Natural Lake Management Methods: An Overview

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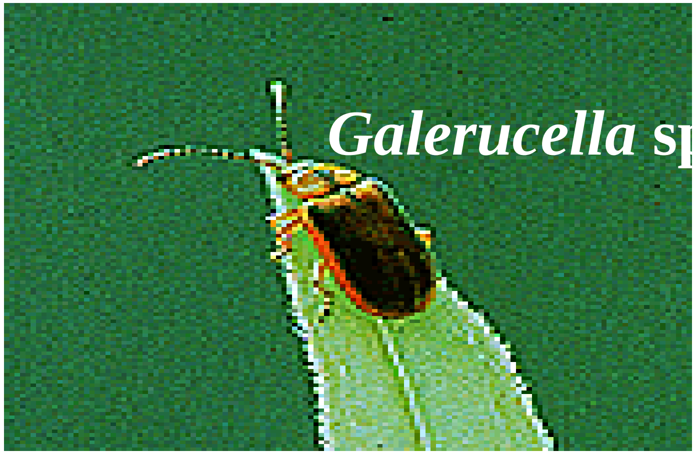
Myriophyllum spicatum (Eurasian milfoil)

- Early season canopy-forming growth
- Exotic submersed macrophyte from Eurasia
- Shades light from native macrophytes
- Creates a high BOD, depletes oxygen
- Must be controlled with herbicides or biological control

Lythrum salicaria (Purple loosestrife)



- Exotic wetland plant
- Seeds viable and fire-resistant
- Out-competes favorable emergent macrophytes
- Controlled with systemic herbicides or *Galerucella* sp. beetles

Euhrychiopsis lecontei (Milfoil weevil)

- Biological control
- Requires adequate over-wintering habitat and milfoil biomass
- Larvae burrow into stem, de-vascularize tissue
- Milfoil not eradicated, but controlled
- ~ Not available now

Benthic Barriers

- Function by limiting light from germinating plants
- Best installed in early spring
- Can be up to 400x400 feet and are best for beachfront areas
- Easy installation

Weed Rollers

- Weed Rollers are mounted on lake docks and use a wide arc to pulverize lake bottom to prevent aquatic plants from growing
- Useful in beachfront areas
- May cost us to $5,000

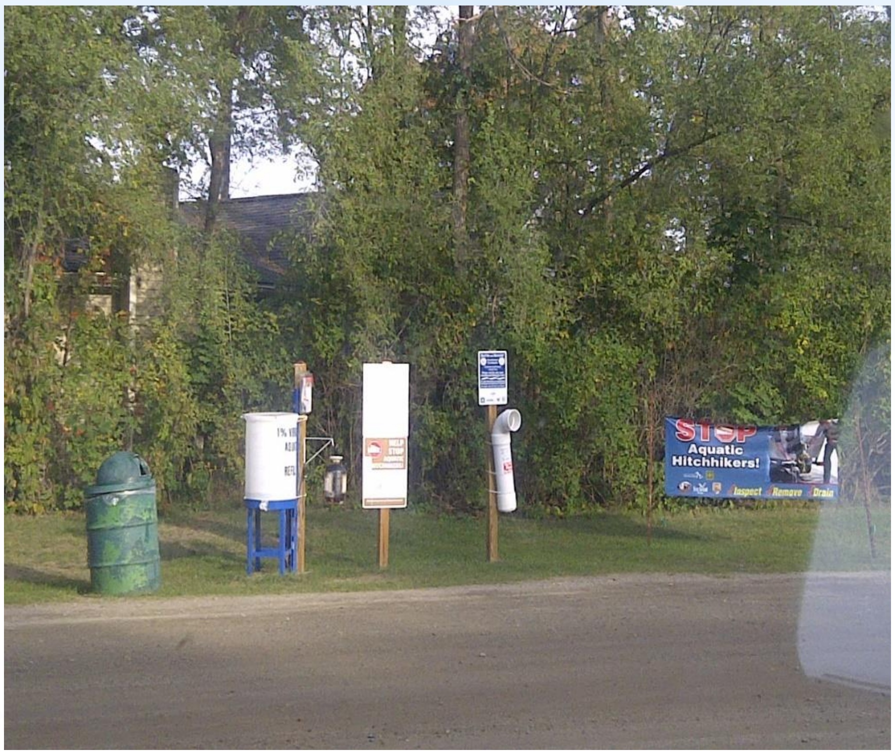
DASH

- Use of SCUBA divers and hoses to suction aquatic vegetation out of the lake after hand-pulling
- Biomass is taken to a farm for compost
- Costly but useful in small areas-ideal for problem areas

Mechanical Harvesting

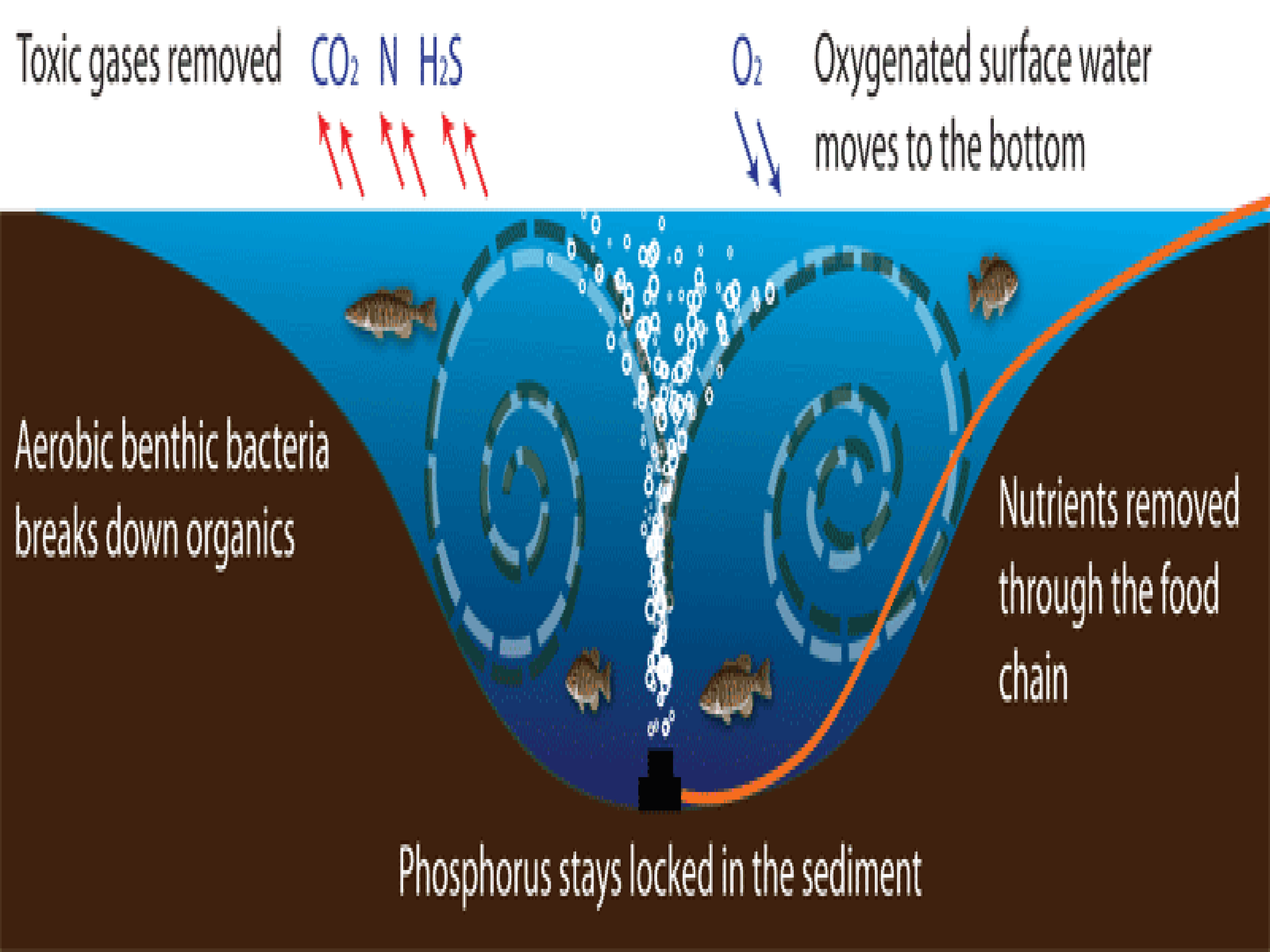
- Immediate removal of aquatic plant biomass
- Non-selective
- Great for lakes that desire a non-chemical approach
- Biomass is taken to a farm for compost

Boat Washing Station



- Can be an accessible reminder to de-contaminate all boats/trailers
- Information on site usually provided
- Relies on self awareness but recent law is recited on scene

The Mechanics of Aeration and Bioaugmentation



Toxic gases removed
CO_2 N H_2S
O_2
Oxygenated surface water moves to the bottom
Aerobic benthic bacteria breaks down organics
Nutrients removed through the food chain
Phosphorus stays locked in the sediment

