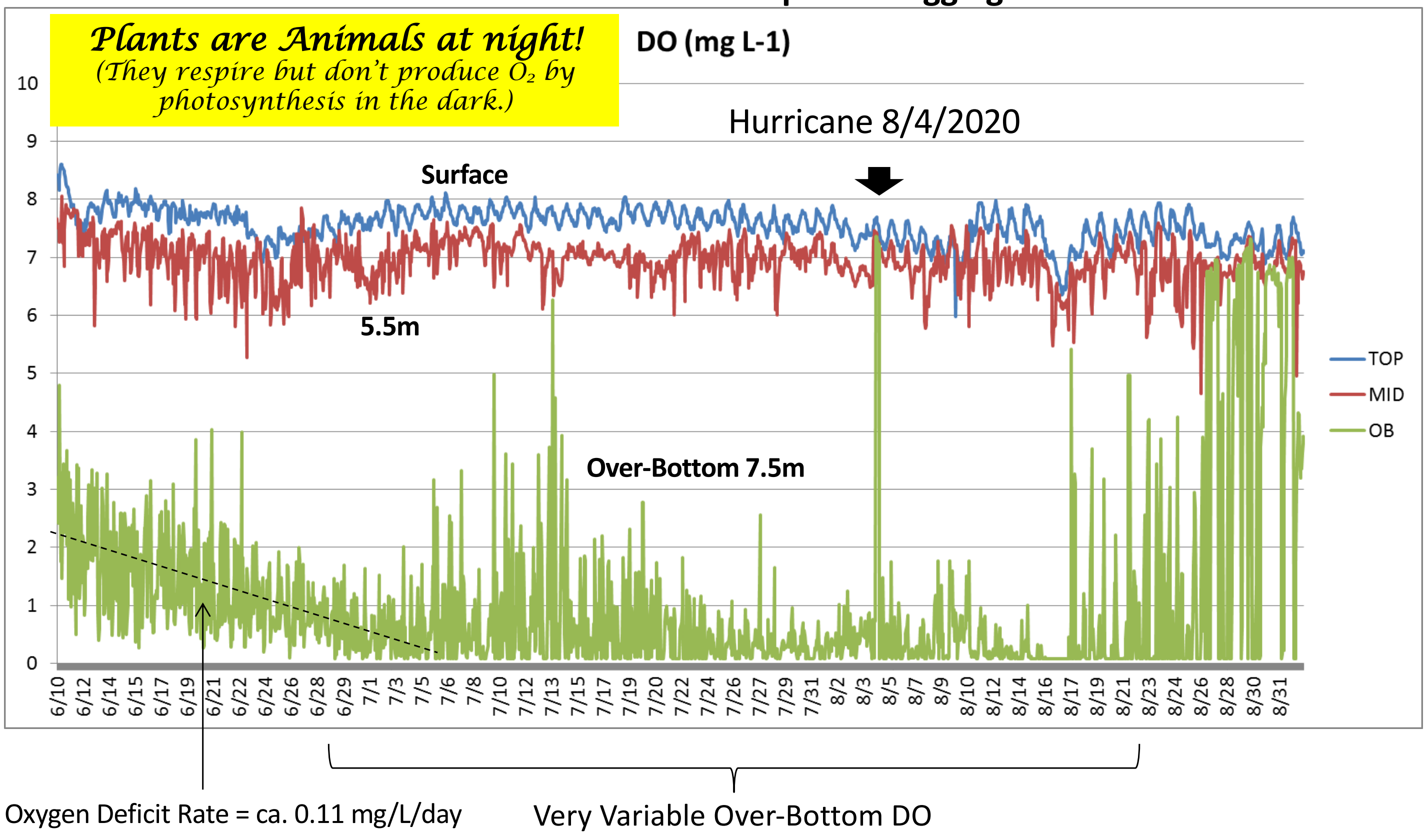
Lake Western Branch Reservoir, Norfolk VA

Lake Glen Reservoir, SCCRWA

Wanaque Reservoir, NJDWSC

Hypolimnetic Aeration and depth-selective Layer Aeration has been especially useful for managing source water reservoirs in relation to raw water intake depths & locations.

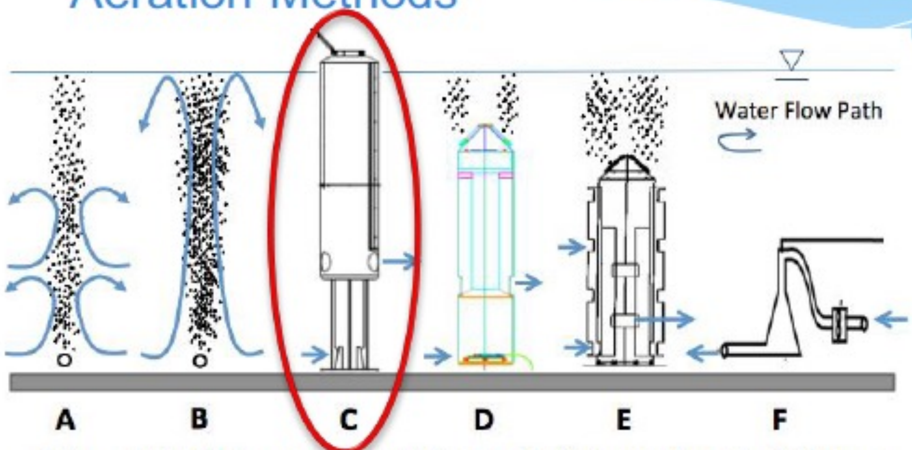
Continuous DO and Temp Data Logging



- *A lot is missed by sampling only during the day*
- *Diurnal DO Swing increases through the Summer*
- *You can only measure Oxygen Consumption when there is DO to be consumed*
- *You can measure CO_2 Accumulation and convert to Oxygen Equivalents*

Types of Aeration and Mixing

Aeration Methods



Schematic Diagrams of Aeration and Oxygenation Techniques

A. Line Diffuser with Low Enough Gas Flow to Maintain Stratification
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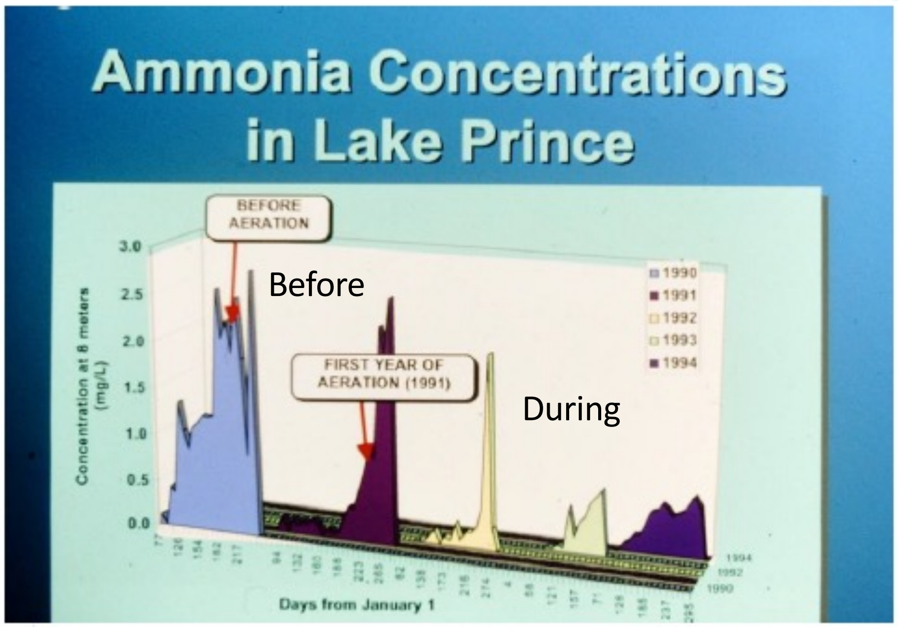
E. Depth-Selective Layer Aeration
F. Conical Oxygen Contactor, A.K.A. "Speece Cone".

Moore, et.al. Lakeline 2015

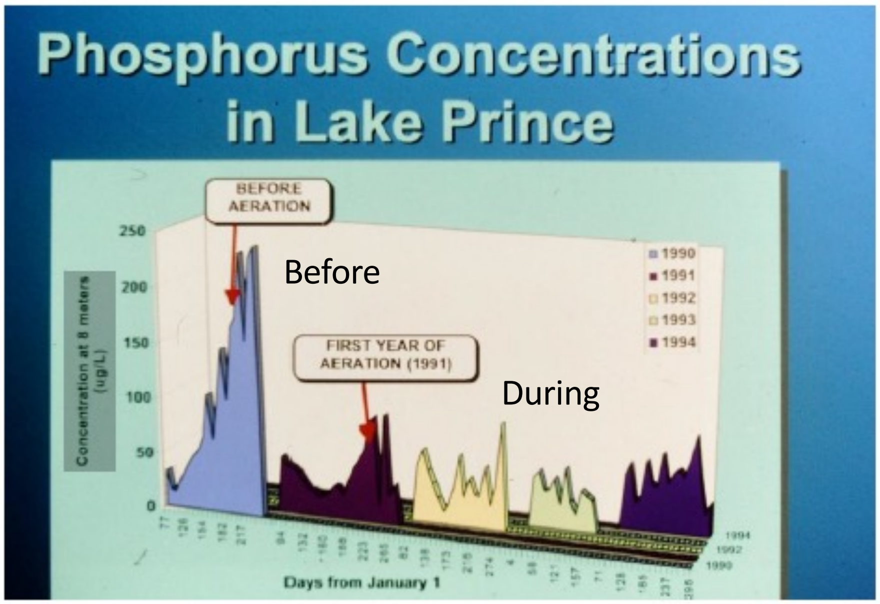
Norfolk selected combination full lift aerators due to the relatively small hypolimnion (10-20% of total lake volume). This significantly reduced aeration requirements

Initial Results of Aeration (cont.)



- Immediate reduction in ammonia
- Similar reductions in iron, and phosphorus concentrations

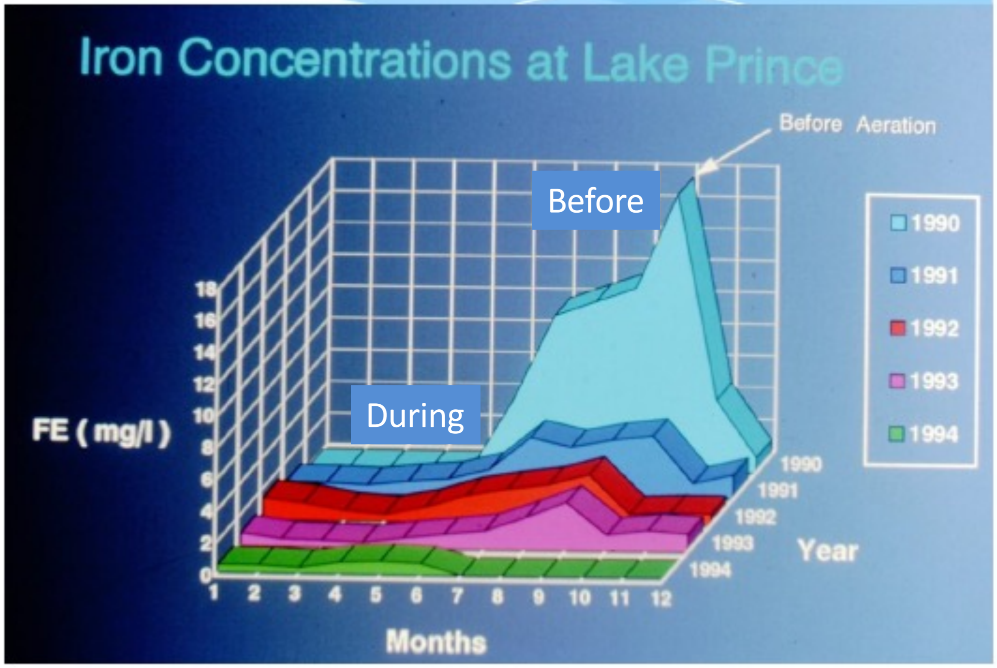
Initial Results of Aeration (cont.)



- Immediate reduction in phosphorus
- Similar reductions in iron concentrations

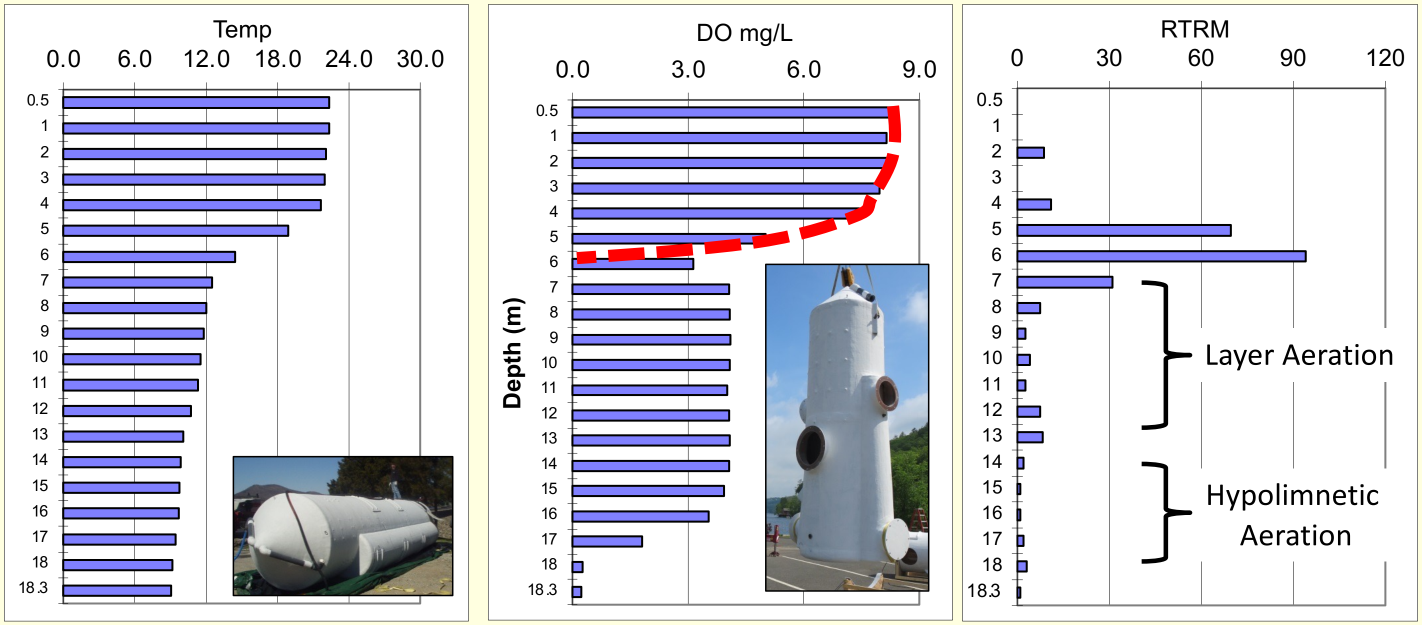
Initial Results of Aeration

* Approx. 90% reduction in iron concentrations
* Similar reductions in manganese
* Aeration eliminates the need for prechlorination



Benefits Realized

* ***Improved water quality*** of the reservoirs and reduced algae blooms
* ***Reduced iron, manganese***, phosphorus, ammonia, and sulfides
* ***Eliminated prechlorination*** at treatment plants
* ***Extended plant filter runs*** and increase finished water production
* ***One-tenth the cost of alternative*** – Total cost of \$6M for aeration and chloramination vs. \$50-\$60M compared to ozone/carbon alternative
* ***Production of high quality water that meets or exceeds all regulatory requirements***



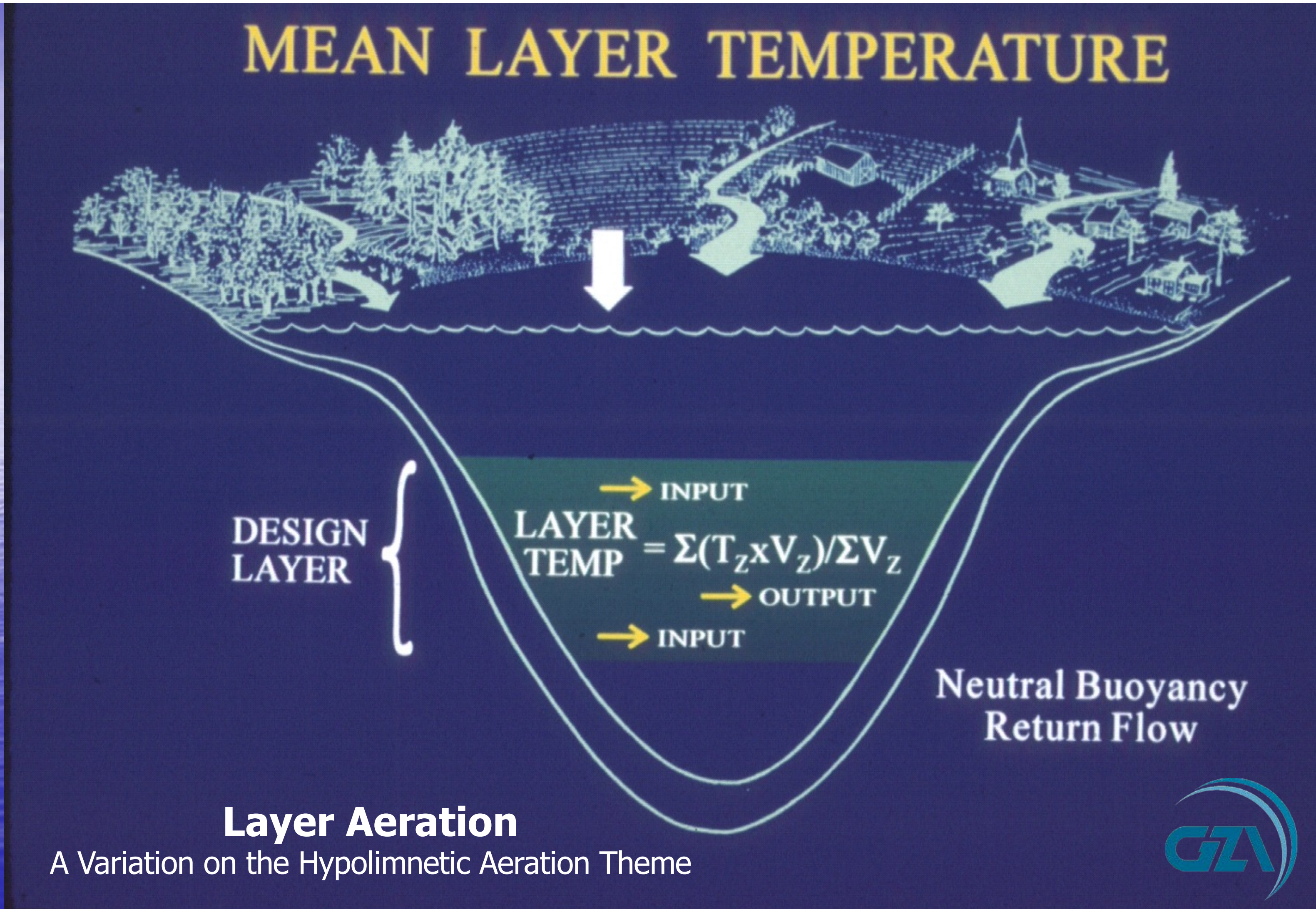
Lake Shenipsit – Summer Profiles during Layer Aeration