MI Lakes with LFA Technology

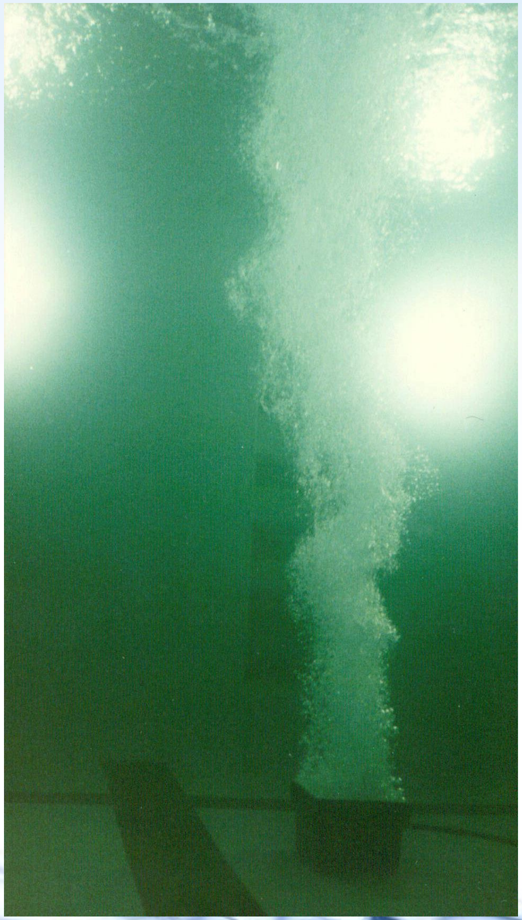
MI Lakes with LFA Technology

- Austin Lake, Kalamazoo Co.
- Indian Lake, Cass Co.
- Sherman Lake, Kalamazoo Co.
- Keeler Lake, Kalamazoo Co.
- Maple Lake, Van Buren Co.
- Paradise Lake, Emmet Co.
- Pickerel Lake, Kalamazoo Co.
- Sand Lake, Newaygo Co.
- Podunk Lake, Barry Co.
- Wing Lake, Oakland Co.

WQ Parameters Measured

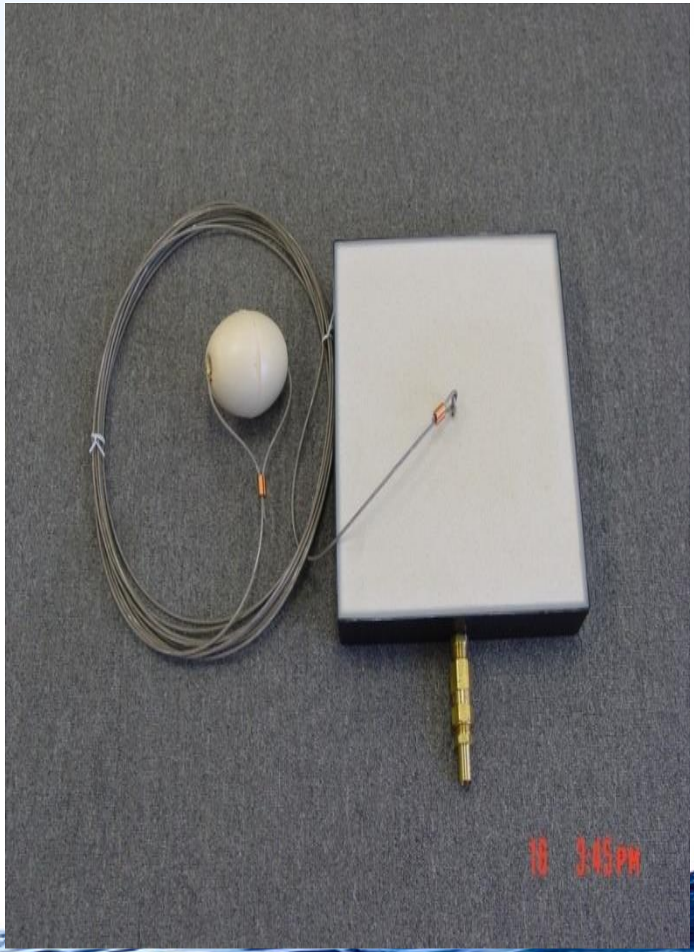
- Water temp, pH,DO,conductivity, ORP, TDS, TSS, chl-a
- Algal composition
- Sediment reduction, nutrients, organic matter, depth
- Aquatic vegetation communities

Inversion Oxygenation Aeration Components

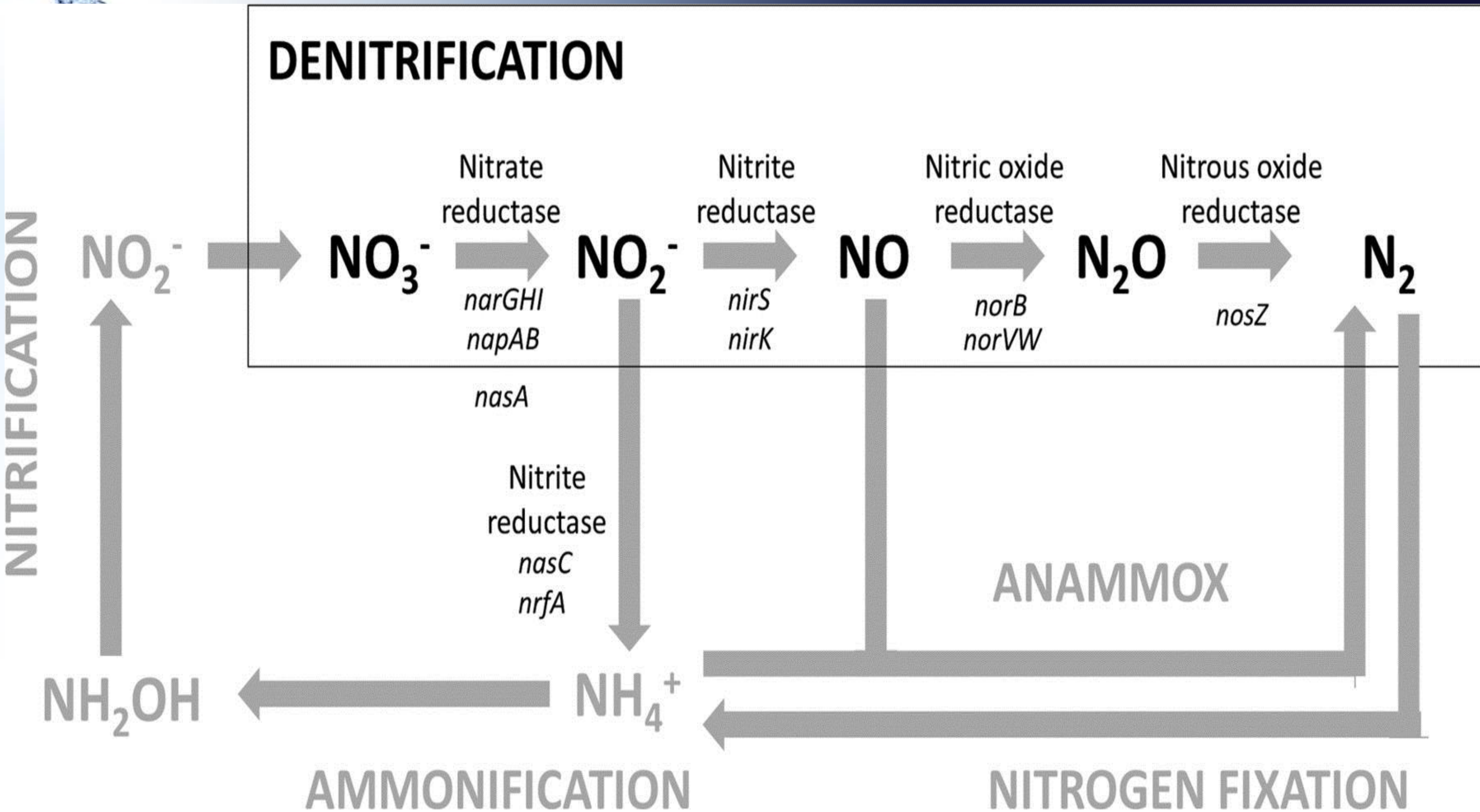


End-on view: non-turbulent flow

Ceramic diffuser head and anchor



The Nitrogen Cycle



Alvarez L et al. Appl. Environ. Microbiol. 2014;80:19-28

Destratification: Increase DO from top to bottom

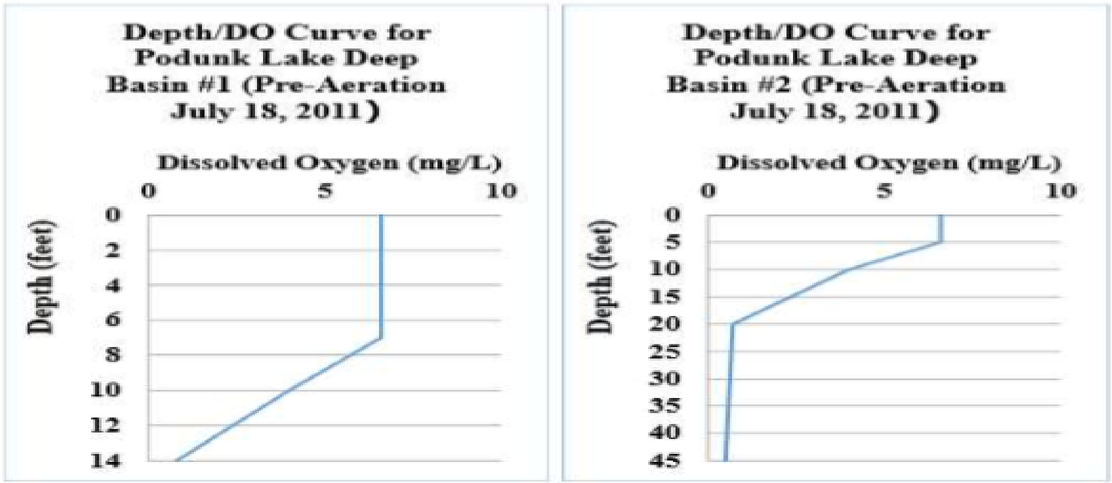


Figure 2a. Pre-aeration DO vs. curves for Podunk Lake deep basins.