Layer Aeration uses Oxygen Produced by Photosynthesis to Offset Deeper Oxygen Demands

Maintains Separation of Mixing Depth and Anoxic Boundary
Reduces Internal Loading
Restores Habitat

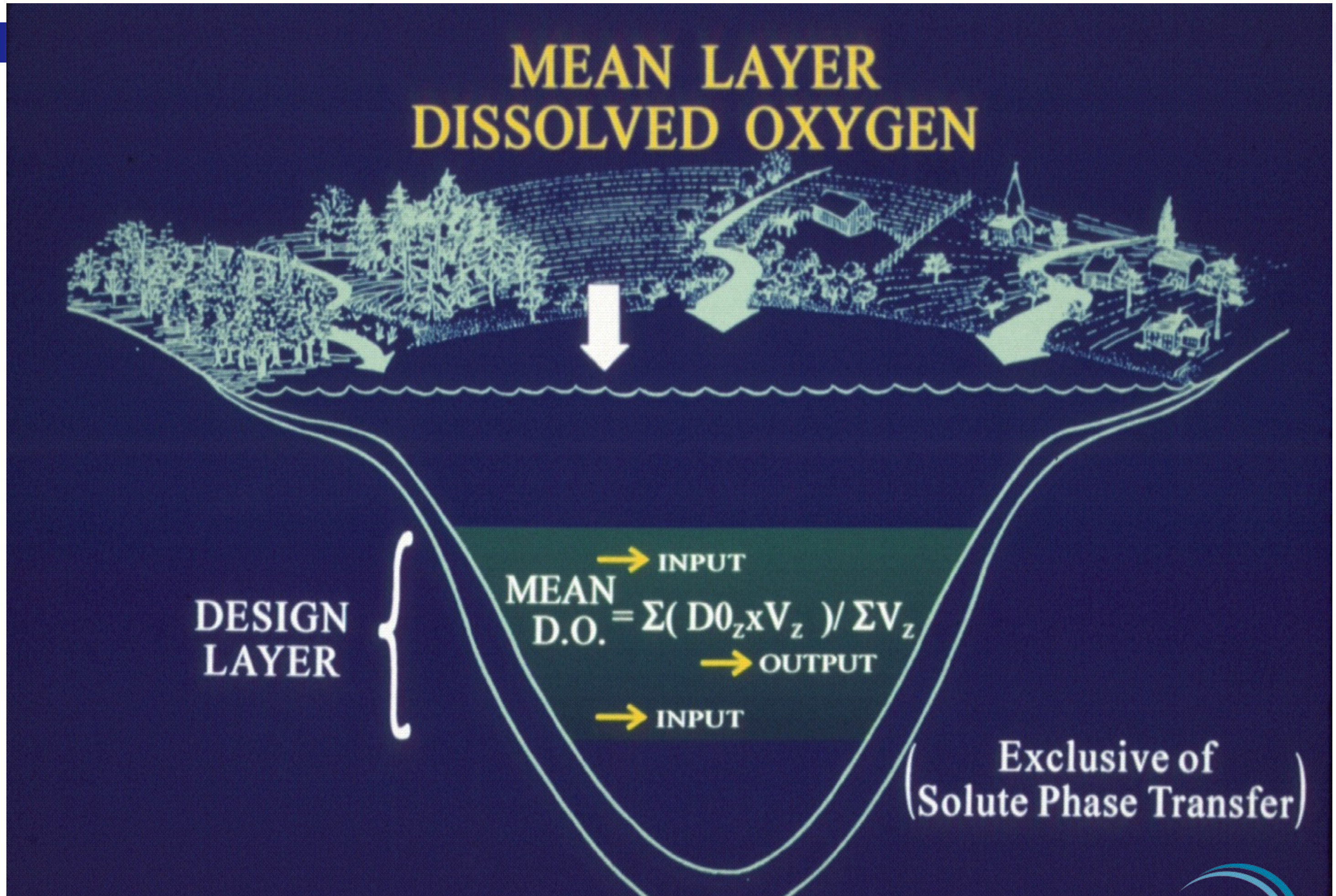
DO Before Layer Aeration

Environmental Technology Innovator Award 1999 EPA New England



Layer Aeration

A Variation on the Hypolimnetic Aeration Theme



Layer Aeration

A Variation on the Hypolimnetic Aeration Theme

Lake Shenipsit Water Supply

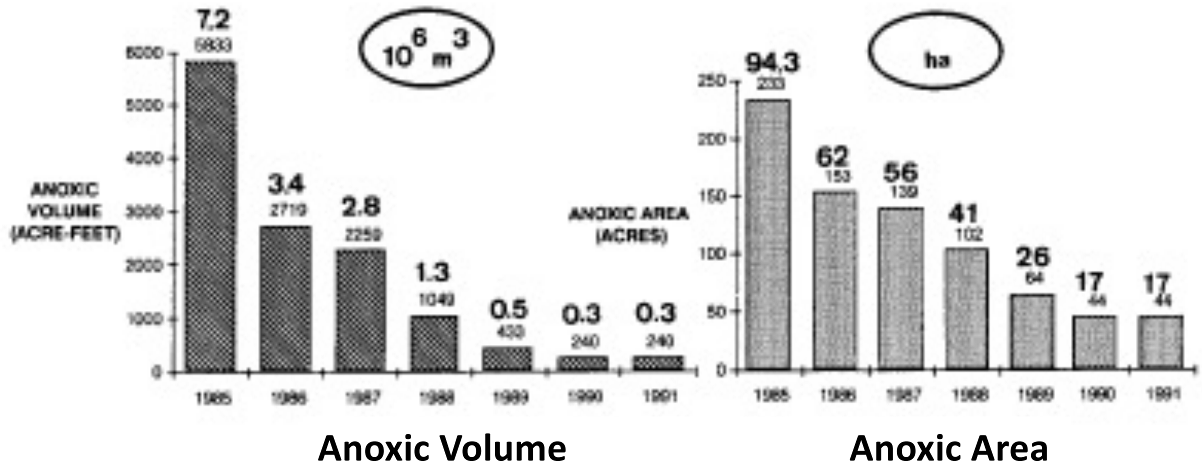
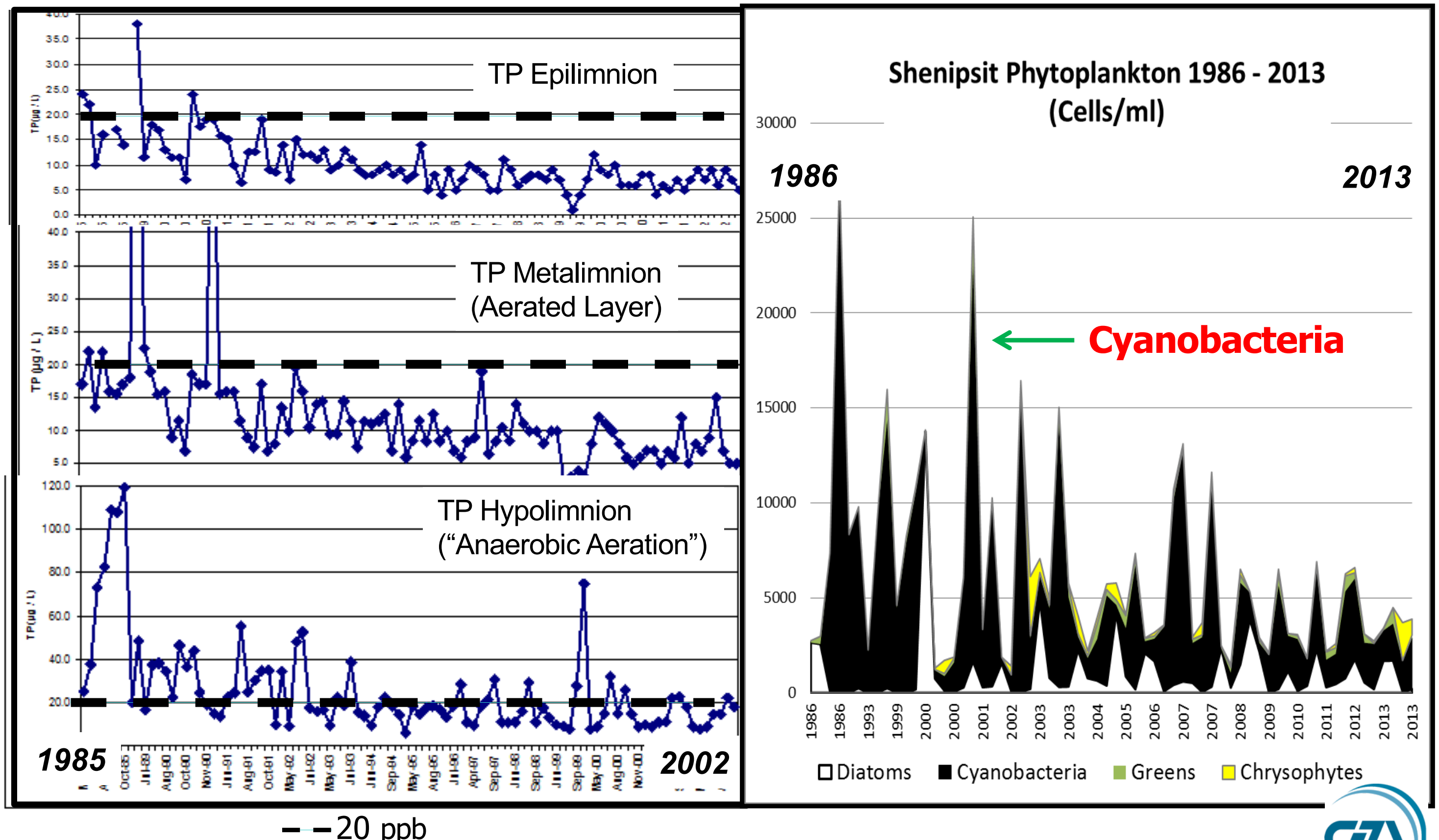


Figure 6.—Physical ecosystem responses to layer aeration from 1985-86 (pre-aeration) through 1991 (post-aeration).

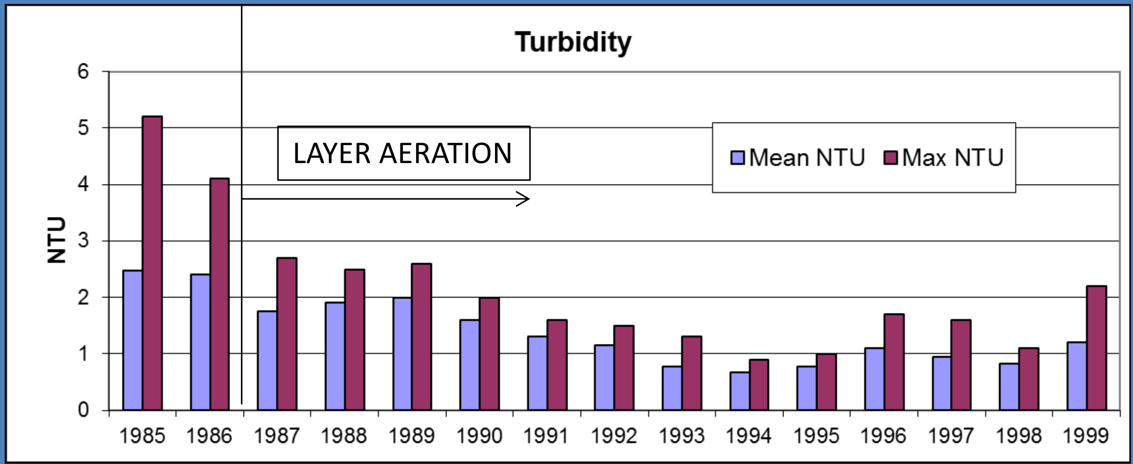
Kortmann, et.al., 1994

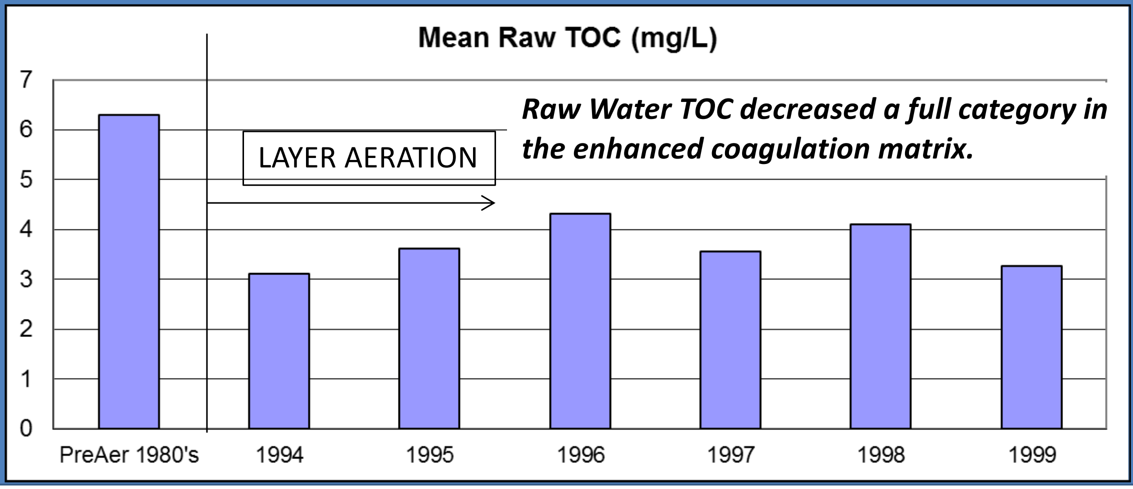
Anaerobic Volume Decreased from 5,800 Acre-Feet to 243 Acre-Feet
Anaerobic Bottom Decreased from 233 Acres to 42 Acres

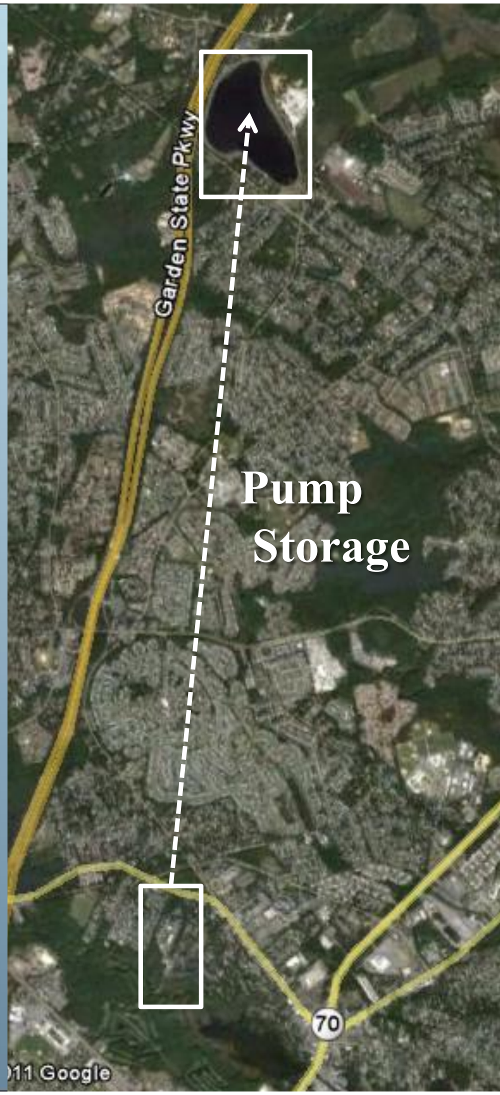


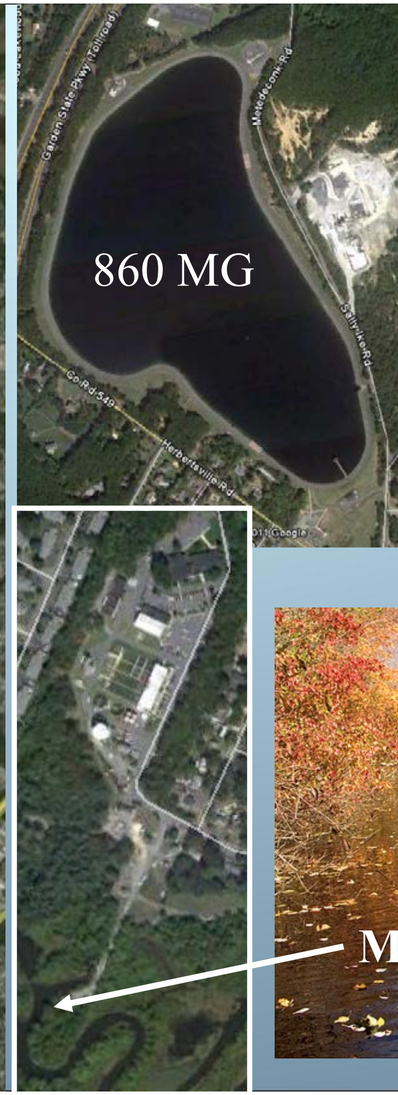
Layer Aeration decreased internal loading of phosphorus (SRP, TP) which decreased the abundance of phytoplankton (especially Cyanobacteria), increased light penetration (deepening the compensation depth), and improved habitat quality.

Raw Water Composition









Brick Township, NJ

Integrated Systems

Multiple Operating Modes

What can we do to Adapt to Climate Change?

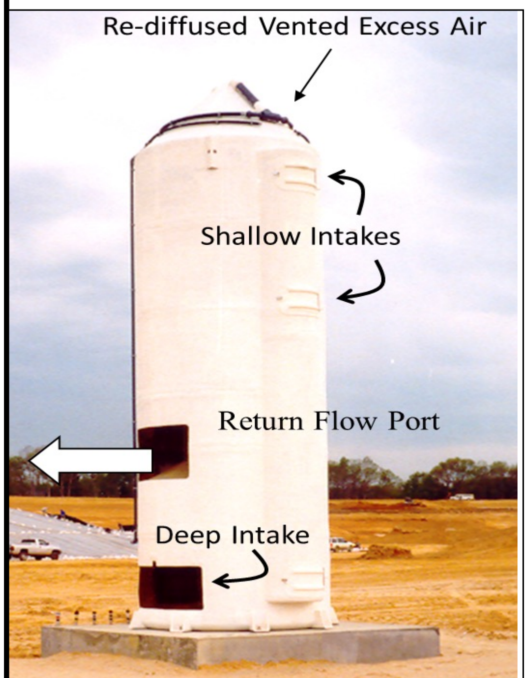
Aeration and Circulation

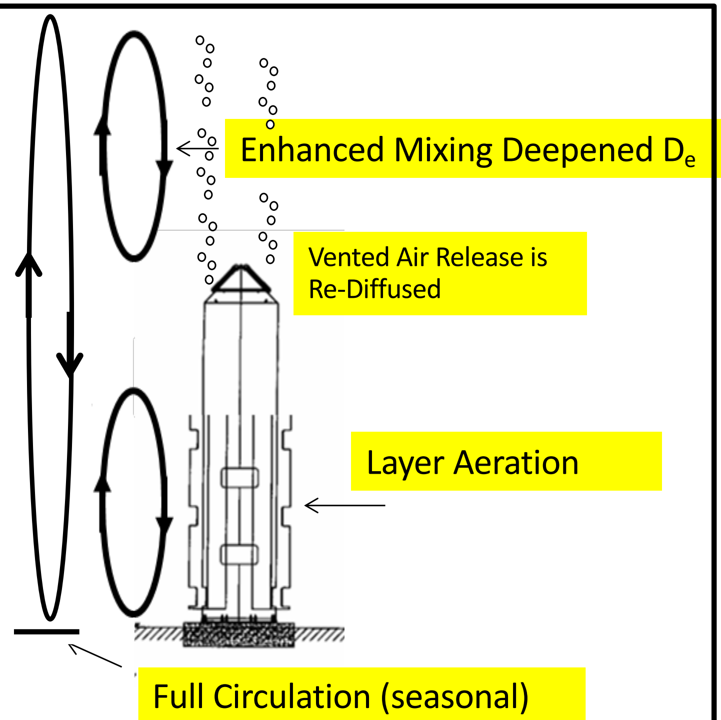
Source System Operations

Kortmann and Karl, 2011

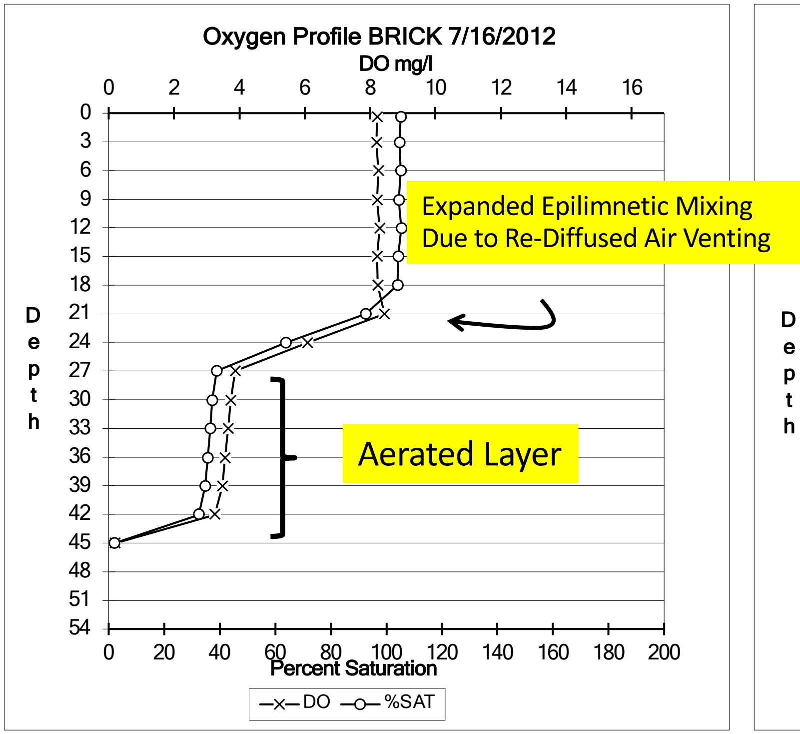
Brick Off-Line Storage Reservoir

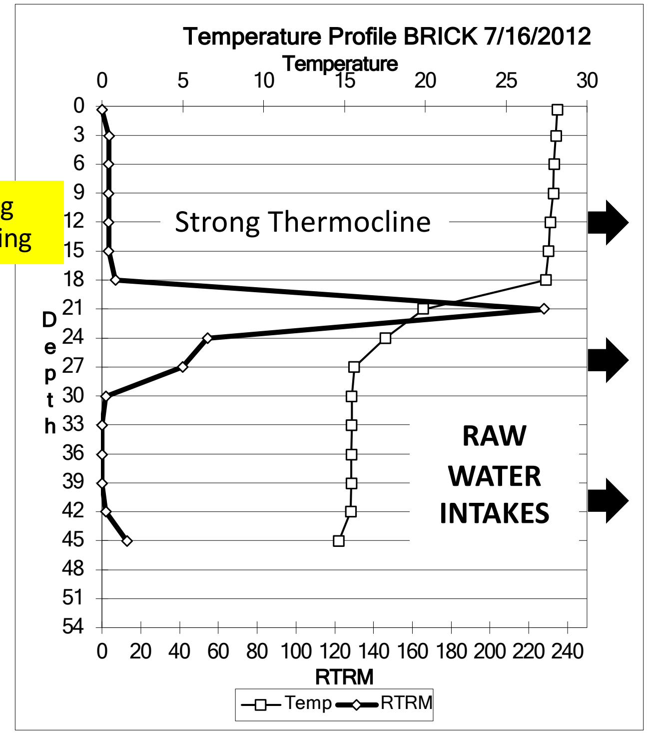
Brick Township, NJ





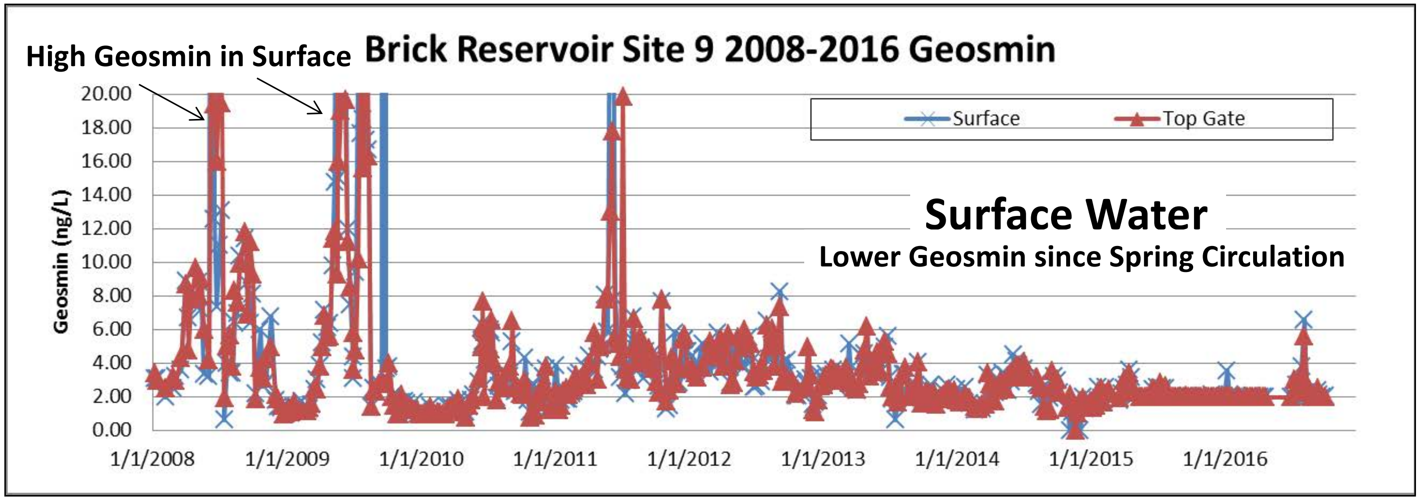
Layer Aerator
Full Circulation Module

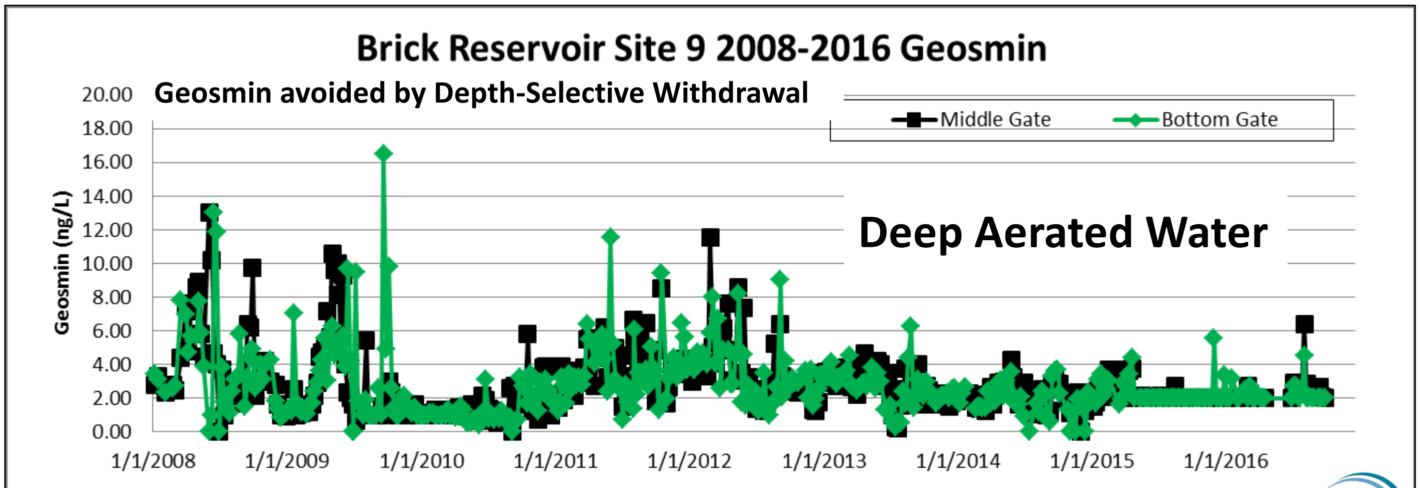




Brick Township Reservoir

Temperature and Oxygen Vertical Profiles during Layer Aeration





Depth-Selective Vertical Intake Gates Available

C.W. Bill Young Reservoir – Tampa Bay Water

Water Supply Limnology:

Source Water System

Water Treatment Process

Why a Combined Hypolimnetic Layer Aeration and Artificial Circulation Technique?
Seasonal Reservoir Levels and Demands

Pump-Storage Reservoir to decrease dependence on Groundwater and Desalinization.

Integrated (Seasonal/Water Level):
Hypolimnetic Layer Aeration (when near full)
Full Diffused Air Artificial Circulation (when level is low)

Reservoir is filled and nearly emptied annually.
Aerators exposed during hurricane season.

mentorship began in 1979; in 1986 we

on a design for a “down-flow contact

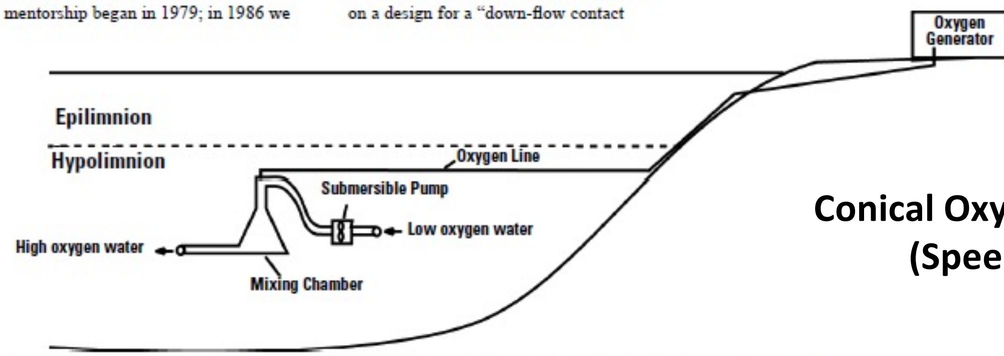


Figure 1. Diagrammatic view of the Newman Lake downflow contact bubble aerator (Speece Cone) system (not to scale).

Conical Oxygen Contactor (Speece Cone)

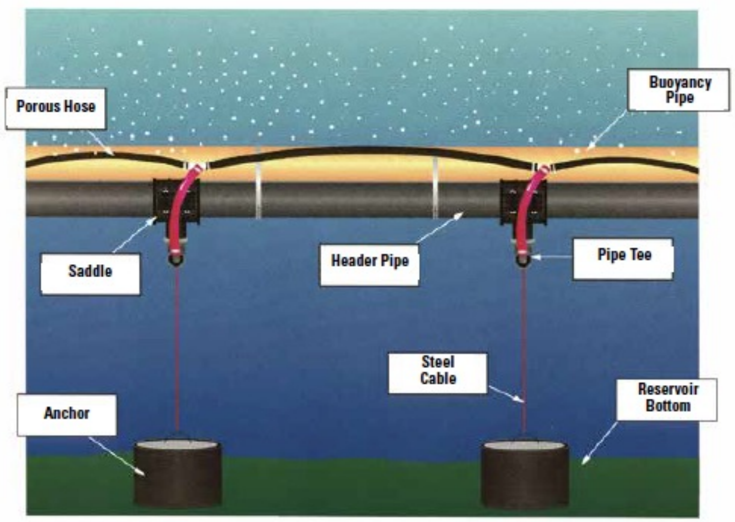


Figure 6: Line diffuser construction details (Graphics – TVA).