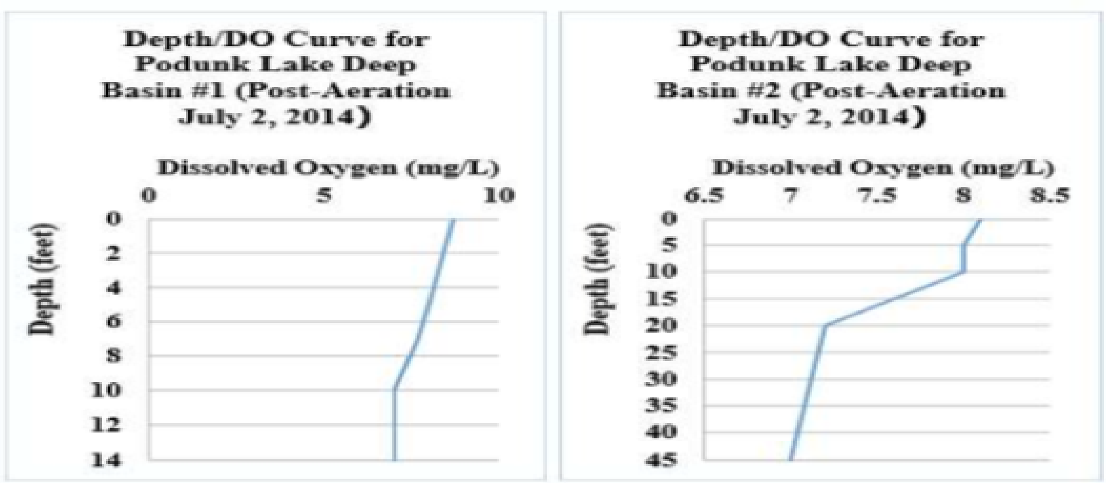
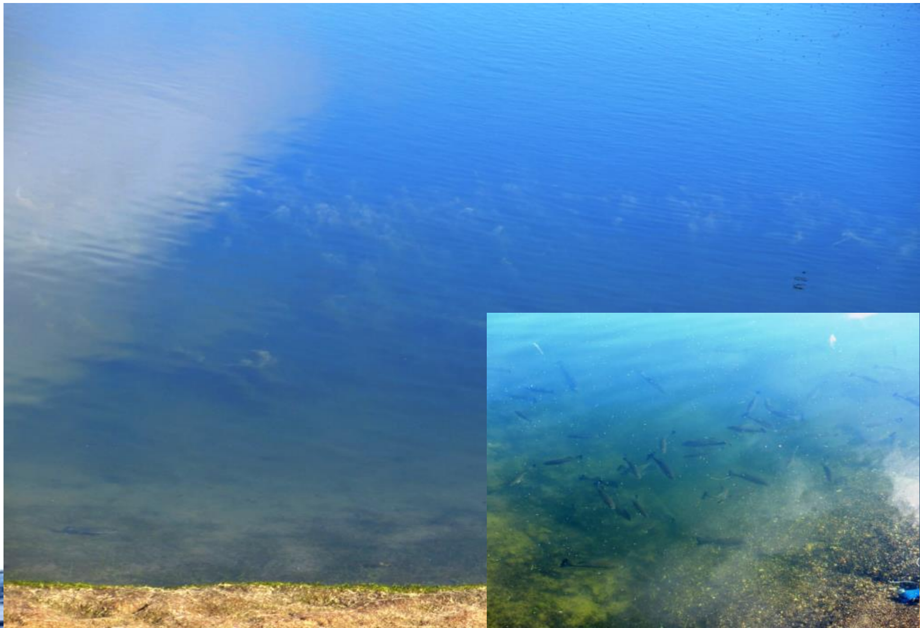


Figure 2b. Post-aeration DO vs. curves for Podunk Lake deep basins.

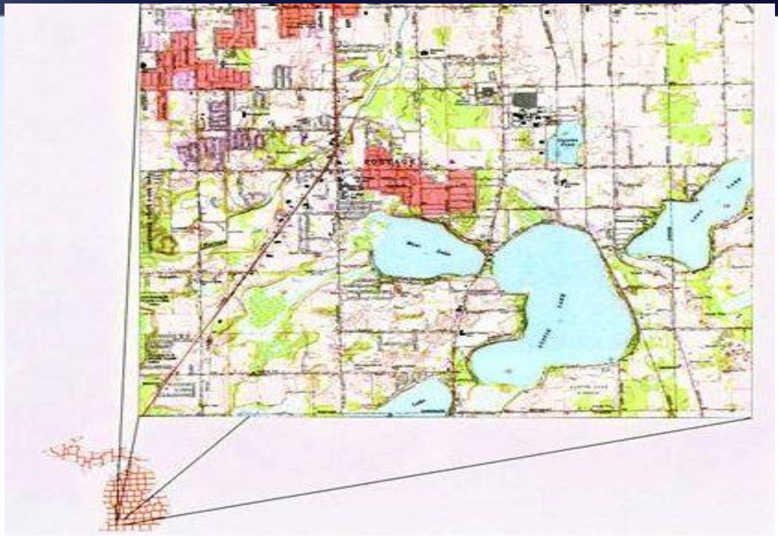
Bear Gulch Reservoir (Example of Need for Bioaugmentation)



Effects of Aeration on Sediments:

Austin Lake Basin & Watershed Data

- Lake Area = 1,090 acres (South Basin = 245 acres)
- Lake Volume = 4,408 acre-feet
- Mean Depth = 4.0 feet
- Max Depth = 14.0 feet
- Mean Annual Runoff = 330 acre-feet
- Mean Annual Pfizer Outputs = 350 acre-feet
- Mean Annual Inlet Inputs = 724 acre-feet
- Watershed: Lake Ratio = 16.8



Austin Lake South Basin & Mandigo Marsh

- Road was constructed between Mandigo Marsh and South Basin resulting in low outflow of sediments/nutrients
- Steep slopes around most of shoreline; impaired soils
- Sediment accumulations up to 17 meters in Basin
- Pre-aeration sediments were highly anoxic, high in H_2S, impeding navigation

Austin Lake South Basin Impairments

- Unconsolidated, silty
- Intense H2S odor
- High ammonia concentrations
- Anoxic sediments
- High in organic matter
- Black, jelly-like in some areas
- Impediment to recreation

Why not Dredging?

- In order to remove approximately 1,666,666 cubic yards (yd^3) of sediment from the South Basin of Austin Lake, (assuming a dredging cost of $17 per cubic yard), to a depth of 5 feet, the cost of a dredging project would be approximately $28,333,322 dollars.

- A study by Straw et al., 1978 determined that 28 of the 50 sediment samples analyzed were lead-contaminated with concentrations up to 224.9 ppm.