Bubble Plume Oxygenation

Oxygenation Methods

Table 1. Capacities and Costs of Selected Installations

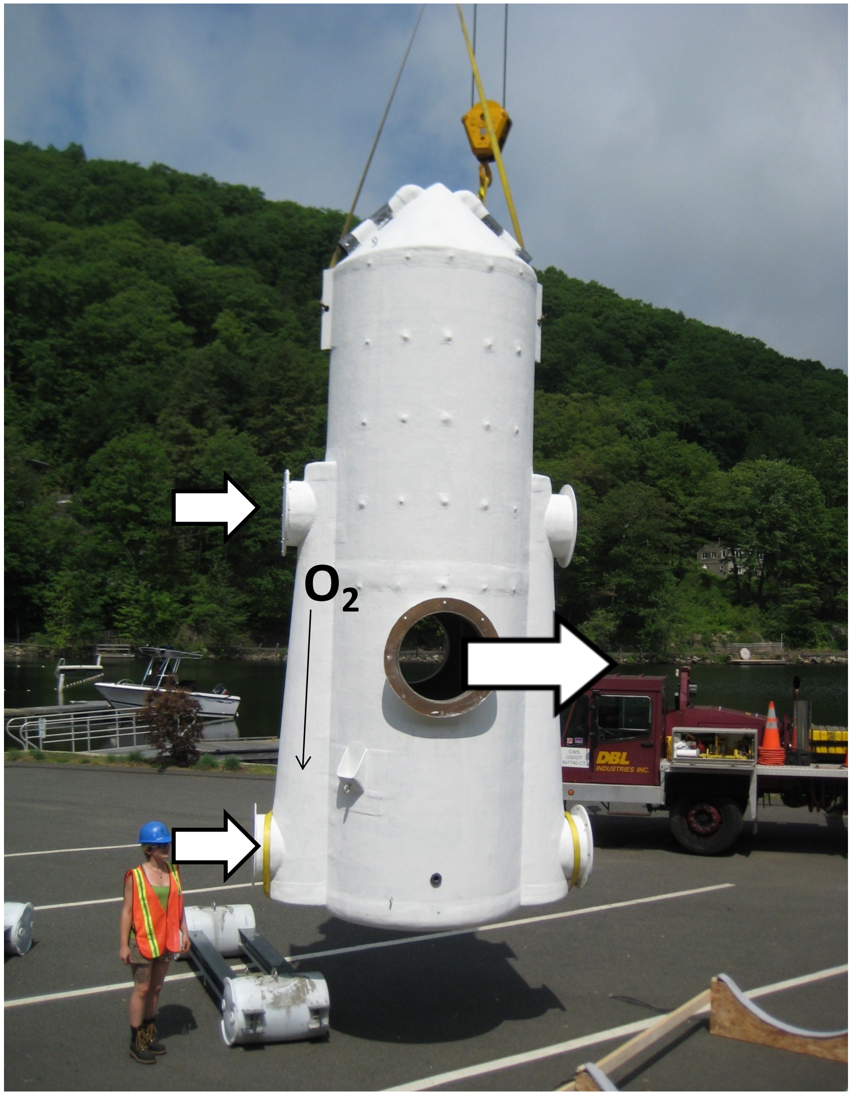
Reservoir	*Type*	*Application*	*Capacity/Cost*[1]
Camanche 7,700 ac	Speece Cone (1 unit)	Hydropower	9 tons O_2/day $1.8M; $108K OM/yr
Lakes Prince and Western Branch 2,231 ac	Airlift Aerators (25 units)	Water supply	Compressed Air $2.8M
Richard B. Russell 26,650 ac	Bubble Plume (10 x 1200 m)	Hydropower	200 tons O_2/day $1.6M; $2.4M OM/yr
Upper San Leandro 620 ac	Bubble Plume (2 x 730 m)	Water supply	9 tons O_2/day $450K; $108K OM/yr
Spring Hollow 158 ac	Bubble Plume (1 x 400 m)	Water supply	0.3 tons O_2/day $200K; $3.6K OM/yr
Carvin's Cove 800 ac	Bubble Plume (2 x 600 m)	Water supply	2 tons O_2/day $450K; $24K OM/yr
Brick Reservoir 110 ac, 50' max depth	Two Layer Aerators Two Diffuser Modules	Water supply	160 SCFM[2]; 32 MGD $197K, $20K OM/yr
Shenipsit Lake 530 ac, 70' max depth	Two Layer Aerators	Water supply, Fishery	240 SCFM[2]; 55 MGD $270K, $23K OM/yr

[1]Annual cost includes only liquid oxygen for oxygen systems, power and service for compressed air systems. Costs vary widely by application goal and site-specific conditions.

[2]SCFM = standard cubic feet per minute

Liquid oxygen costs ~ $100/ton

Moore, et.al., *Lakeline* Spring 2015



Layer Aeration

Oxygen Ready

Pure O_2 Contactor
or > 21% O_2

Water is blended and aerated from several depths to take advantage of oxygen produced by photosynthesis.

Additionally, the aerators are designed to "make bubbles sink rather than ascend" which increases oxygen transfer efficiency; and diffuser systems are included to enhance Diatoms seasonally (decreasing Cyanobacteria.)

(More Oxygen, Less Apparatus)

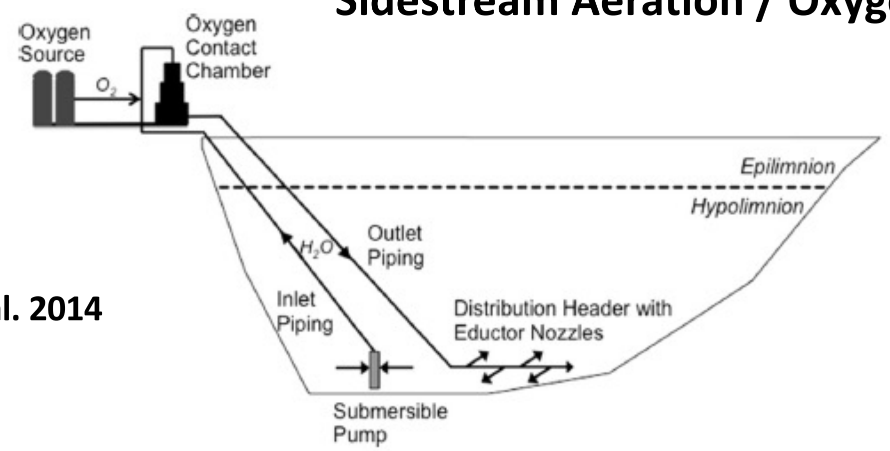
Analogous to the "Speece Cone" but requiring no foundation, and no underwater pump (driven by air-lift)

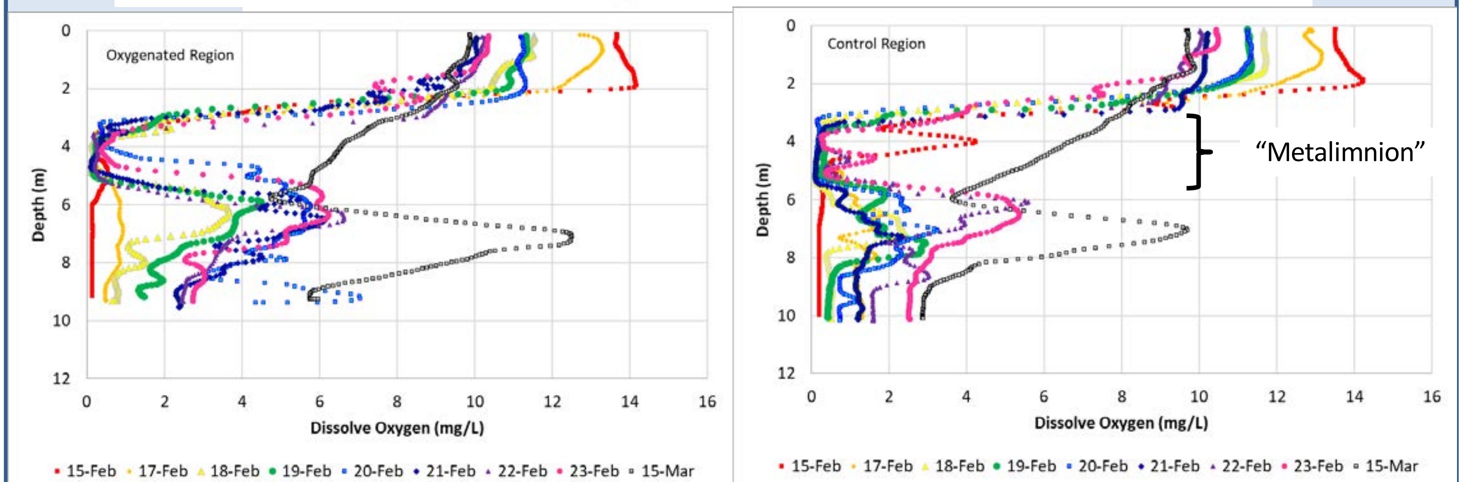
US Pats. 4,724,086; 5,755,976

Emerging Technology

Sidestream Aeration / Oxygenation

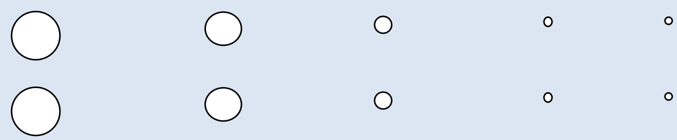
Gerling, et.al. 2014





Nano Bubble Technologies

Airlift Pumping



SOTE

Bubbles are so small they aren't buoyant. *But*, consider that you are adding tiny gas bubbles to a volume of water.

- Will that water volume become less dense?
- Will the less dense water tend to ascend?
- Will stratification and a cold bottom temperature persist?

Nanobubble technologies are good in some situations, not all.

Emerging Technologies

Possible Emerging Technology

Not ready for prime time!

Re-Oxidation of Anaerobic Respiration Products (Fe+2); P Sedimentation

$$2\ \mathbf{Fe}^{+2} + \mathbf{H_2O_2} + 4\ OH^- \rightarrow 2\ \mathbf{Fe}\ (OH)_3$$

P

Precipitate

Sodium Carbonate Peroxyhydrate

$$2Na_2CO_3 \bullet 3H_2O \longrightarrow 3H_2O_2 + 4Na^+ + 2CO_3^{\ 2+}$$

(Non-Cu Algaecide)

(Sample Na)

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

See: Molot, et.al. 2014 & 2020
Kortmann and Rich, 1994

"Solid Oxygen"

Possible Emerging Technology

Not ready for prime time!

Sodium Carbonate Peroxyhydrate

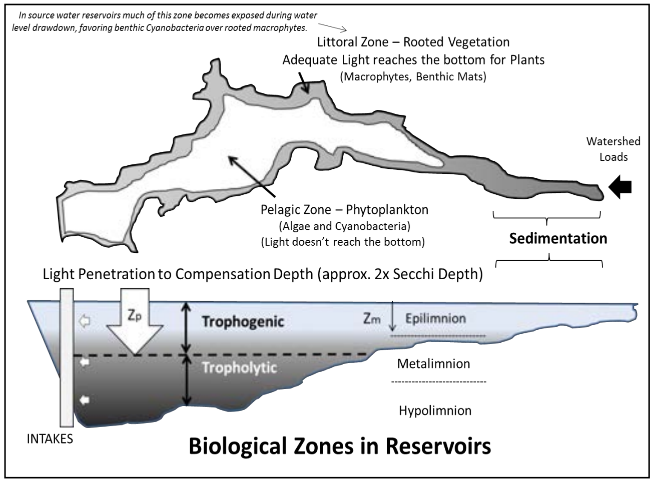
$$2Na_2CO_3 \bullet 3H_2O$$

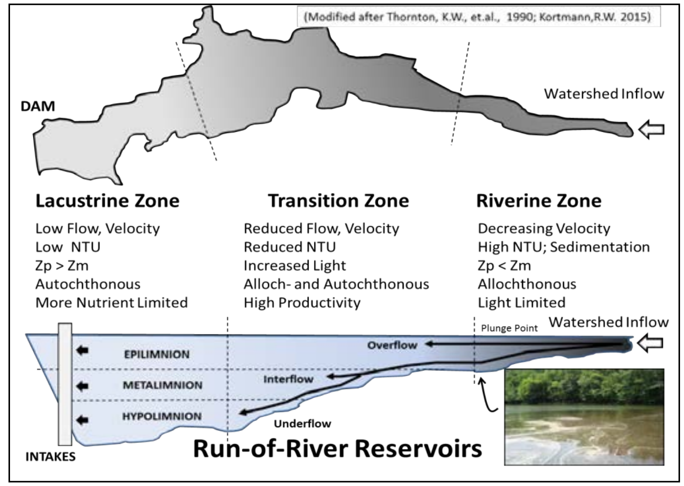
(Non-Cu Algaecide)

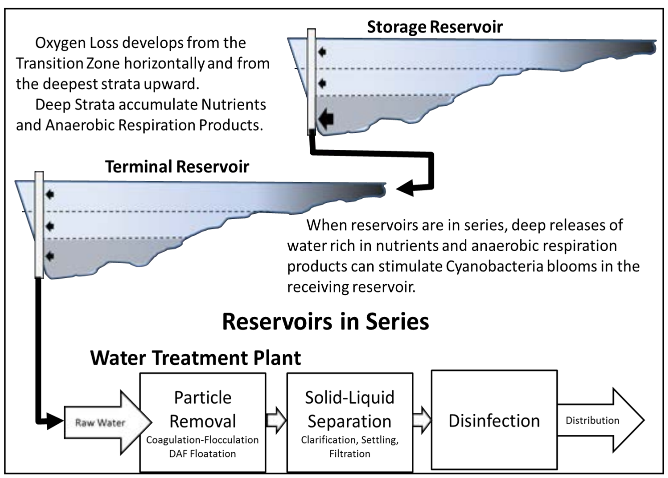
Potential Applications:

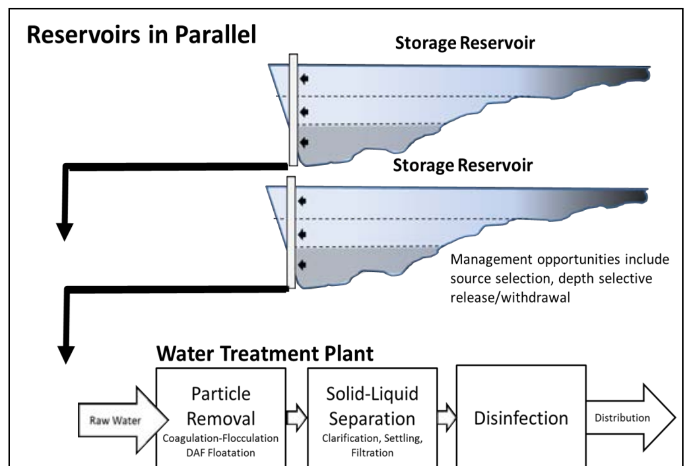
- Bottom at 0-4m Early June: Akinete Germination,
  - Elevate ORP at S-W Interface
- Bottom at >6m June-July: Elevate ORP at S-W Interface,
  - D_e – AB Separation
- Depth-Selective Temporal Treatments:
  - Phytoplankton Layers
  - Preparation for Decent of $D_{e\,;}$ (“Turnover”)

Precautions: Source Water Na, Mn Fractions…

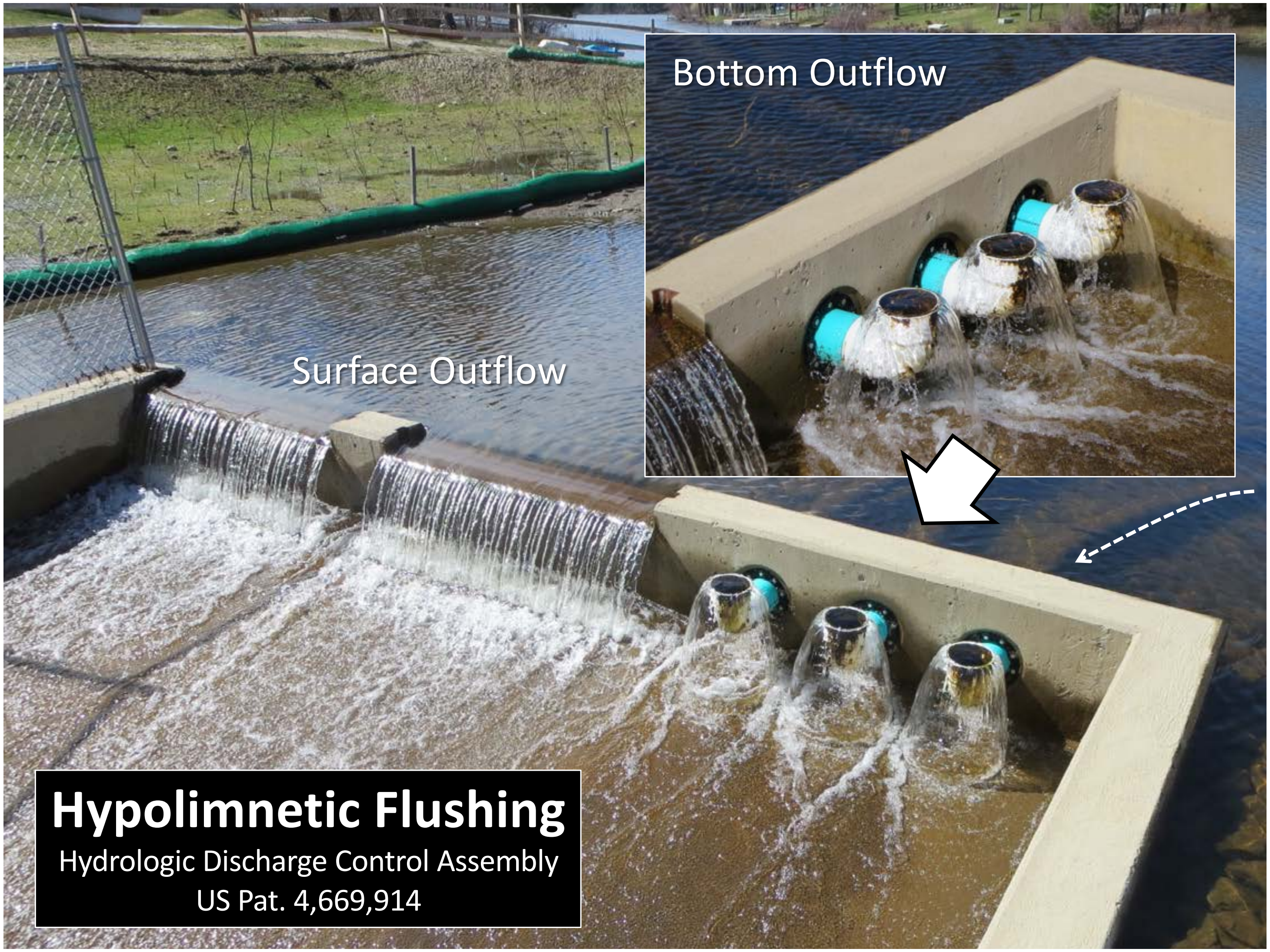








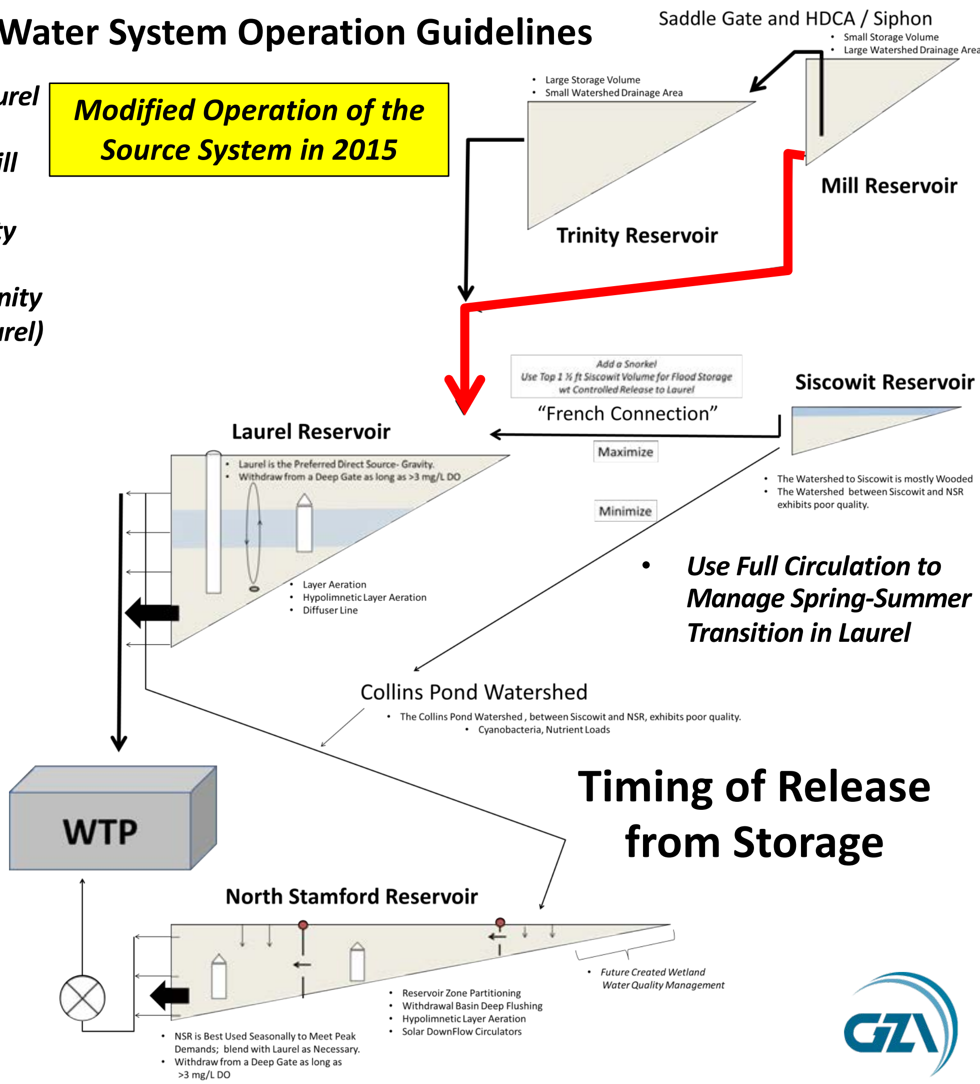
Know your Whole Source Water System


Bottom Outflow
Surface Outflow
Hypolimnetic Flushing
Hydrologic Discharge Control Assembly
US Pat. 4,669,914

Recommended Source Water System Operation Guidelines

- ***Deep Release from Mill to Laurel May-July to Maintain Laurel Storage and to Hypo Flush Mill***
- ***Ultimately- Deep Mill to Trinity Transfer System***
    - ***(Route flow through Trinity from deep in Mill to Laurel)***
- ***Avoid Release from Mill & Trinity during Loss of Stratification (October)***
- ***Maximize Siscowit to Laurel (Quality and Gravity)***
- ***Deep Raw Withdrawal from Laurel whenever Quality Permits,***
- ***Deep Release from Laurel to NSR June-August when Practical to Maintain NSR Storage June-September***
- ***Use Raw Laurel/NSR Blend to Maintain Treatable T&O when necessary***
- ***Deep Raw Withdrawal from NSR May - June***

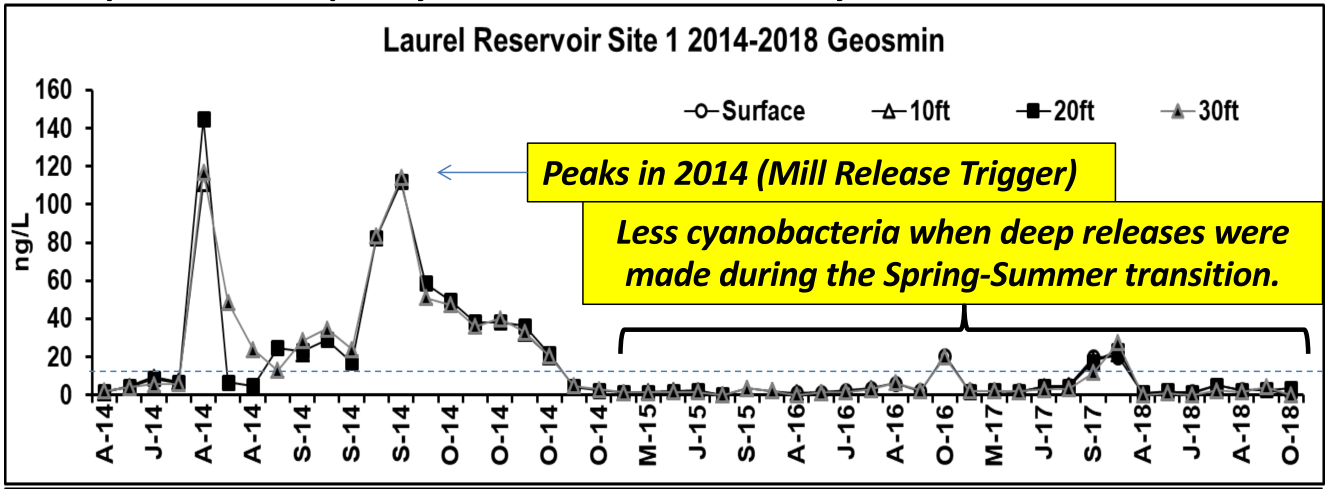
Modified Operation of the Source System in 2015

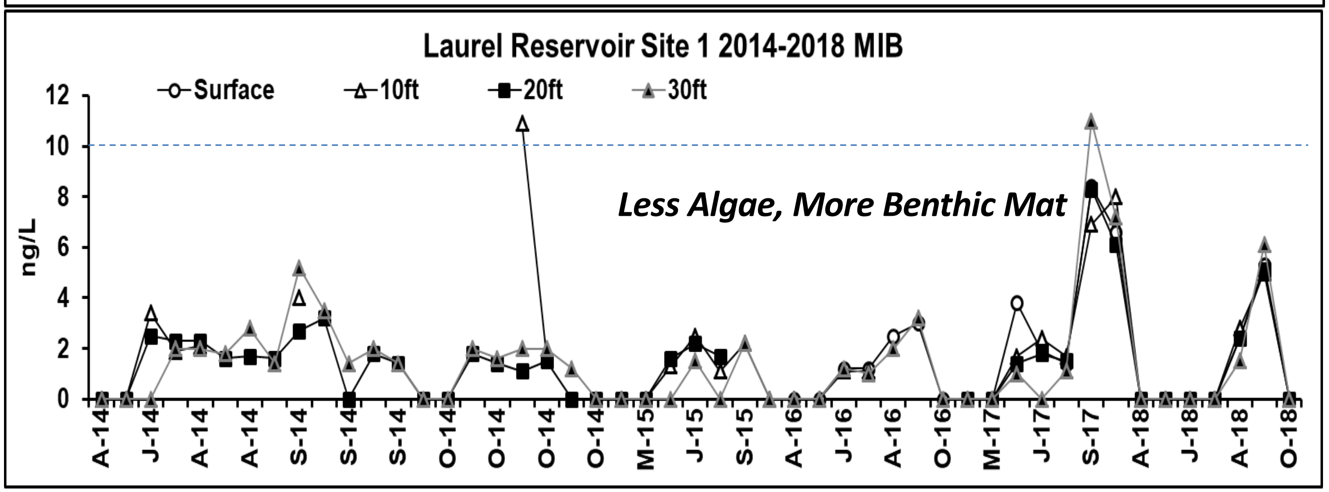


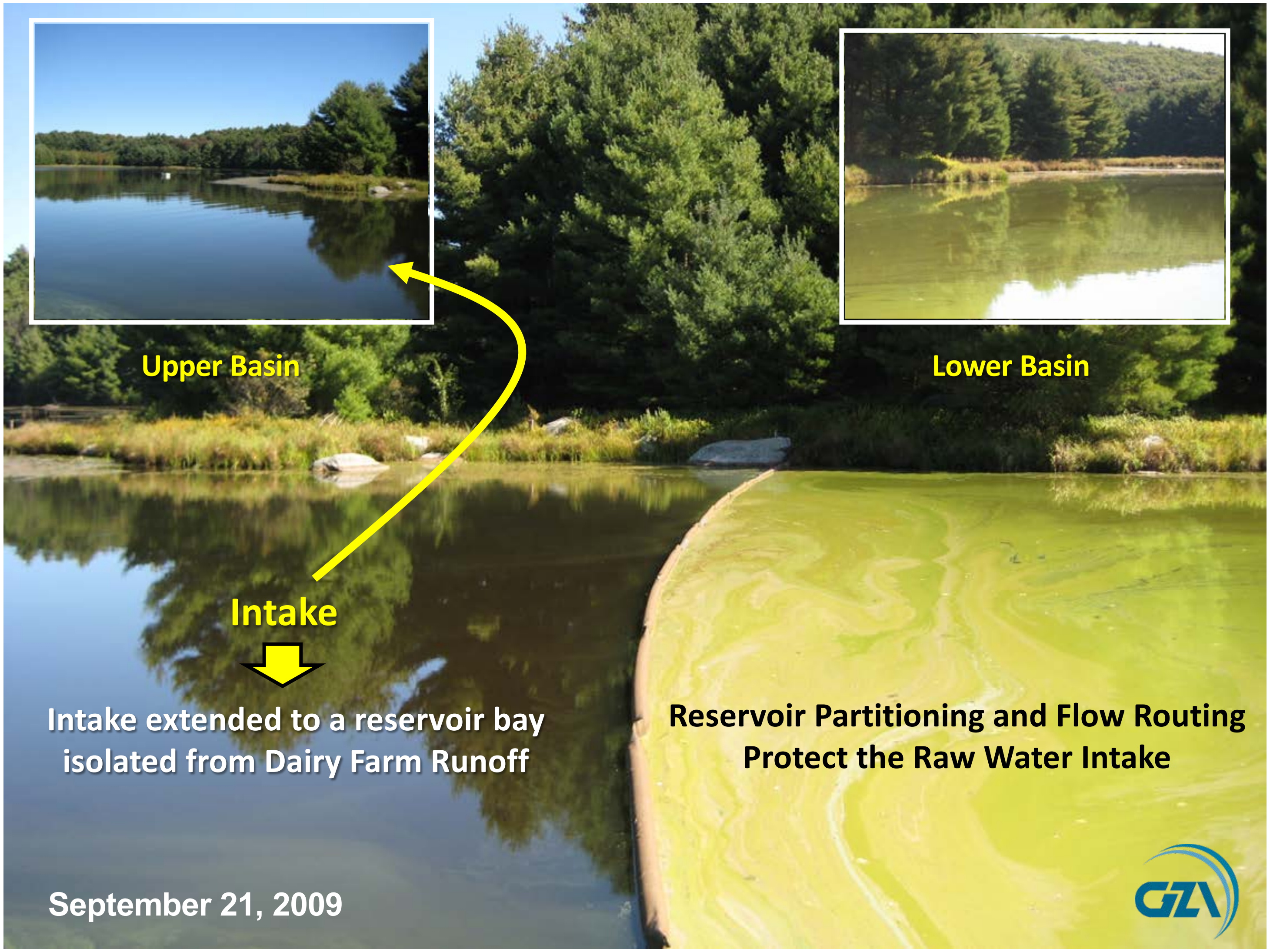
- ***Use Full Circulation to Manage Spring-Summer Transition in Laurel***

Timing of Release from Storage

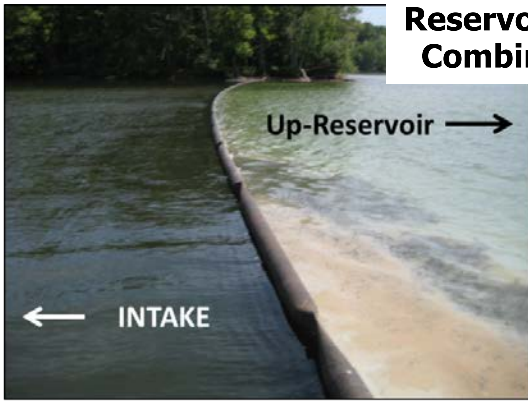
Sometimes a simple change in how a whole source system is used can improve water quality and reduce the risk of cyanobacteria blooms.



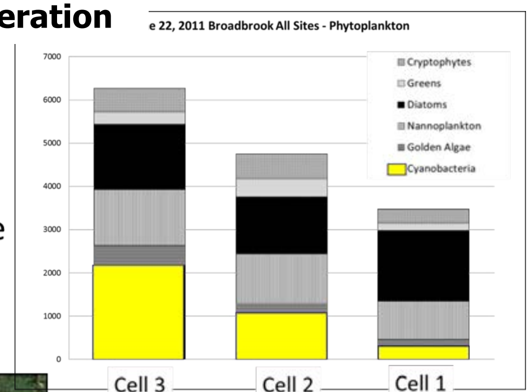



Upper Basin
Lower Basin
Intake
Intake extended to a reservoir bay
isolated from Dairy Farm Runoff
Reservoir Partitioning and Flow Routing
Protect the Raw Water Intake
September 21, 2009
GZA

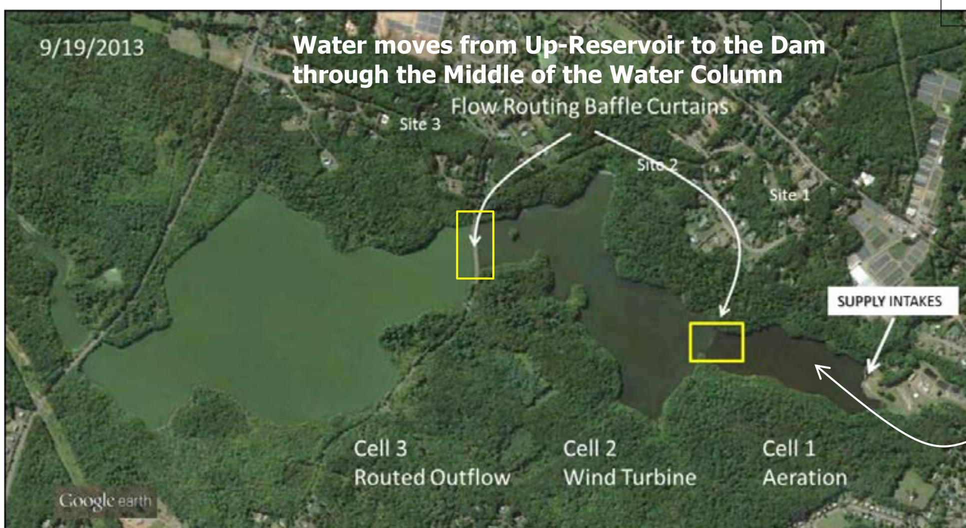
Reservoir Partitioning and Flow Routing Combined with Hypolimnetic Aeration



Cyanobacteria blooms are contained Up-Reservoir



Cyanobacteria



Water flows through the middle of the water column from the headwater end to the dam.

Hypolimnetic Aeration

Managing Longitudinal Zones in Reservoirs

- Compartments created in a run-of-river reservoir,
- Each managed individually and as part of the whole,
- Focusing on the water quality functions of each reservoir reach.

Known for excellence. Built on trust.

Questions?

Select References:

- Kortmann, R.W., G.W. Knoecklein, C.H. Bonnell, 1994. **Aeration of Stratified Lakes: Theory and Practice**. *Lake and Reservoir Management Journal*, 8(2):99-120.
- Barry Moore, Mark Mobley, John Little, Bob Kortmann, and Paul Gantzer. 2015. **Aeration and Oxygenation Methods for Stratified Lakes and Reservoirs.** NALMS *LakeLine* Spring 2015.
- Kortmann, R.W., 2015. **Cyanobacteria in Reservoirs: Causes, Consequences, Controls**. *NEWWA Journal*, June 2015.
- Kortmann, R.W., 2020. **Layer Aeration in Reservoirs: A 35 Year Review of Principles and Practice.** *NEWWA Journal- September 2020*
- Kortmann, R.W., 2021. **Managing Reservoir Stratification in a Variable Climate.** *NEWWA Journal- March 2021.*
- *Molot, Lewis, et.al. 2021.* **Low sediment redox promotes cyanobacteria blooms across a trophic range: Implications for management.** *Lake and Reservoir Management.*
- *Molot, Lewis, et.al. 2014.* **A novel model for cyanobacteria bloom formation: the critical role of anoxia and ferrous iron.** *Freshwater Biology*. (2014) 59, 1323–1340.

2nd Presentation

Dr. Elizabeth Crafton-Nelson is a Source Water Quality Engineer with Hazen and Sawyer where assists utilities across the country by working to increase their source water quality and treatability.

Dr. Crafton-Nelson received her PhD from the University of Akron where she studied cyanobacteria and cyanobacteria dominated harmful algal blooms.

During her PhD research, Dr. Crafton-Nelson worked alongside a phycologist and botanist with over 40 years of experience who was also a contributing author for the commonly referenced Freshwater Algae of North America textbook. The dual advisement from both the civil engineering and biology departments provided her with an interdisciplinary training and education, which makes her a unique asset for assisting with source water management.