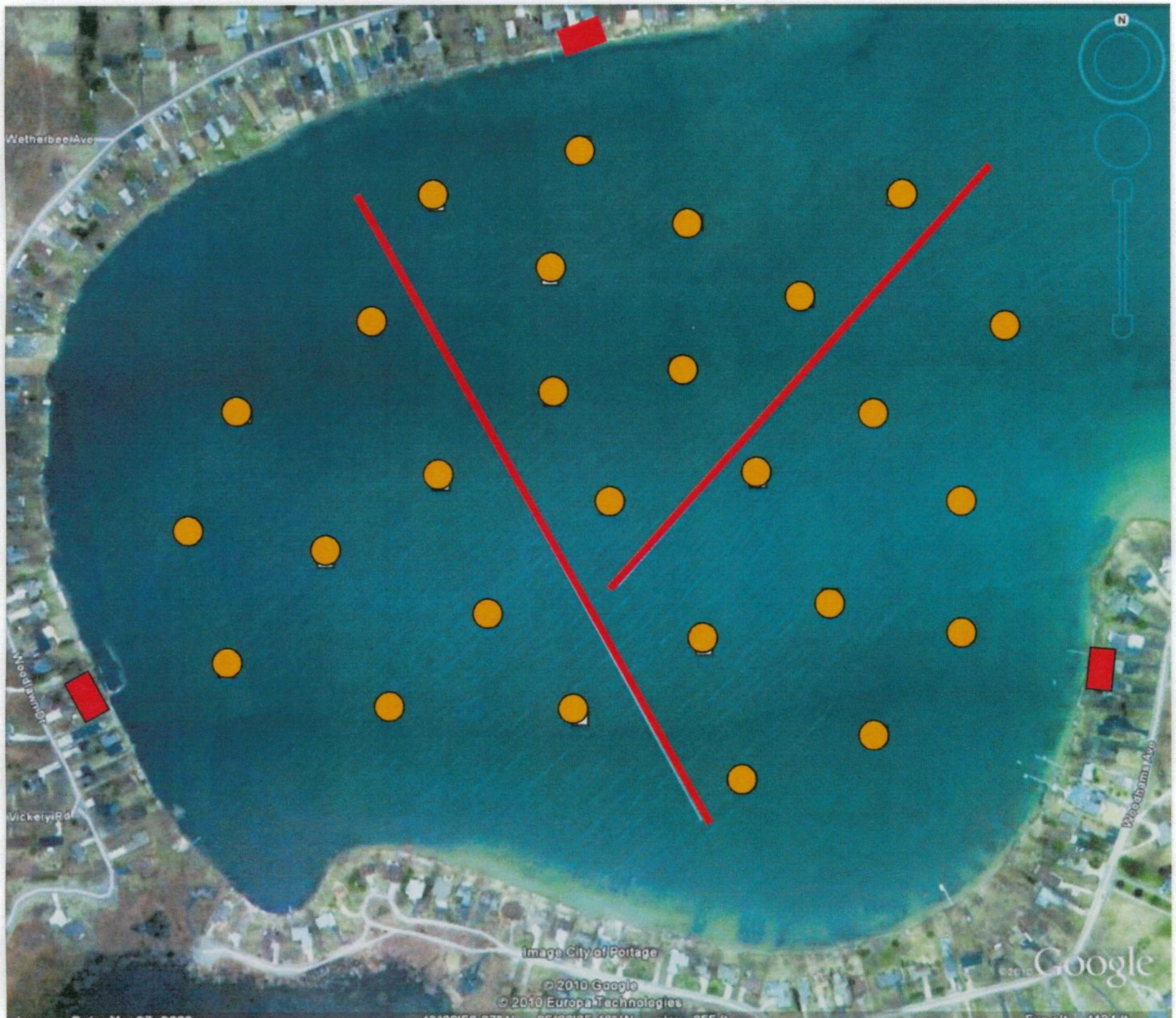
Supporting Research

- Beutel (2006): lake oxygenation eliminates release of NH_3+ from sediments through oxygenation of the sediment-water interface.
- Allen (2009): NH_3+ oxidation in aerated sediments significantly higher than control mesocosms with a relative mean of 2.6 ± 0.80 mg N g dry wt day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry wt day^{-1} in controls.
- Ankley et *al*. (1990) & Camargo et al. (2005): Elevated NH3+ toxic to flathead minnows, *Ceriodaphnia*, other aquatic life; Recommended aeration of lake sediments
- Boyd et *al*. (1984): Microbe addition alone did not affect N, P, or Chl-a

Austin Lake South Basin System

- 27 micro-porous ceramic Clean-Flo® diffusers
- 28,500 feet of self-sinking airline
- Bacteria and enzyme treatments which consist of 50 gallons of bacteria for nitrogen reduction, 200 gallons of enzyme as a catalyst for muck reduction, and 200 lbs. of bacteria for muck reduction.
- On-land components consist of 3 locally-sourced sheds and 5.4HP rotary claw compressors along with cooling fans and ventilation.

System Design for Austin Lake South Bay



Compressor Shed (not to scale it will be much smaller)

Diffusers placed on the bottom (not to scale they will be much smaller)

Line demarcating which diffusers are powered by each of the compressor stations

Design courtesy of Clean-Flo, Inc. & Lake Savers

Sampling Methods

- Sediment samples collected via sediment corer at each of n=24 sampling sites (GPS used to locate specific points)
- Samples analyzed in EPA-certified laboratory
- Water quality/DO measured with Hanna® Multi-probe meter (calibrated) at depth = 1.5 ft. for water column and in sediment "soup" for sediment parameters
- All data collected within same week in November 2010 (pre) and 2013 (post)
- Data analysis included Repeated Measures ANOVA

Austin Lake
Kalamazoo County,MI
Legend
Water Depth Sample Site
2785
2786
2767
2784
2787
2745
2766
2788
2744
2746
2783
2768
2730
2789
2743
2747
2765
2782
2764
2769
2790
2748
N42.1668°
2781
2742
2763
2770
2791
2731
2749
2771
2780
2792
W85.554°
2741
2772
2793
2732
2762
2750
2740
2779
2733
2773
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Google earth
© 2013 Google
N
1000 ft

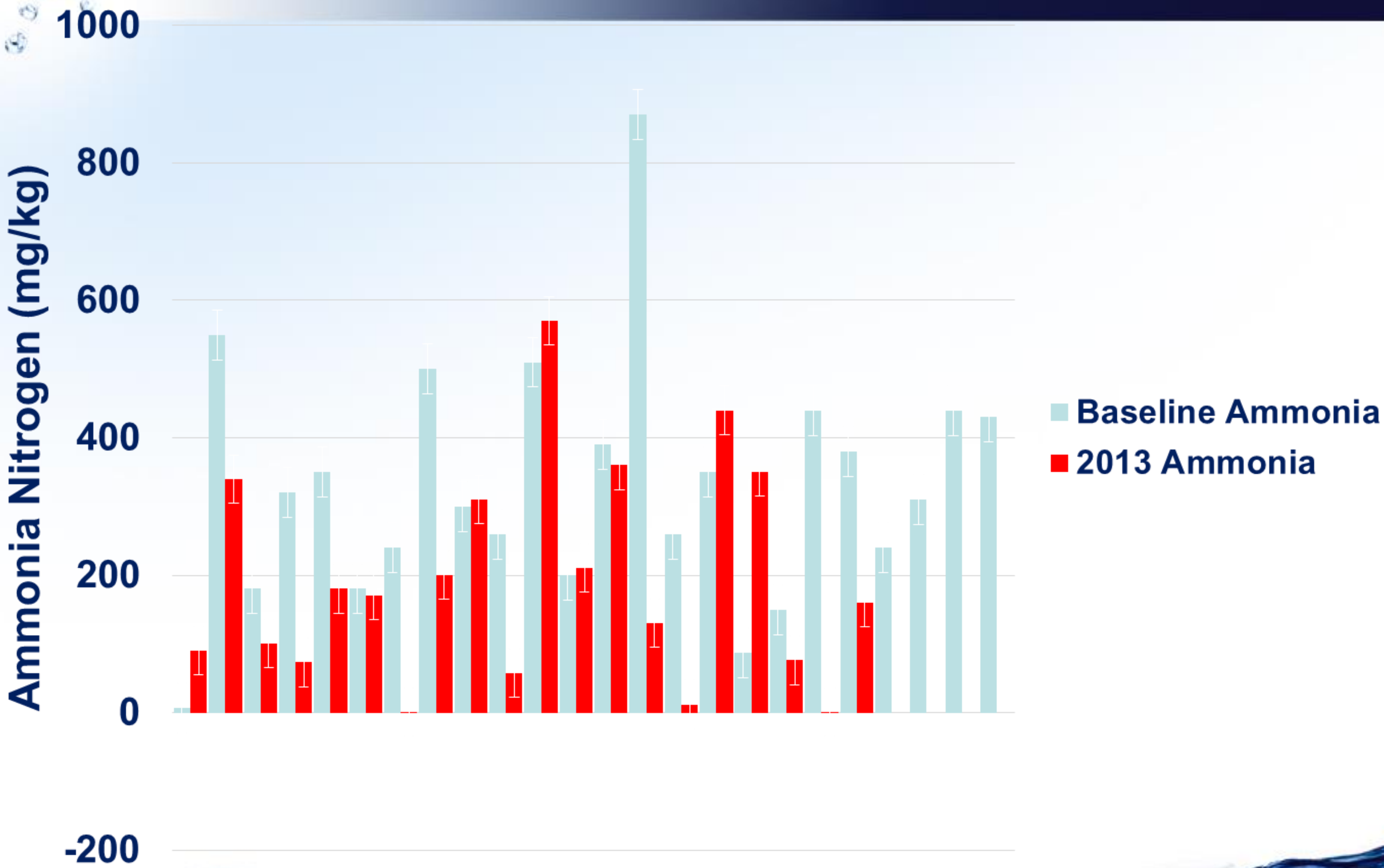
Changes in Austin Lake South Basin WQ before and after Inversion Oxygenation

Date	Water Column DO (mg/l)	Sediment DO (mg L^{-1})	Redox Potential (mV)
Nov 11, 2010	10.9± 1.2	0.33±0.6	-69.8±27
Nov 13, 2013	11.9± 0.6	6.5±0.9**	30.2±9.6**