Hazen

Holistic Management of HABs: The Road to Nutrient Reductions

Elizabeth Crafton

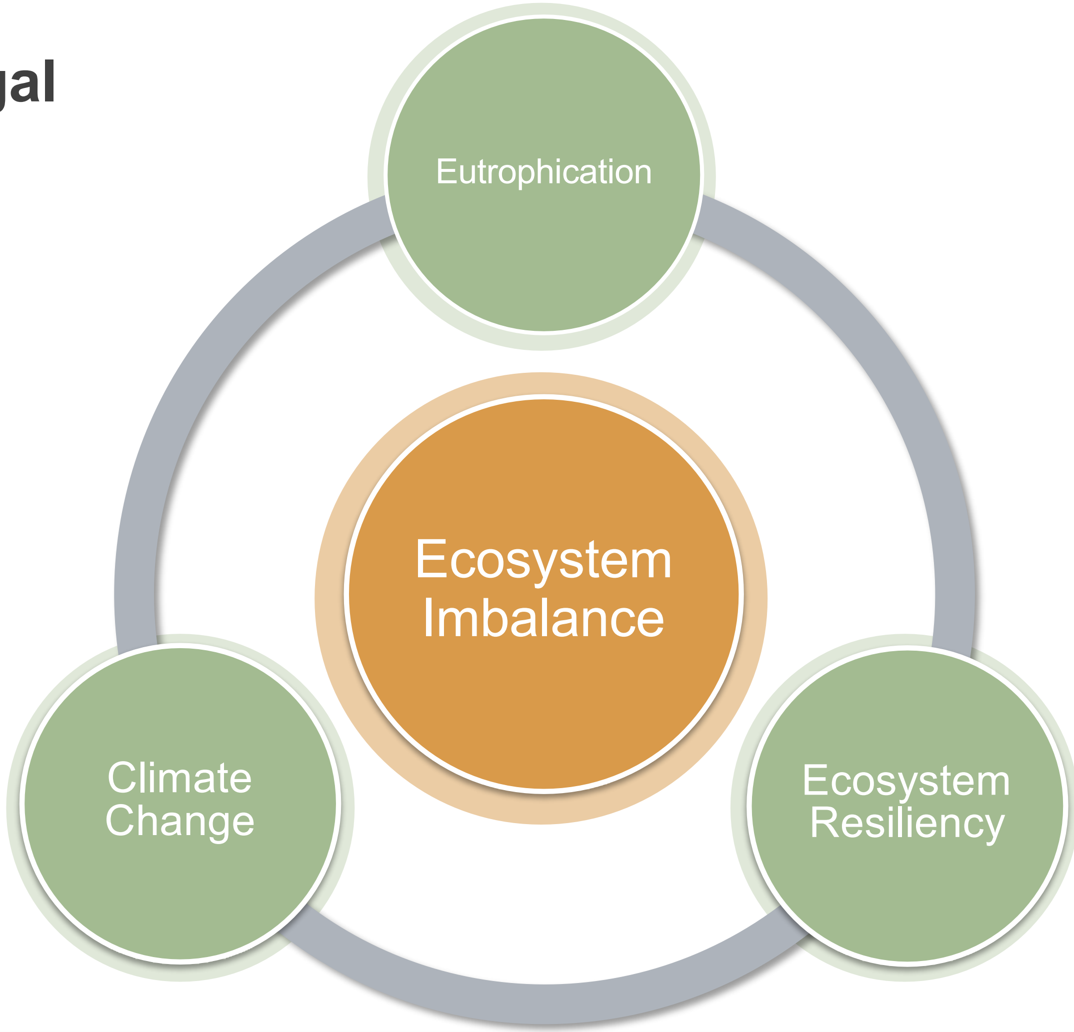
Agenda

- *Overview of harmful algal blooms*
- *Monitoring*
- *Short-term management*
- *Case Study #1*
- *Long-term management*
- *Case Study #2*

What Causes Harmful Algal Blooms?

"Harmful Algal Blooms (HABs) are symptomatic of ecosystem imbalance"

caused the by many environmental changes that manifest with the expanding global human footprint and climate change



Wehr et al. 2015

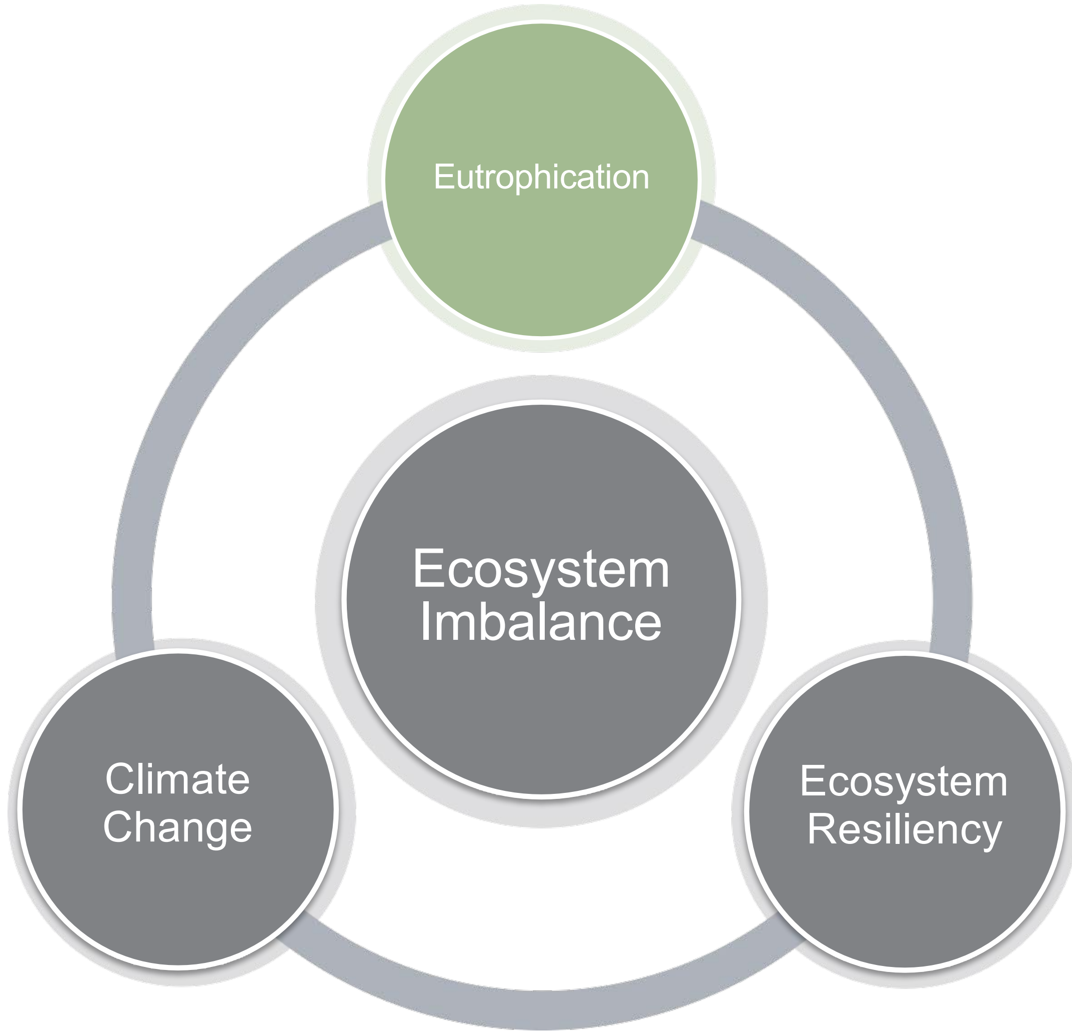
Eutrophication

Nutrient enrichment of water systems

Drives ecosystem changes and increases productivity

Key items to evaluate

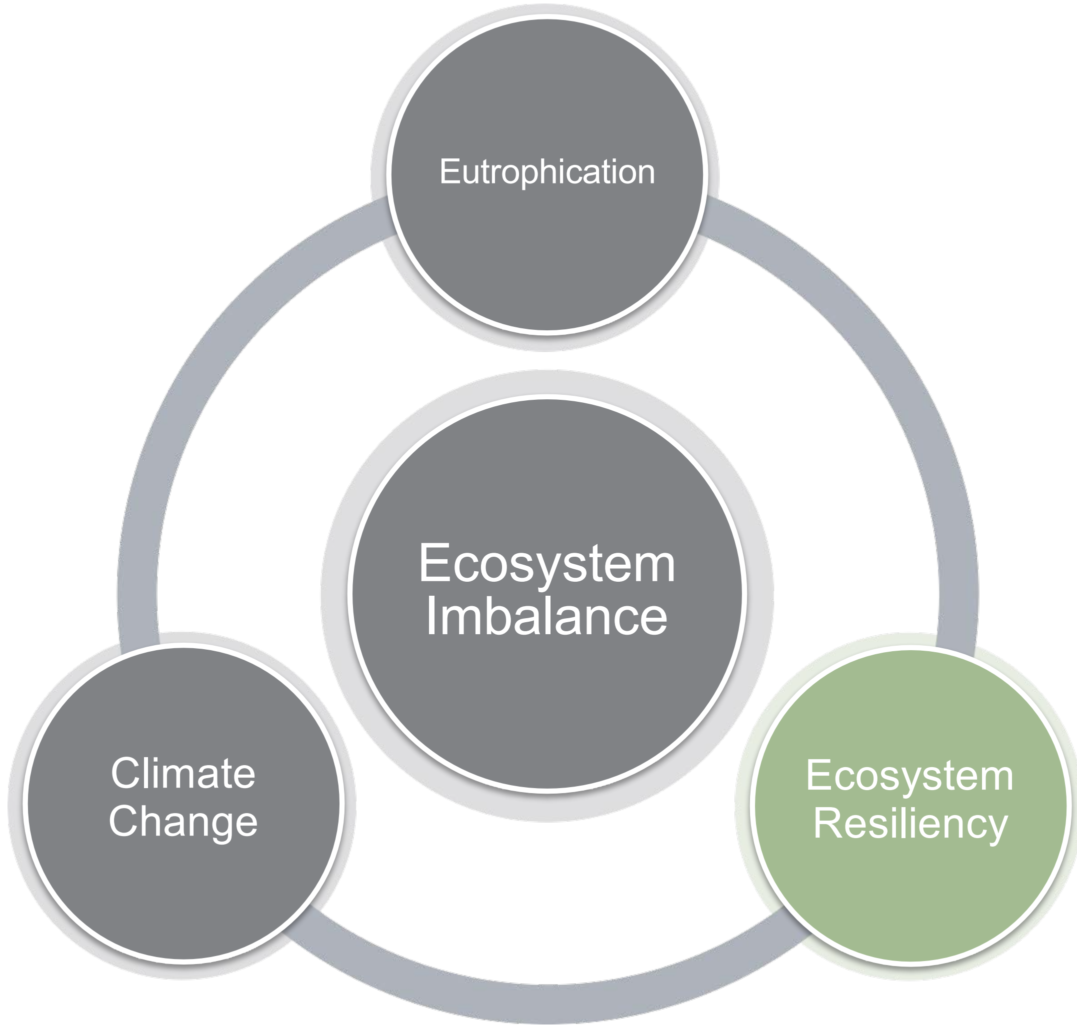
- Land Use-Land Cover (LULC)
- Watershed size
- Ratio to perimeter and water depth



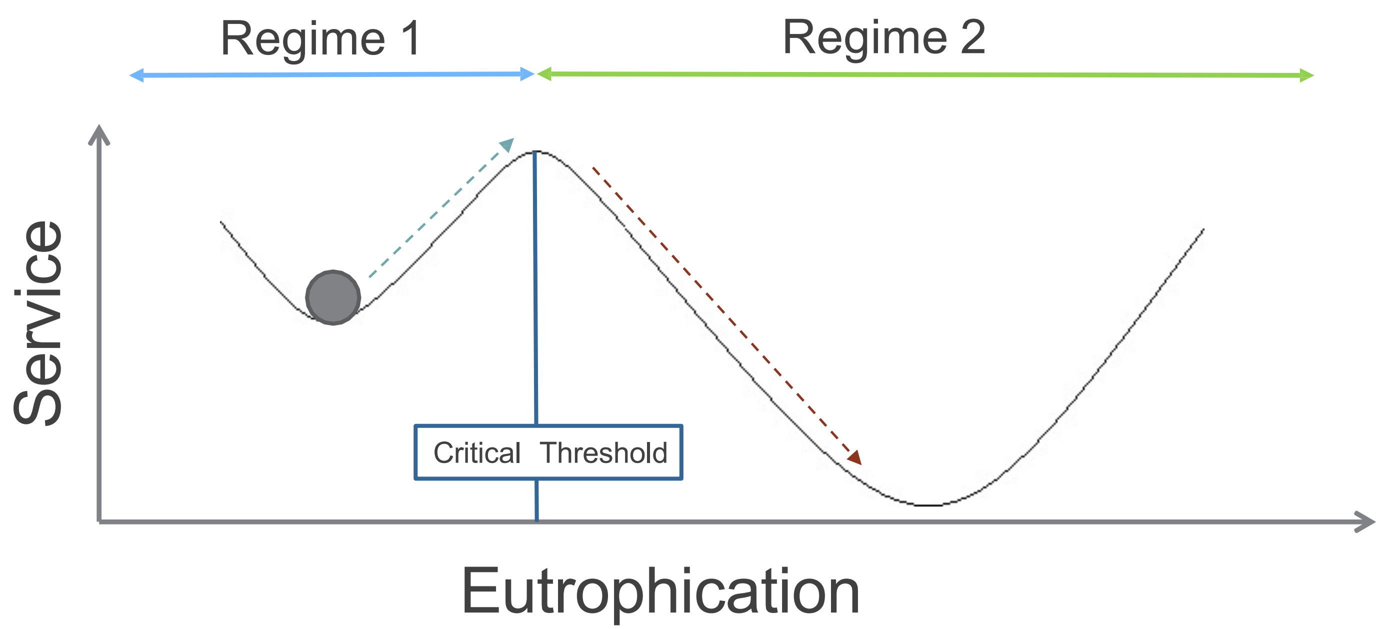
Ecosystem Resiliency

Capacity of an ecosystem to absorb disruption without shifting to alternative state

Ability to maintain normal patterns, nutrient cycling, and biomass production



Ecosystem Resiliency – Regime Shift

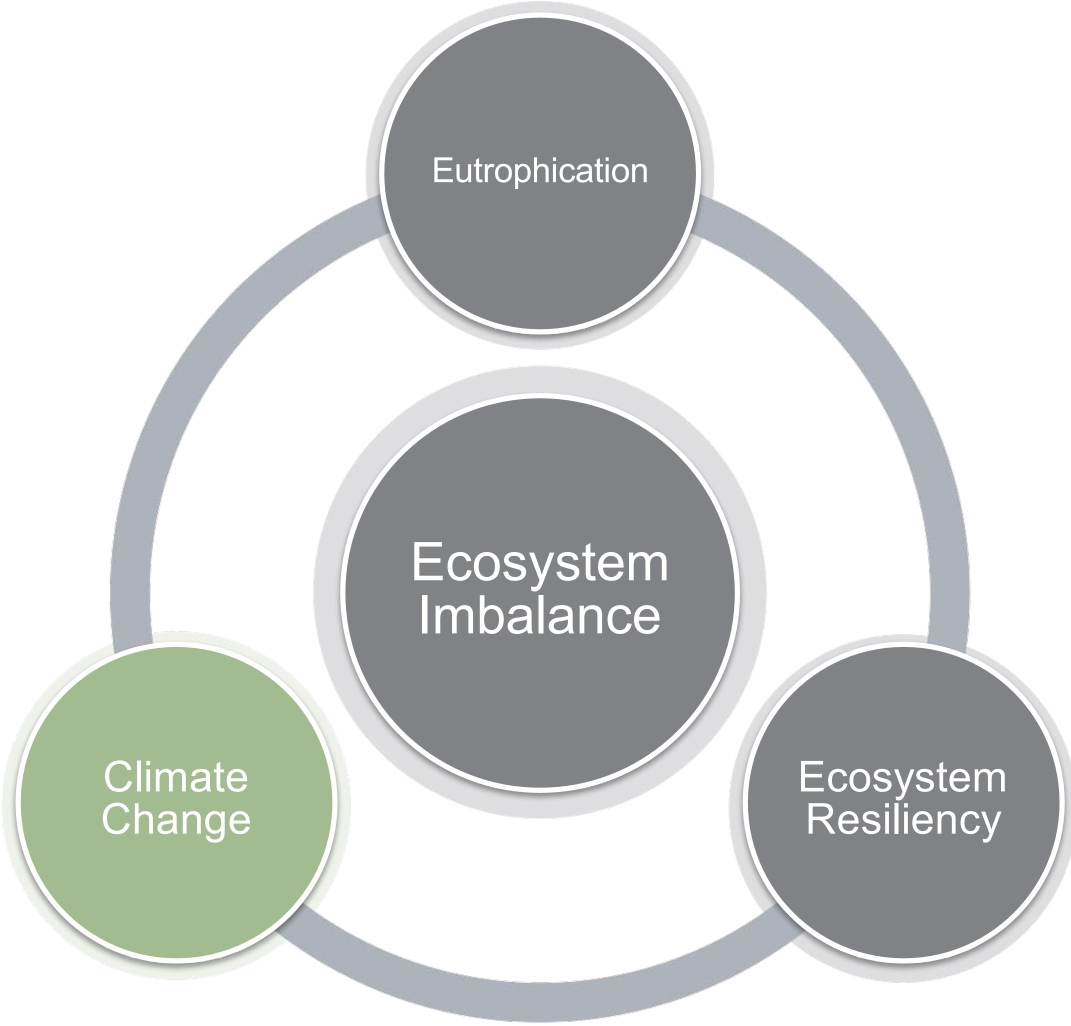


"Reorganization in system structure, functions and feedbacks"

Climate Change

Changes in temperature, weather patterns, and carbon dioxide loading associated with climate change will increase frequency and magnitude of HABs

Promote cyanobacteria dominance based on physiological characterizes of organisms



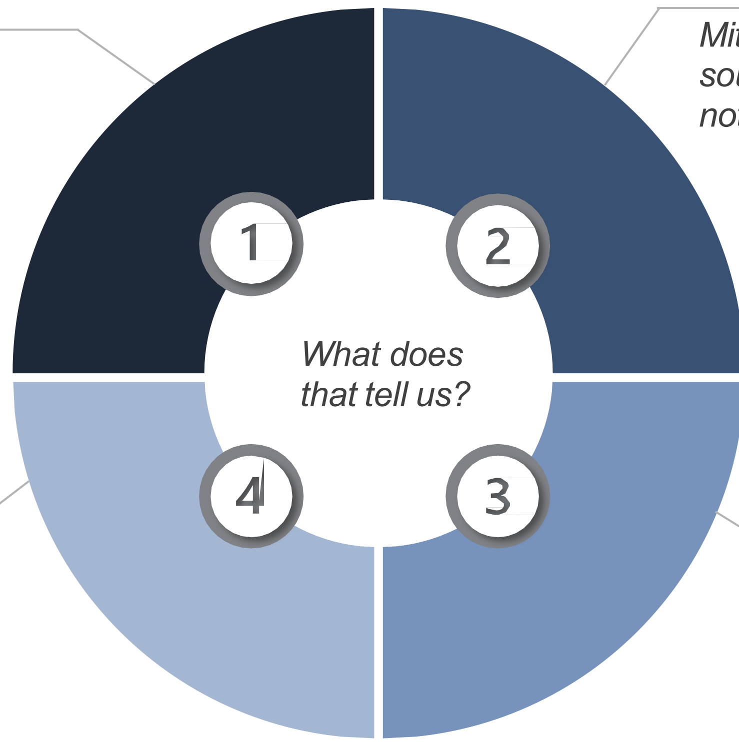
Take Away Message

Complex

HABs are more complicated than eutrophication

Comprehensive

Mitigating external sources of nutrients is not enough



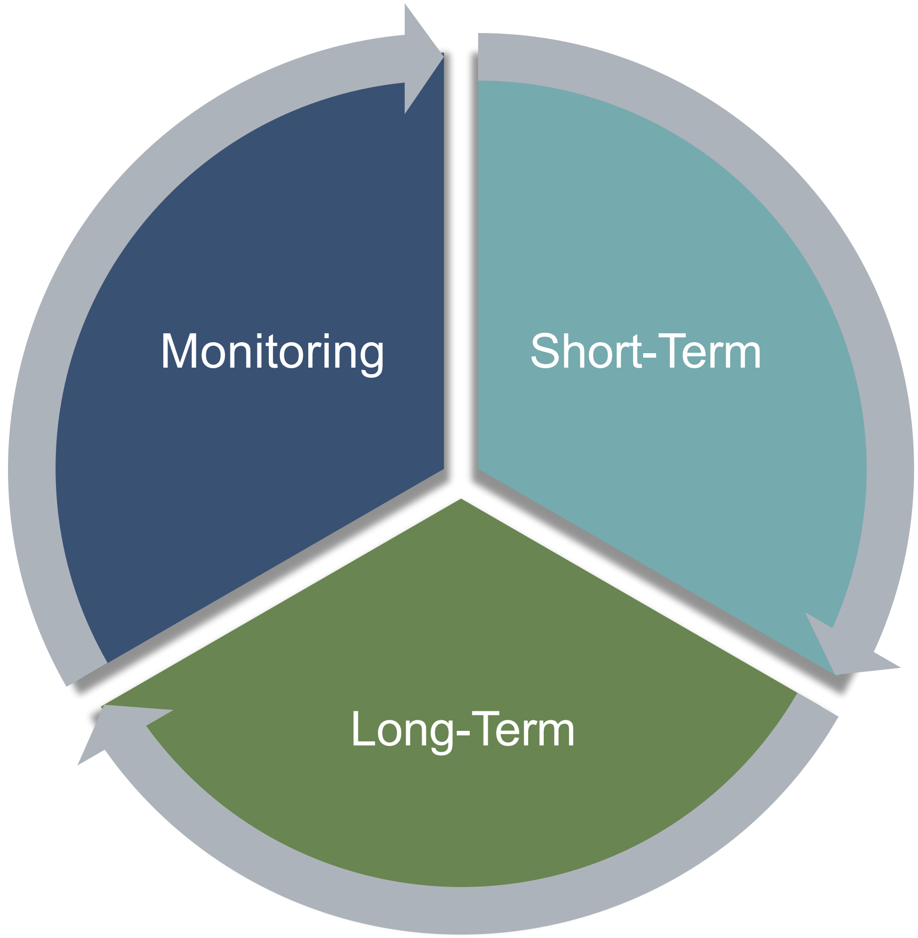
Capacity

Need to balance ecosystem and increase absorption capacity (resiliency)

Climate

Climate change plays a key role increased frequency and magnitude

Successful management requires a three-prong approach



Road to Nutrient Management

Long-Term Management

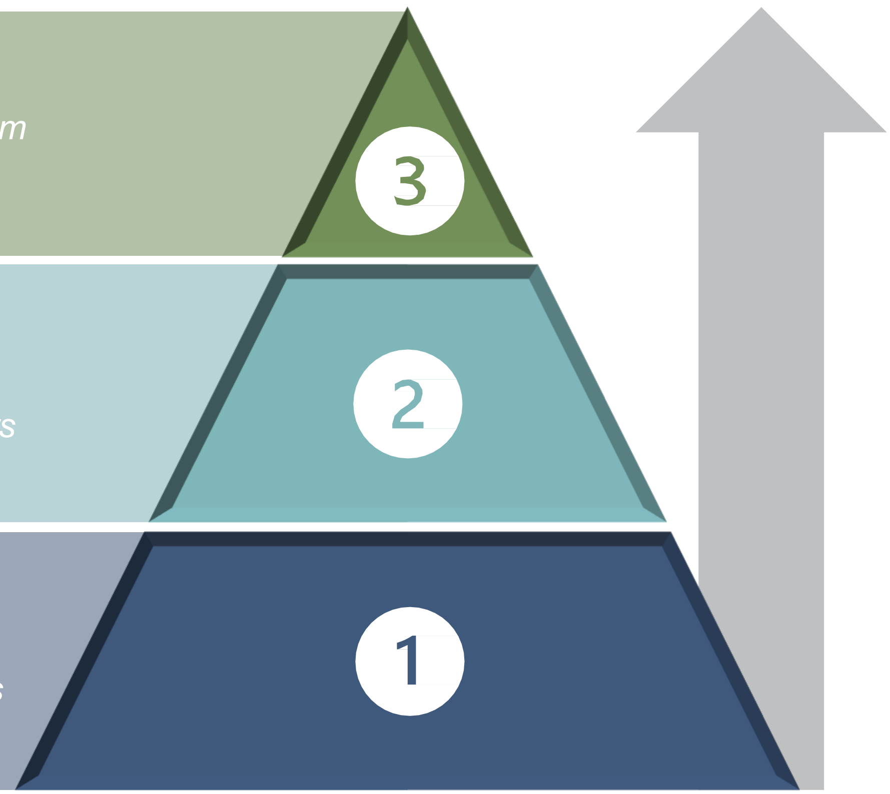
- Address the driving forces to prevent the problem
- Increase ecosystem resiliency
- Correct the ecosystem imbalance

Short-Term Management

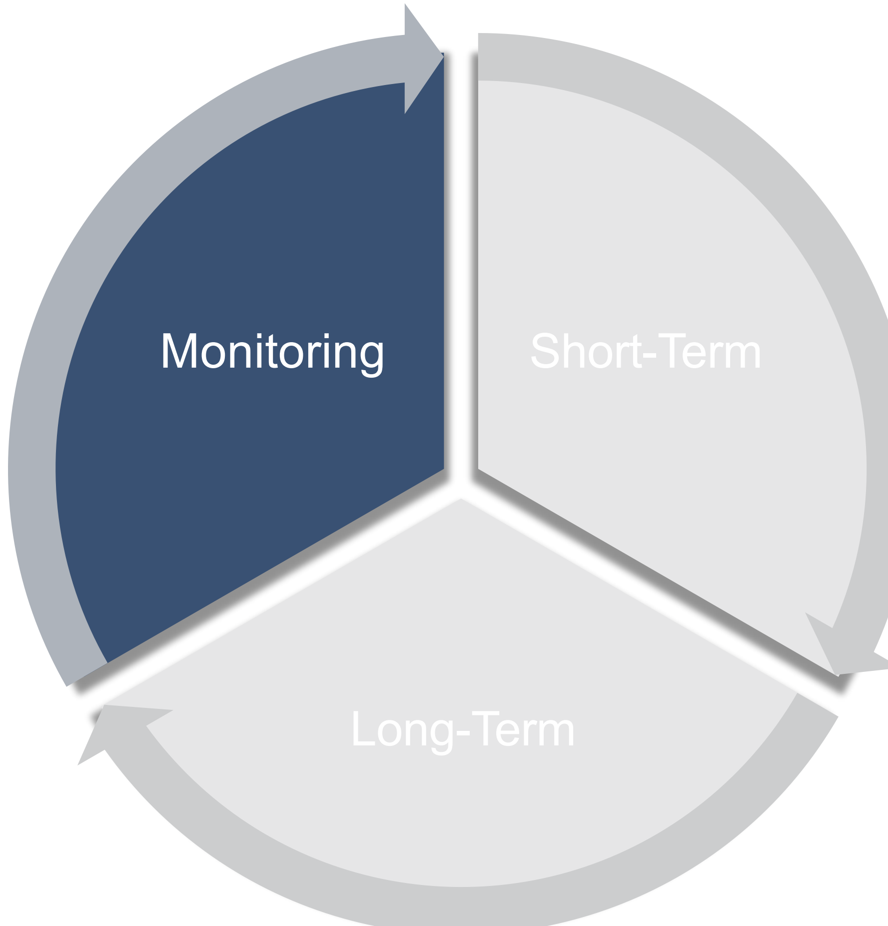
- Immediate action to maintain WQ
- Proactively manage growth of primary producers
- Prevent symptoms of overgrowth

Monitoring Program

- Characterize the system
- Design short- and long-term management plans
- Drive management program



Successful management requires a three-prong approach



Comprehensive Monitoring Goals

Monitoring Goals

Seasonal Trends

- Inter- and intra-seasonal trends
- Develop WQ parameter triggers
- Triggers are specific to each system

Key Biological Characteristics

- Gained through enumerations
- Dominant genera of phytoplankton
- Biological succession

Correlate to Secondary Metabolites

- Determine source of cyanotoxins and T&O
- Delineate risk of secondary metabolites
- Build predictive capacity

Key Elements of Monitoring Program

Comprehensive Monitoring

In-Situ Profiles

- *1-m intervals*
- *WQ Parameters*
- *Photosynthetic pigments*
- *Chlorophyll-a and phycocyanin*

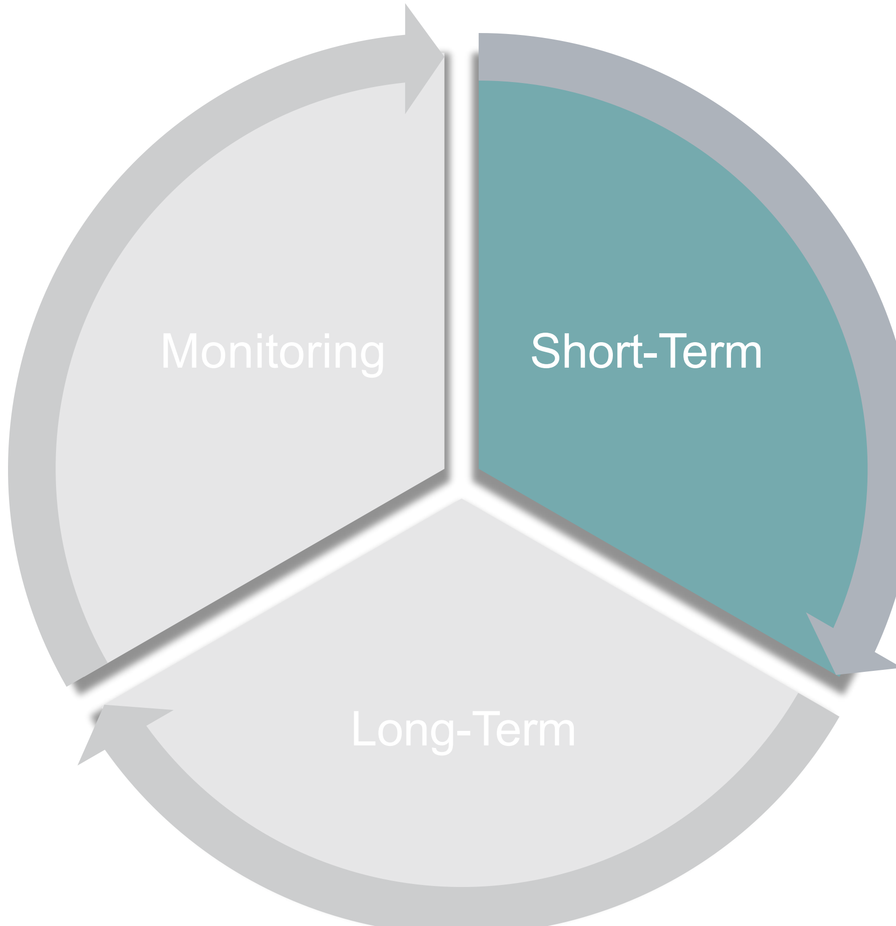
Metabolites

- *Grab Samples*
- *Taste & Odor analysis*
- *Cyanotoxins analysis*
- *qPCR*

Enumerations

- *Grab Samples*
- *Microscopic analysis with counting chambers*
- *FlowCAM*

Successful management requires a three-prong approach



Short-Term Management Goals

Short-Term Goals

Maintain Current WQ

- Immediate action to maintain current water quality
- Water quality will continue to decline if overproduction continues
- Shift dominance away from cyanobacteria

Reduce Risk

1 Taste and Odor

- MIB/geosmin
- Additional T&O compounds

2 Toxicity

- Cyanotoxins presence
- Limit growth of toxic cyanobacteria

Limit Overproduction

- Preserve water quality
- Phytoplankton and aquatic nuisance species
- Limit the probability of secondary metabolites

Common Strategies for Short-Term Management

Low-Powered Ultrasound

SolarBee Mixers

Algaecide Treatments

→ *Proactive management to minimize growth*

Low-Powered Ultrasound Systems

- LG Sonic and Sonic Solutions
- Collapse of gas vesicles in cyanobacteria
- Sonoporation mechanisms
- Couple with algaecide treatment
- On-going research with OSU

Images: LG Sonic

Ultrasound

SolarBee Mixers

Algaecides

SolarBee Mixers

- Solar-powered
- Mixes the upper portion of the water column
- Aerates upper layers by mixing
- Composition of phytoplankton population

Images: SolarBee

Algaecide Treatments

Ultrasound

SolarBee Mixers

Algaecides

- Advances in products
- Application approaches and timing of treatment
- Minimize risk to non-target organisms
- Prolonged suppression

Peroxide treatment

Copper treatment

Algaecide Product Types

Ultrasound

SolarBee Mixers

Algaecides

Copper

- Toxicity to suppress growth
- Non-selective
- Product advancements
- Liquid products
- Chelated products
- Bind available phosphorus while delivery copper

VS

Hydrogen Peroxide

- Oxidative stress
- Selectively target cyanobacteria
- Injure not kill
- Granular and liquid products
- Sodium carbonate peroxyhydrate (27% H_2O_2)

Algaecide Product Types: Hydrogen Peroxide

Ultrasound

SolarBee Mixers

Algaecides

- *Cyanobacteria prokaryotic*
- *Mehler reaction*
- *ROS-eliminating enzymes*
- *Ascorbate peroxidase (APX)*

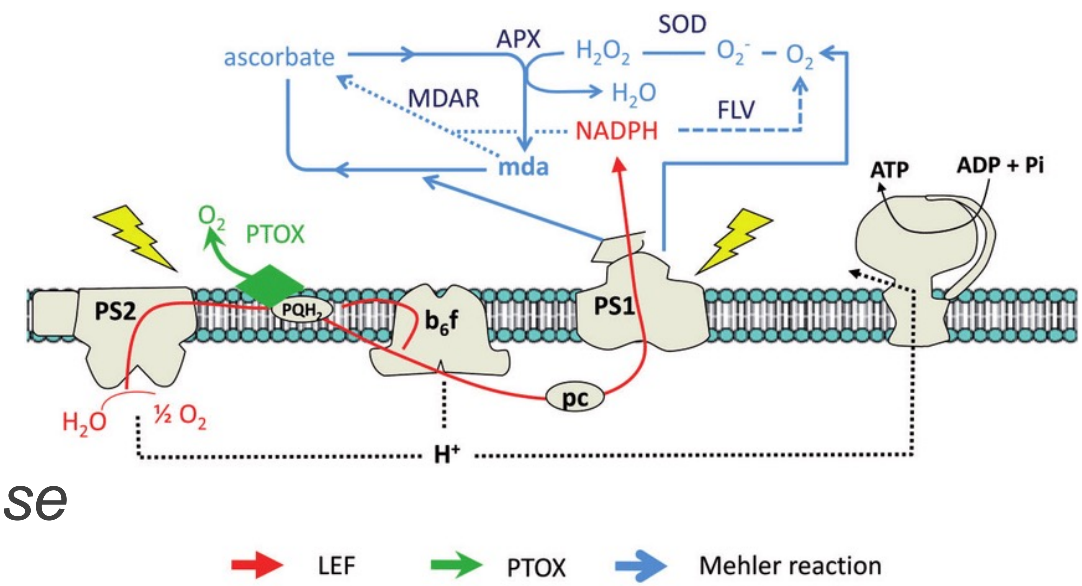


Image: Curien et al. 2016

Algaecide Product Types: Hydrogen Peroxide

Ultrasound

SolarBee Mixers

Algaecides

- Disrupts circadian rhythm
- Impacts metabolic and physiological function
- Reproduction, nitrogen fixation, carbon uptake, synthesis of secondary metabolites, photosynthesis
- Downregulates microcystin genes (mcyA, mcyD, mcyH)