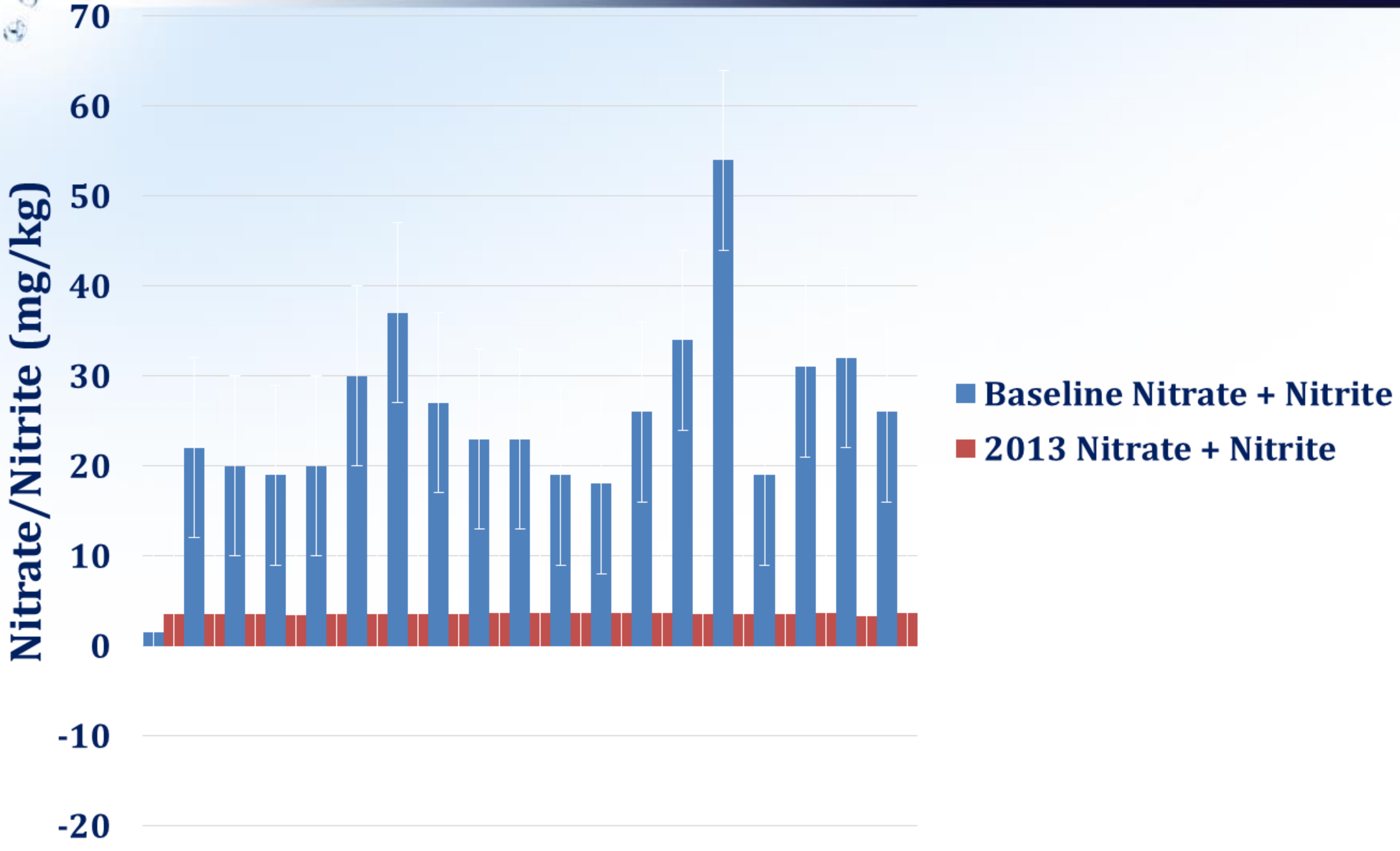
Changes in Austin Lake South Basin Sediments before and after Inversion Oxygenation

Date	Sediment NH3+ (mg/kg)	Sediment Nitrate + Nitrite (mg/kg)
Nov 11, 2010	331±97	37.5±59
Nov 13, 2013	192±52**	3.5±0.1**

Changes in Sediment Ammonia before and after Inversion Oxygenation and Bioaugmentation of Austin Lake



Changes in Sediment Nitrate/Nitrite before and after Inversion Oxygenation and Bioaugmentation of Austin Lake



Conclusions

- No significant differences in water column DO (due to shallow depths)
- Significant differences in water column redox potential (oxidative state post-aeration)
- Significant differences in sediment DO post-aeration (increase)
- Significant differences in both sediment ammonia and nitrate/nitrite (both decreased)
- This data set yields insight into inversion oxygenation mechanism
- Observed changes in sediments may also explain reduction in ammonia-loving aquatic vegetation (i.e. milfoil)

Literature Cited

- Allen, J. 2009. Ammonia oxidation potential and microbial diversity in sediments from experimental bench-scale oxygen-activated nitrification wetlands. MS thesis, Washington State University, Department of civil and Environmental Engineering.
- Ankey, G.T., A. Katko, and J.W. Arthur. 1990. Identification of ammonia as an important sediment-associated toxicant in the lower Fox River and Green Bay, WI. *Environmental Toxicology and Chemistry* 9:313-322.
- Beutel, M.W. 2006. Inhibition of ammonia release from anoxic profundel sediments in lakes using hypolimnetic oxygenation. *Ecological Engineering* 28(3): 271-279.
- Boyd, C.E., W.D. Hollerman, J.A. Plumb, and M. Saeed. 1984. Effect of treatment with a commercial bacterial suspension on water quality in channel catfish ponds. *Prog. Fish. Cult*. 46:36-40.
- Camargo, J.A., A. Alonso, and A. Salmanca. 2005. Nitrate toxicity to aquatic animals: a review with new data for freshwater invertebrates. *Chemosphere* 58: 1255-1267.

Overall Trends (based on RLS research/data in Issued Reports)

- Secchi transparency had nearly doubled in most lakes (note: this is an issue for increased weed growth that necessitates weed treatments)
- Total suspended solids have been consistently < 10 mg L-1 to undetectable
- Total dissolved solids and conductivity have been significantly lower
- Chlorophyll-a concentrations have declined and Microcystis blooms disappeared
- DO concentrations are nearly uniform among depths for all seasons
- Lakes with highest organic matter in sediments experience greatest reduction in “muck” (Note: area of intense research)
- At this time, no negative impacts observed but prevalent weed growth which requires urgent intervention with weed treatment(s)

SUMMARY:
Benefits & Limitations of LFA/Bioaugmentation

Benefits (Data Supported)

- Destratification (even DO concens among depths)
- Does not suspend solids and lowers turbidity
- In some lakes decreases TP in water column and NH3 in sediments, OM may also decline
- Decreases blue-green algae and increases diatom production
- In some lakes decreases some SAV growth (Starry Stonewort, Sago Pondweed, EWM)

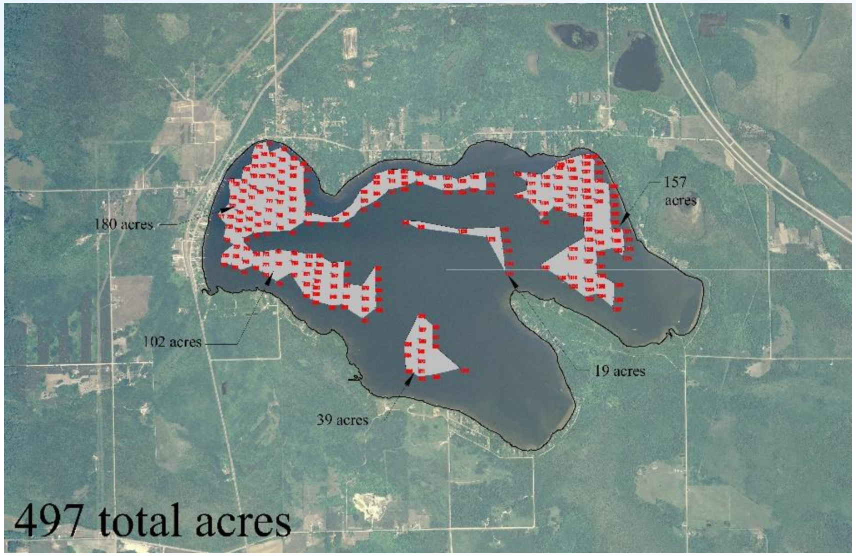
Limitations (Data Supported)

- Cost prohibitive for some communities
- Selective on sediment types for organic or NH3 reduction (RLS/MSU research)
- Differential response on SAV in some lakes (increased light availability can increase weeds)

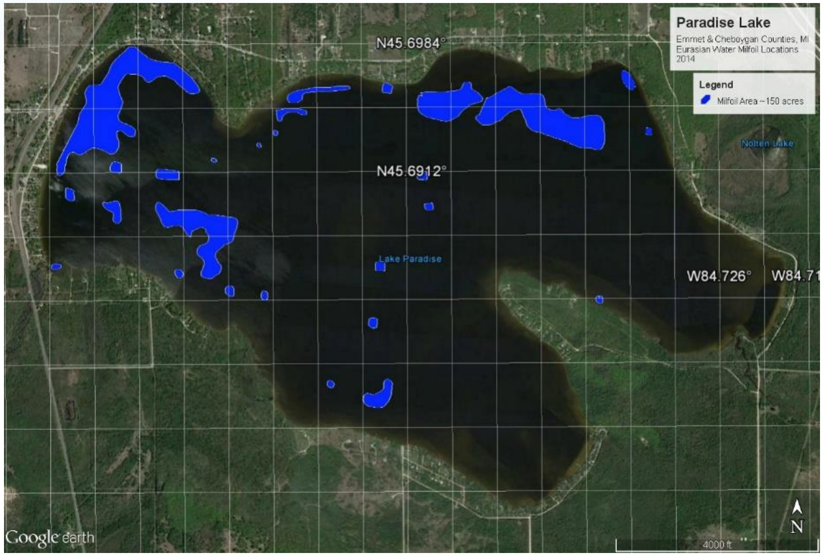
Effect of Aeration on Aquatic Vegetation

Changes in EWM Distribution in Paradise Lake

2010 (Pre-aeration)