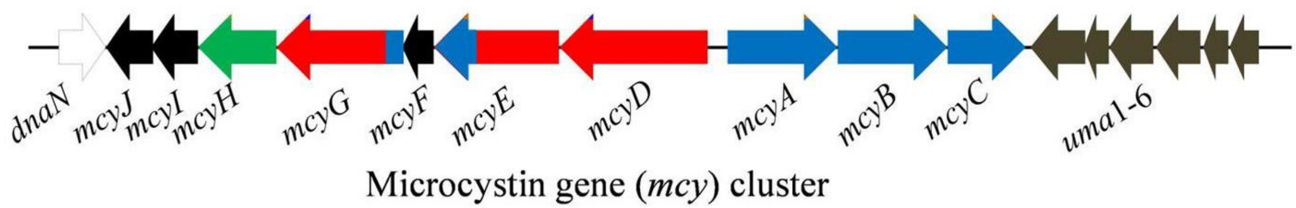


Image: Rastogi et al. 2015

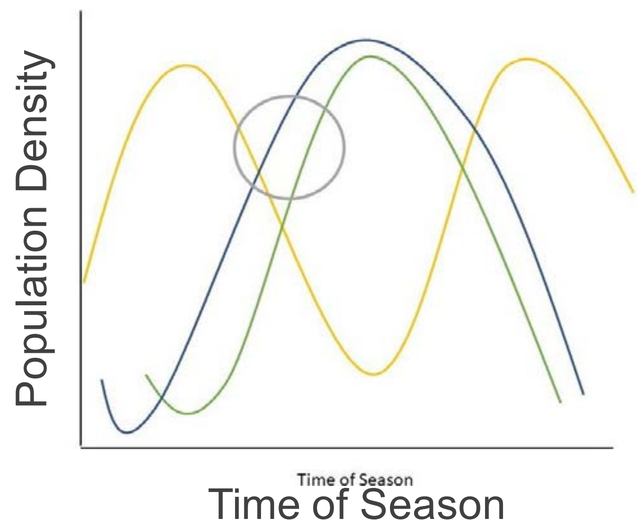
Algaecide Treatment Approach

Ultrasound

SolarBee Mixers

Algaecides

- Target sections of the water column
- Inject at sediment water interface
- Target different section based on product
- Hot spots (H_2O_2) vs. accumulation locations
- Timing of application



Case Study #1

2019

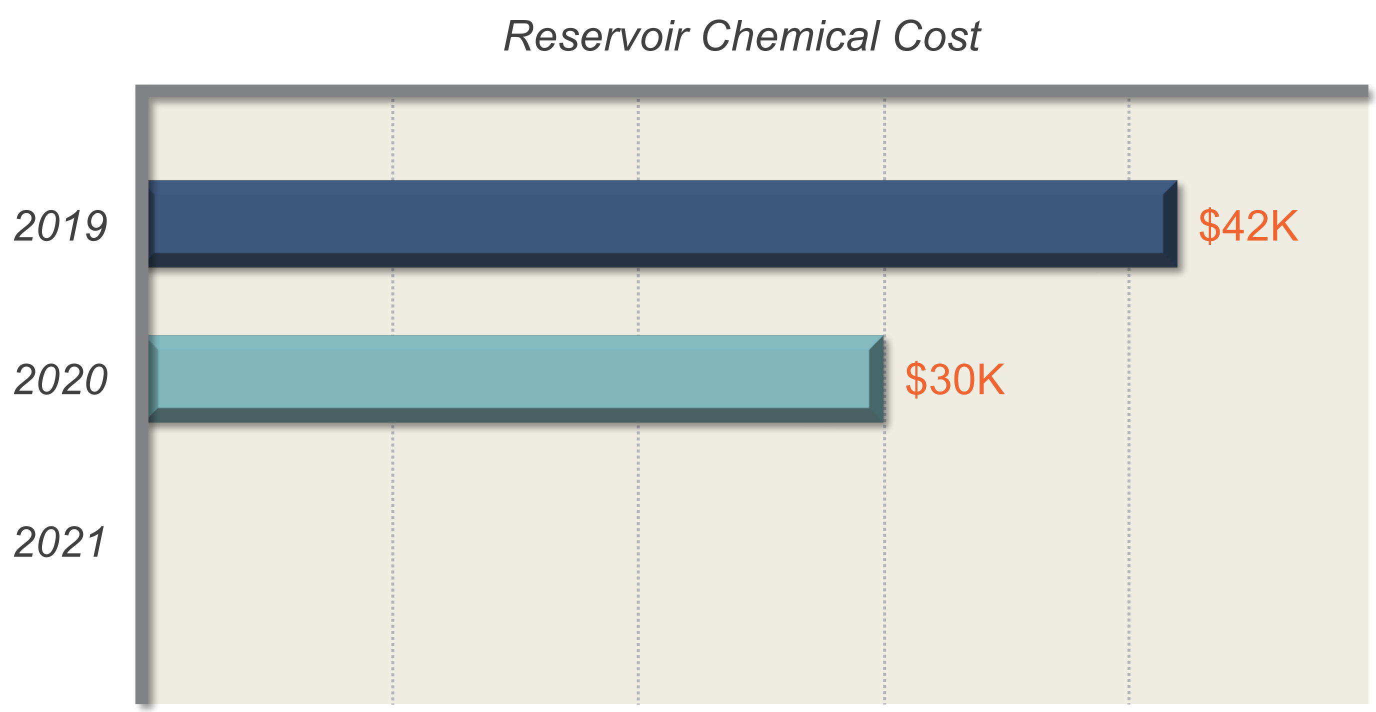
- Copper-based treatments
- Limited monitoring data
- WTP challenges

Case Study #1

2020

- *Switched to hydrogen peroxide-based treatments*
- *Monitoring buoy was installed in June of 2020*

30% reduction in annual cost

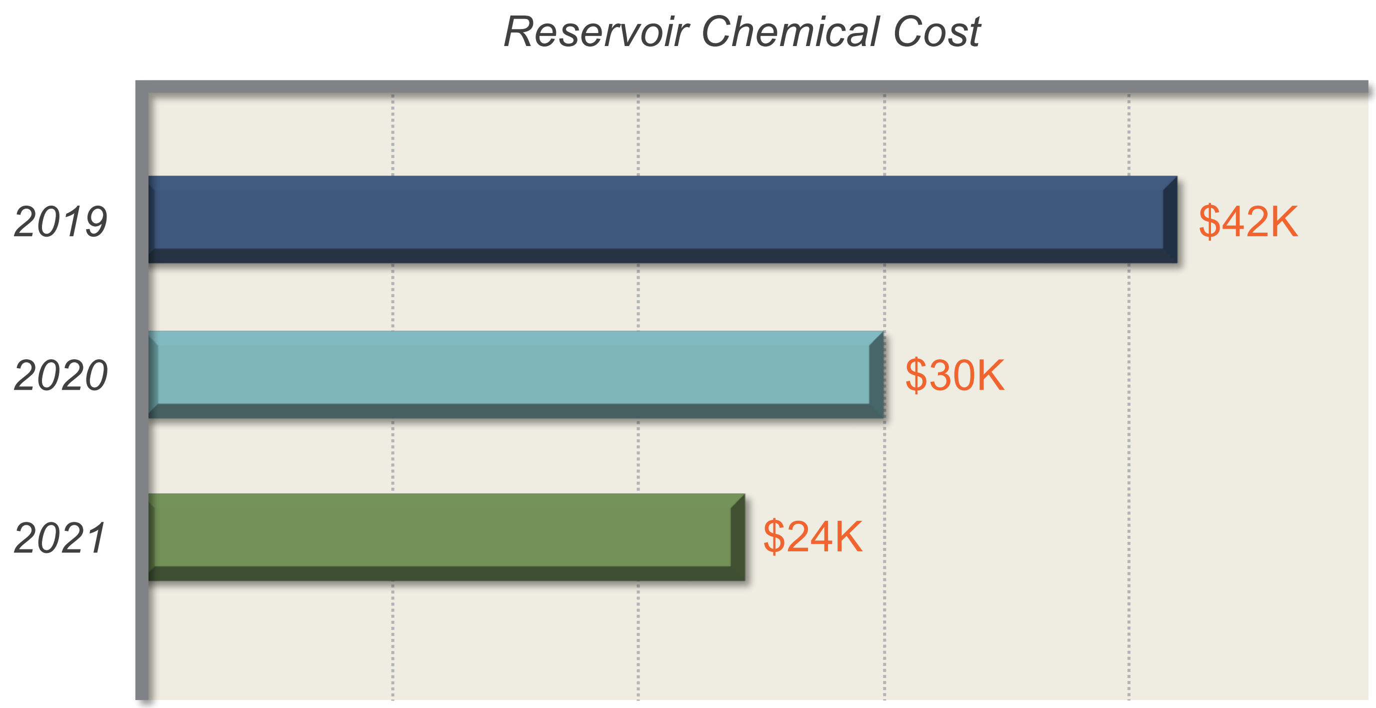


Case Study #1

2021

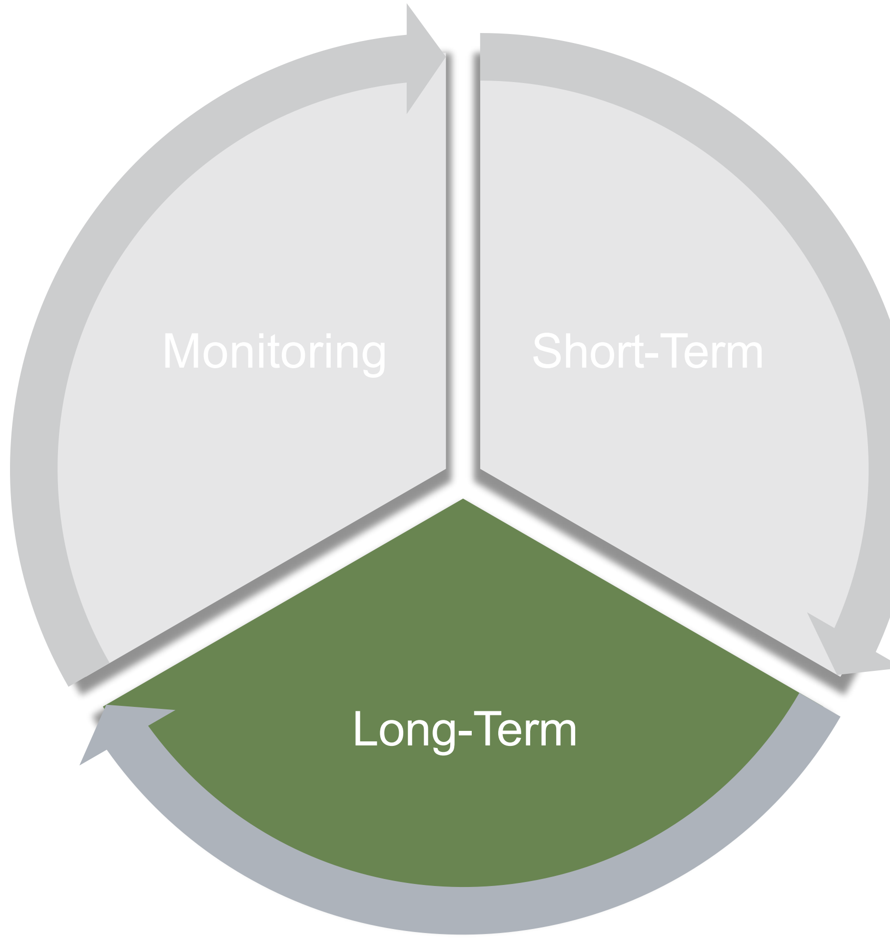
- *Full year of monitoring data*
- *Optimized triggers*
- *Active year*

Additional 20% reduction in annual cost



44% reduction two years after implementing new management program and improved treatability

Successful management requires a three-prong approach



Long-Term management Goals

Long-Term Goals

Perform Comprehensive Nutrient Study

- Build nutrient model for system
- Determine if system is macronutrient limited and which one
- Outline influence of internal and external

Delineate viable BMPs

- Based on study's findings
- Include hydrological analysis for feasibility
- Complete needed sampling for design

Balance ecosystem

- Upward directional flow of nutrient and energy
- Shift dominance from cyanobacteria
- Top-down assessment

Increase biodiversity and ecosystem resiliency

- Increase biodiversity by shifting dominance away from cyanobacteria
- Native aquatic plants to switch regime
- Reinforce resiliency with BMPs

Common Strategies for Long-Term Management

- *Oxygenation*
- *Geoaugmentation*
- *Phytoremediation*
- *Adsorption*

Thank you, Dr. Kortmann

Prevent overproduction by correcting ecosystem imbalance

Common Strategies for Long-Term Management

Geoaugmentation

Phytoremediation

Adsorption

Prevent overproduction by correcting ecosystem imbalance

Geo-augmentation

Phytoremediation

Adsorption

Geo-augmentation for Nutrient Reductions and Cycling

- Uses metals to augment nutrient cycling and availability
  - Fe, Al, and La
  - Alum, Sodium Aluminate, Phoslock®
- Internal nutrient cycling driven by biotic and abiotic factors
  - Anoxia
  - Microbial activity
- Requires preliminary study

Image: NALMS.org

Geo-augmentation for Nutrient Reductions and Cycling

Geo-augmentation

Phytoremediation

Adsorption

- *Discrete application*
  - *Internal nutrient cycling and flux*
  - *Nutrient mapping*
- *Continuous feed*
  - *Moving water*
  - *Influent nutrient loads*
  - *Tributaries*
  - *Coupled with oxygenation system*

Image: HABAquatics.com

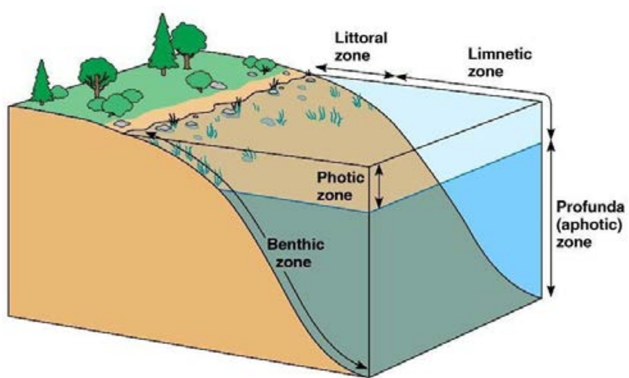
Phytoremediation for Nutrient Reduction and Ecological Balance

Geo-augmentation

Phytoremediation

Adsorption

- *Nutrient removal and increased competition*
- *Reduce internal nutrient cycling*
- *Shift from Regime #2 to Regime #1*
- *Allelopathic interaction between aquatic plants and phytoplankton*
- *Two types*
  - *Littoral zone restoration*
  - *Hydroponic systems*



Graphic: Pearson Education

Phytoremediation for Nutrient Reduction and Ecological Balance

Littoral zone restoration

- *Internal buffer*
- *Provide key habitats*
- *Increase nutrient competition and stabilize internal cycling*
- *Regime shift*
- *Maintenance program*

Images: Lakeandwetland.com

Phytoremediation for Nutrient Reduction and Ecological Balance

Geo-augmentation

Phytoremediation

Adsorption

Hydroponic Systems

- *Optimized floating wetland*
  - *Can be used together*
- *Roots directly exposed in photic zone*
- *Allelochemical release and symbiotic relationship*
- *Maintenance program*

Images: Freshwatersystems.com

Adsorption Methods for Nutrient Reductions

Geo-augmentation

Phytoremediation

Adsorption

- Internal or external use
- Targeted BMP for watershed management
  - Control influent nutrient loading
  - Tributary
- Several media options
- Biochar, UltrAsorb, Nutrient Removal Pellets

Image: SOLitudeLakeManagement.com

Case Study #2

- Completed a comprehensive study
- Outlined a short- and long-term plan
- Approach differed from previously proposed work
- Improved outcome by 20%
  - Expected 40% reduction in TP from previous design
  - Achieved 60% in TP

June 2020

June 2021

Key Takeaways

- *There is no silver bullet*
- *One strategy or technology will not solve the multidimensional problem*
- *Algin strategies with WQ goals and biotic characteristic*
- *Each system is unique and requires an equally unique approach and coupling of management technologies*

Comprehensive Source Water Management

Services

Source Water Monitoring Program

- Construct multi-objective monitoring program
- Obtain key biological information for management
- In-house identification and enumeration for assessments
- FlowCAM calibration and library development

Microscope (Alan)

Source Water Assessment

- Comprehensive analysis
- Annual and total nutrient budget
- Phytoplankton composition

Short-Term Management

- Proactive use of hydrogen peroxide
- Low-powered ultrasound application
- Flushing and mixing (SolarBee ®)

Long-Term Management

- Watershed-based nutrient management
- Targeted BMPs (e.g. biochar, adsorption methods, WTR)
- In-situ phytoremediation (e.g. floating wetland, hydroponics)
- Aluminum addition and sediment phosphorus fractionation
- Oxygenation and aeration application and modeling

NLA Gravity Corer

Thank you!

Questions?

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Questions & Answers

Please post any questions to the “CHAT”.

Please join us next week!