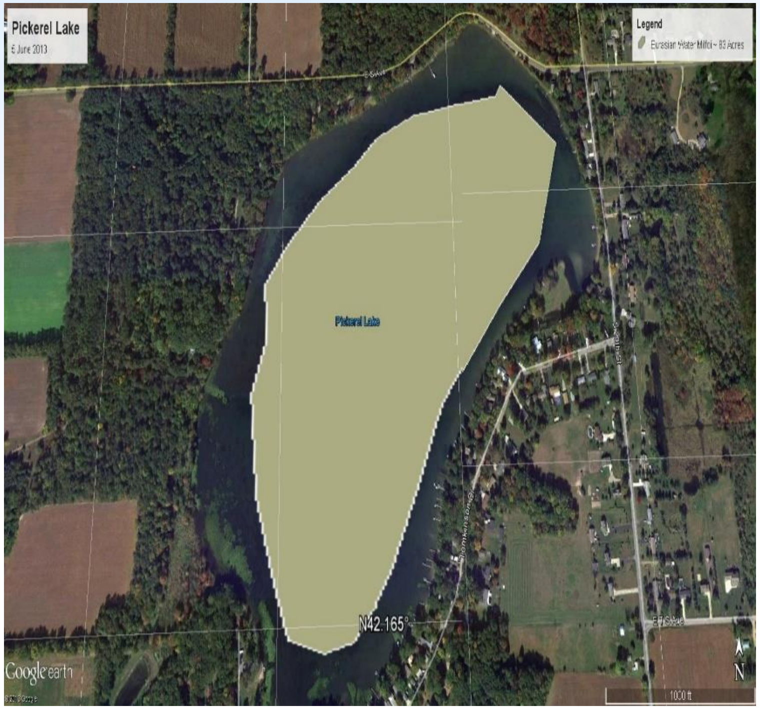


2014 (Post-aeration + weevils)

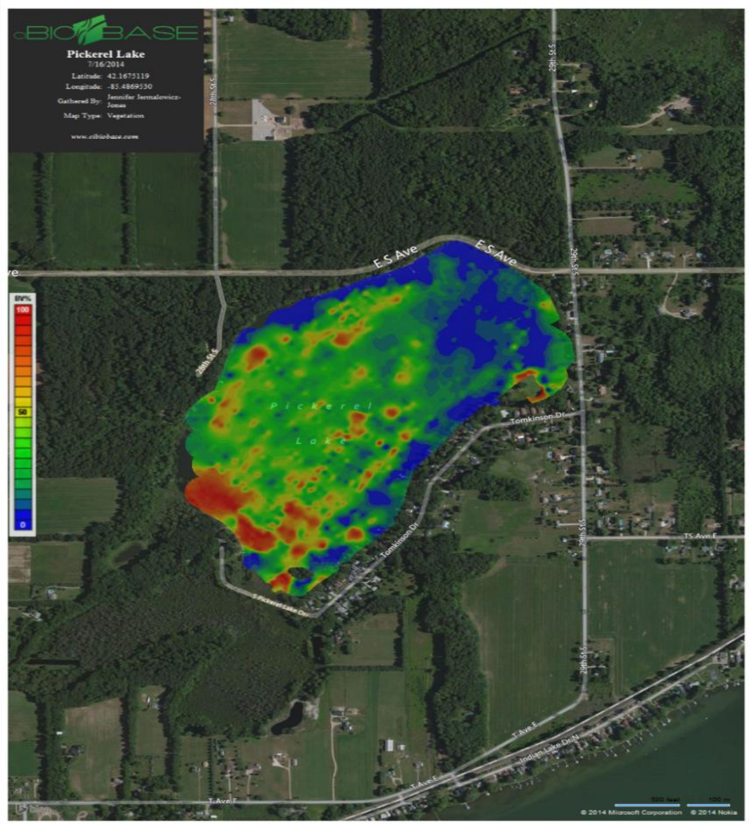


EWM Reduction in Pickerel Lake

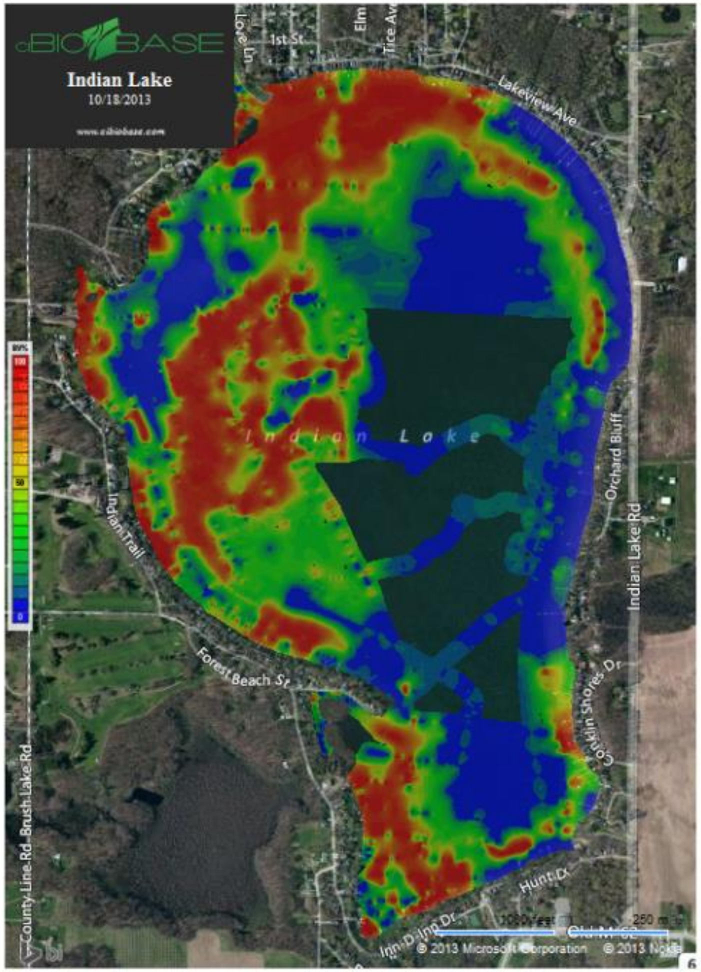
June 2013 (Pre-Aeration)

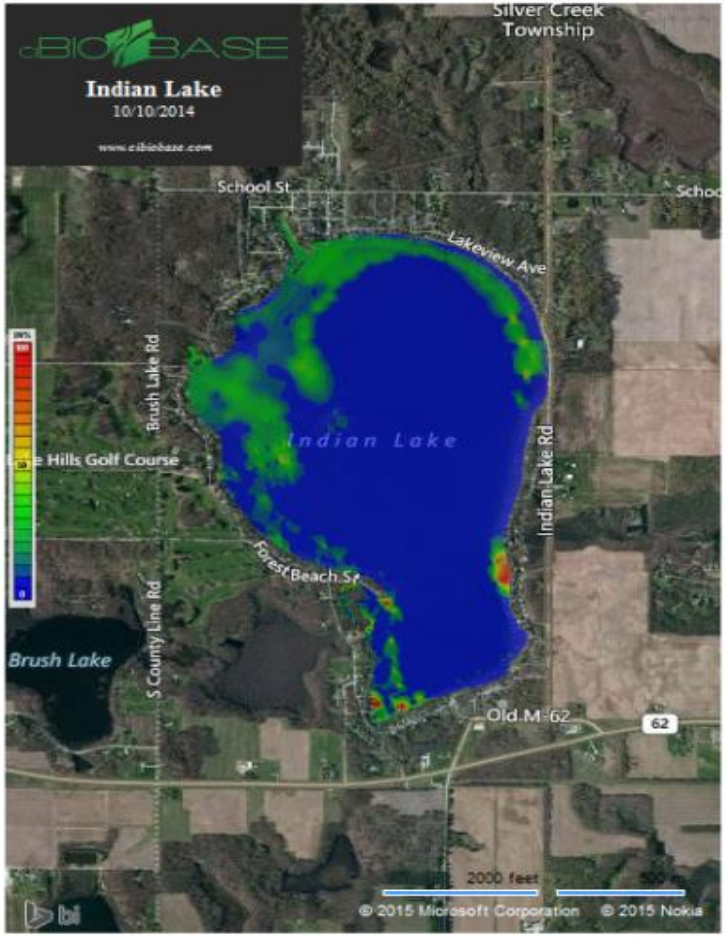


July 2014 (Post-Aeration)



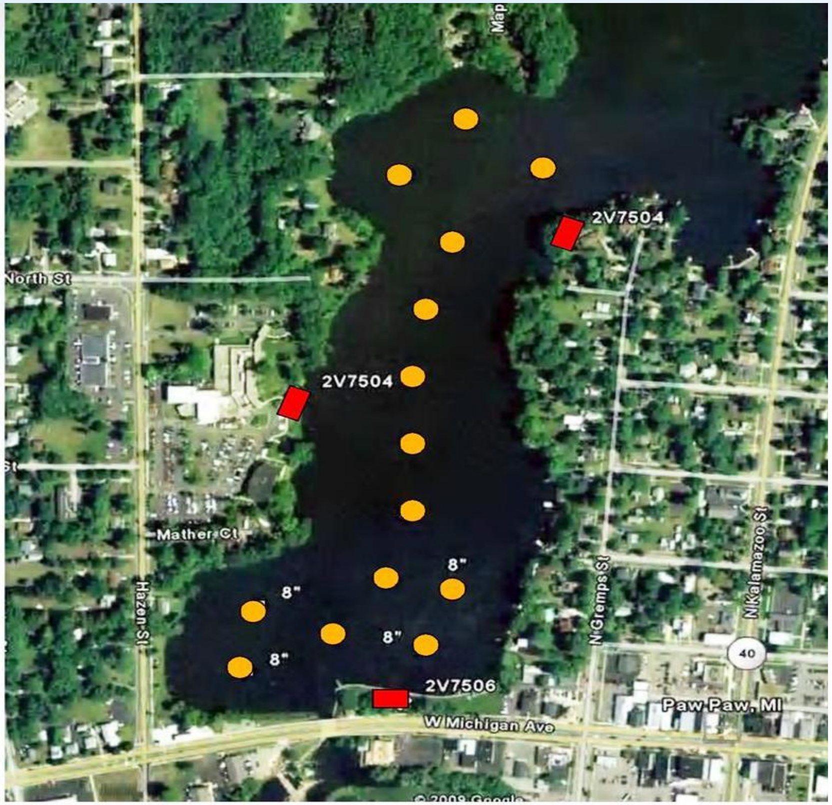
EWM Reduction in Indian Lake



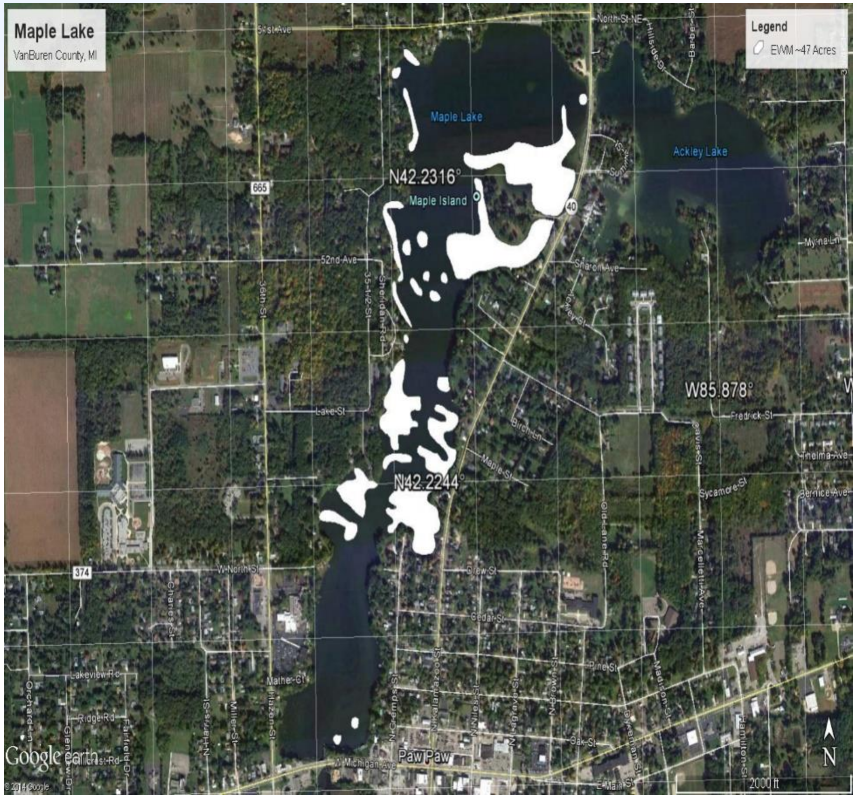


Effects of Aeration on EWM: Maple Lake Data (May, 2014)

South Basin Aeration System



May 2014 (Pre-Treatment) EWM



EWM Reduced in Wing Lake Lagoon (Highly Organic Sediment)

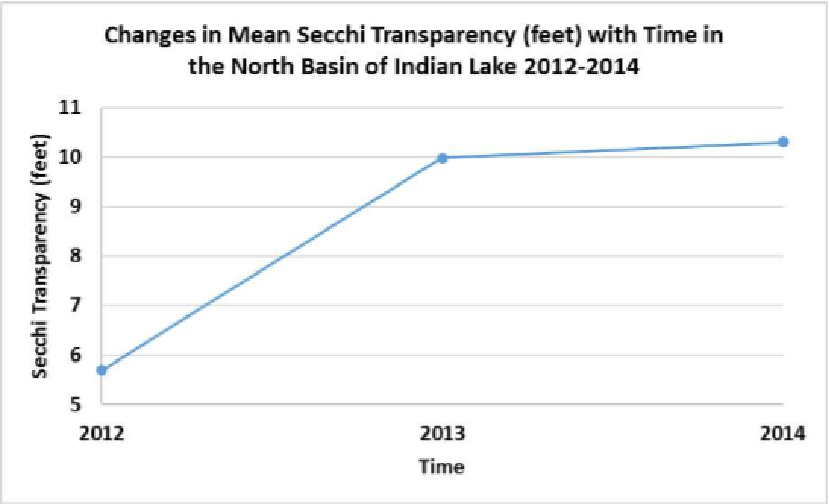
Aeration Supports Favorable Native Aquatic Plant Biodiversity

Aquatic Plant Species And MDEQ code	*Aquatic Plant Common Name*	*% West Basin Covered June 2012*	*% West Basin Covered October, 2014*
Chara vulgaris, 3	Muskgrass	0.2	2.4 (+)
Stuckenia pectinatus, 4	Thin-leaf Pondweed	0.0	0.0
Potamogeton zosteriformis, 5	Flatstem Pondweed	5.1	2.4
Potamogeton robbinsii, 6	Fern-leaf Pondweed	35.2	27.8
Potamogeton gramineus, 7	Variable-leaf Pondweed	4.0	4.9 (+)
Potamogeton praelongus, 8	Whitestem Pondweed	21.1	17.8
Potamogeton richardsonii, 9	Clasping-leaf Pondweed	17.3	19.7 (+)
Potamogeton illinoensis, 10	Illinois Pondweed	11.5	4.1
Potamogeton amplifolius, 11	Largeleaf Pondweed	16.6	13.3
Vallisneria americana, 15	Wild Celery	8.3	5.7
Myriophyllum verticillatum, 18	Whorled Watermilfoil	4.3	5.8 (+)
Elodea canadensis, 21	Common Waterweed	8.4	10.9 (+)
Utricularia vulgaris, 22	Bladderwort	2.6	3.4 (+)
Najas flexilis, 26	Slender Naiad	4.8	11.8 (+)

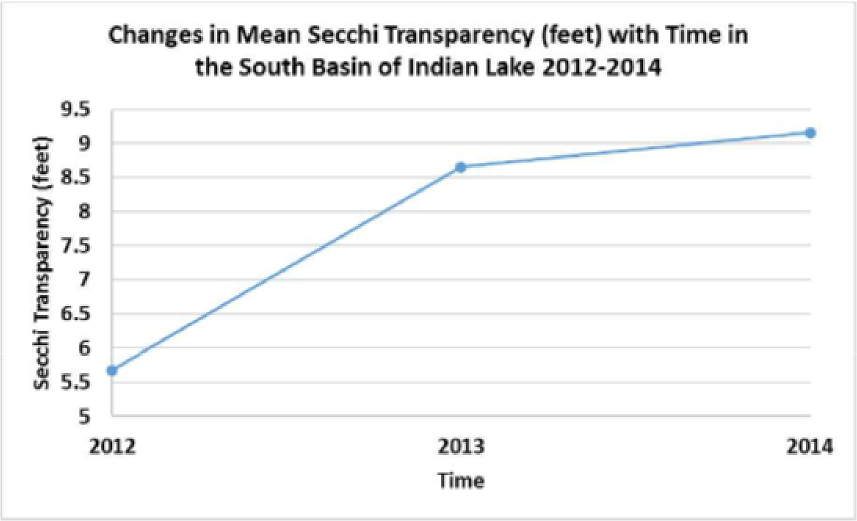
Table 8. Paradise Lake changes in submersed aquatic plant species and relative abundance prior to and after laminar flow aeration (June, 2012 and October, 2014). Note that the (+) represents increases in native relative abundance since aeration began.

What We Do Not Know: Research Needs & Ongoing Research

Effects of Aeration on Water Clarity: Relationship to Phytoplankton?



Graph 11. Changes in North Basin secchi transparency 2012-2014.



Graph 12. Changes in South Basin secchi transparency 2012-2014.

Effects of Aeration on Lake Fishery

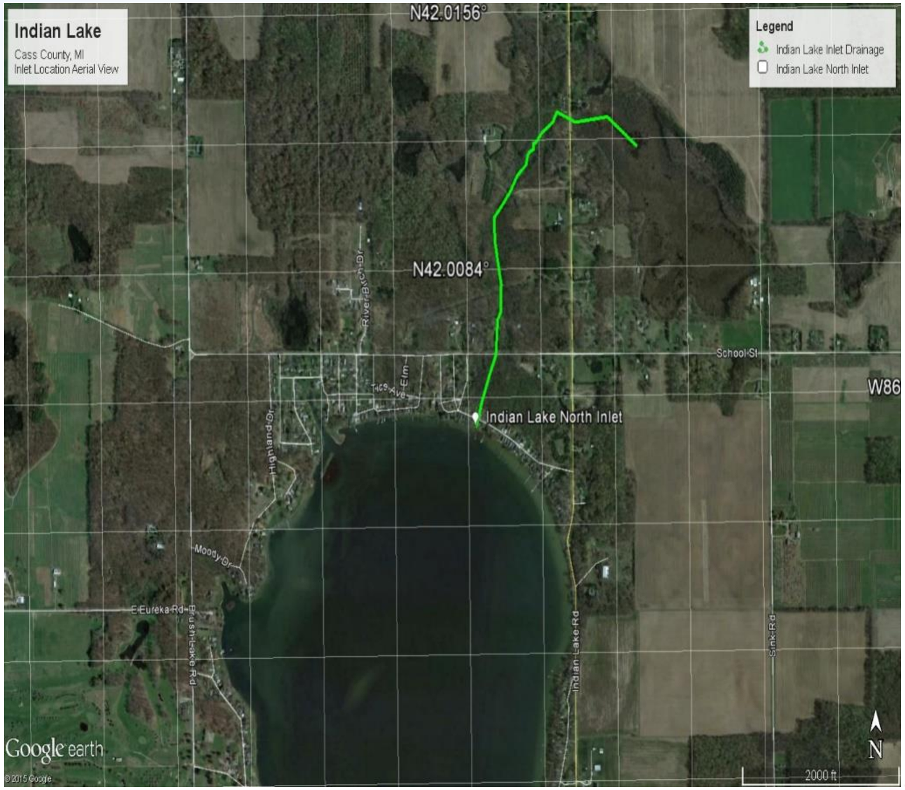
Photo courtesy of Lake Savers, LLC

- Anecdotal evidence supports larger (large) fish species and more game fish – is this the same for ALL aeration lakes?
- What is the link? Food web driven?
- Destratification effects?

Limits to Efficacy on Sediment Reduction

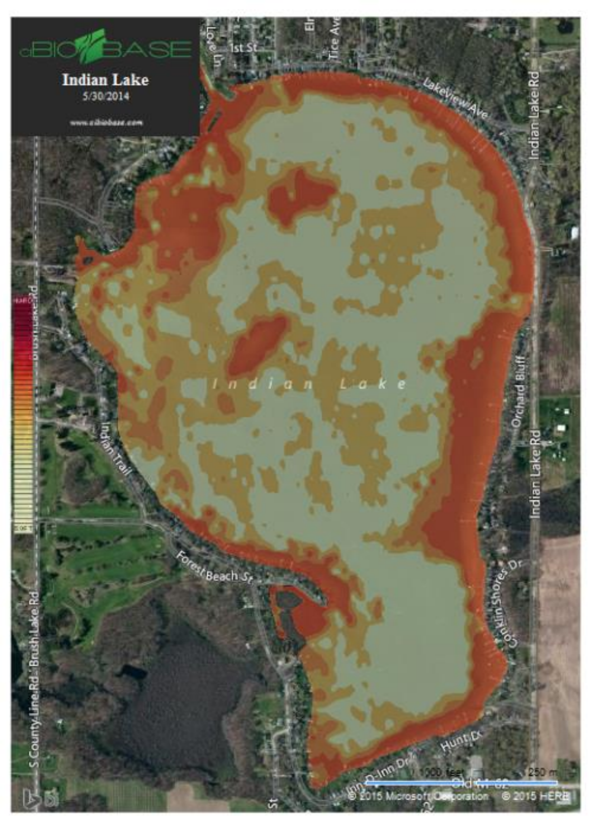
- Once organic fraction is effectively reduced and inorganic (mineral fraction) remains-what next?
- Research needs on accompanying microbial products to better break down specific sediment types

Ability of Aeration to Process Incoming Organic/Nutrient Loads

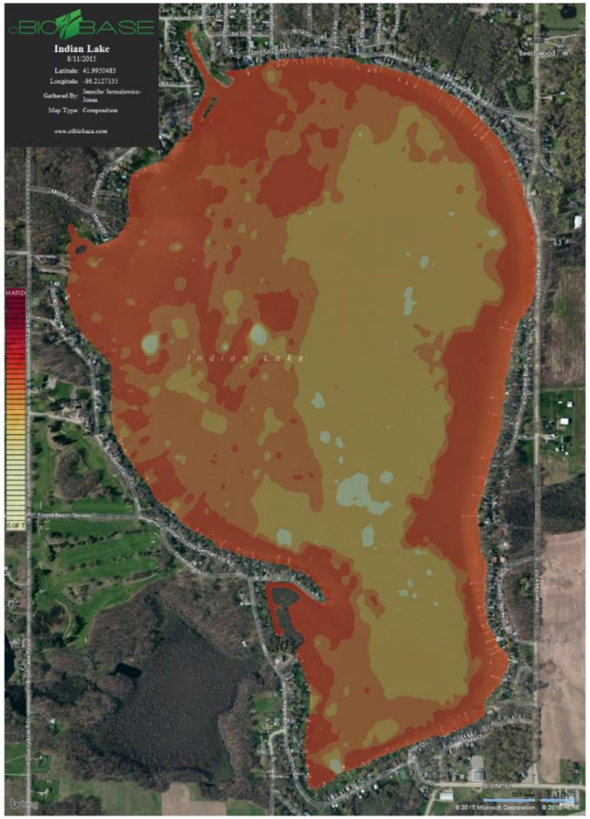


Indian Lake: Bottom Hardness

Pre-Aeration 2014

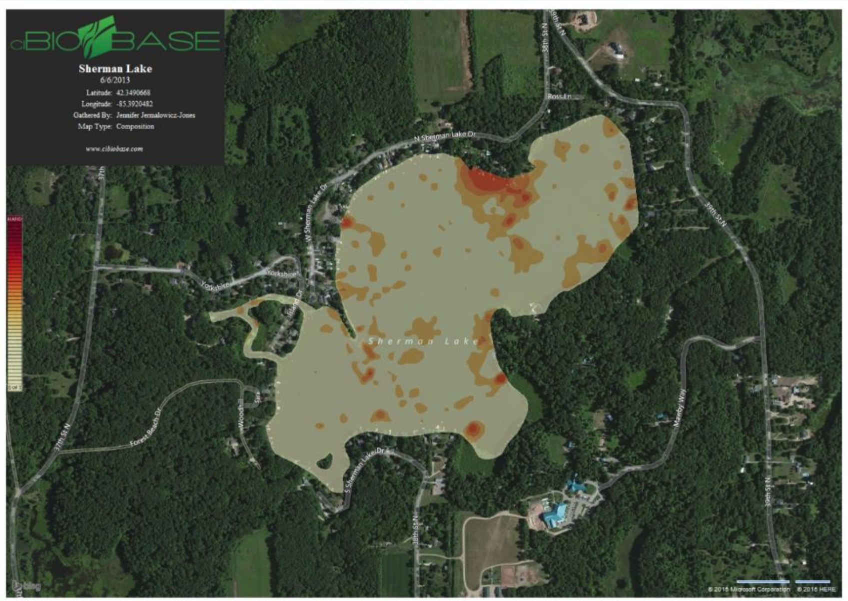


Post-Aeration 2015

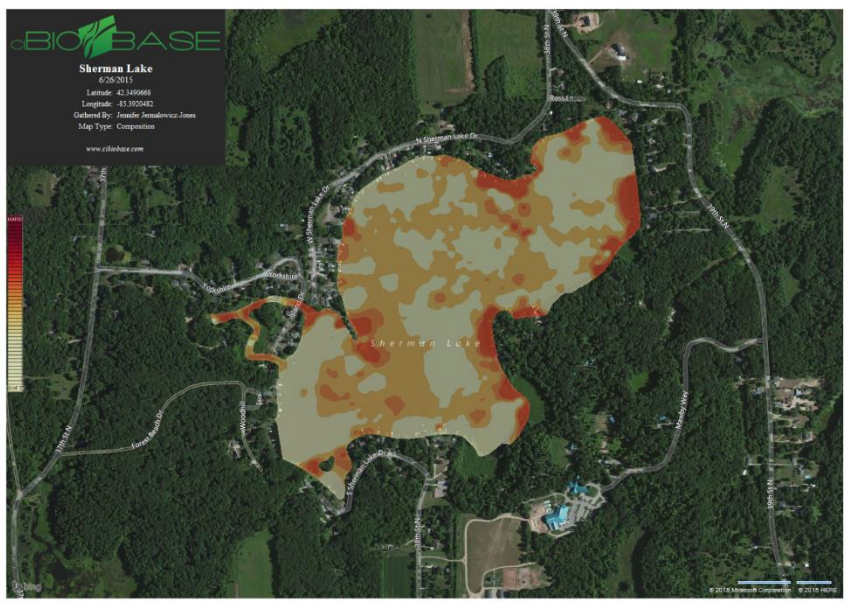


Sherman Lake: Bottom Hardness

Pre-Aeration 2013



Post-Aeration 2015



RLS Research in Progress (Peer-Reviewed Paper Series)

- “Effects of aeration-mixing on in water and sediments. I. Ammonia and nitrate reductions in six contrasting freshwater lakes”
- “Effects of aeration-mixing on in water and sediments. II. *Myriophyllum spicatum* (Eurasian watermilfoil) decline attributable to sediment nitrogen reductions in the sediments”.
- “Effects of aeration-mixing on in water and sediments. III. Effects on phytoplankton biomass and species composition.”
- “Effects of aeration-mixing in water and sediments. IV. Effects on heavy metals, especially iron.”
- “Effects of aeration-mixing in water and sediments. V. Effects on fish and fish kills – possible solutions?”

Acknowledgements

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- Sherman Lake Residents Association, Paradise Lake Improvement Board, Pickerel Lake Association, Indian Lake Improvement Association, ALGLB, Village of Paw , Wing Lake, Inc.


Restorative
Lake Sciences tm