Whole Lake Experiments to Control Harmful Algal Blooms in Multi-Use Watersheds

Report to Middle Huron Partners

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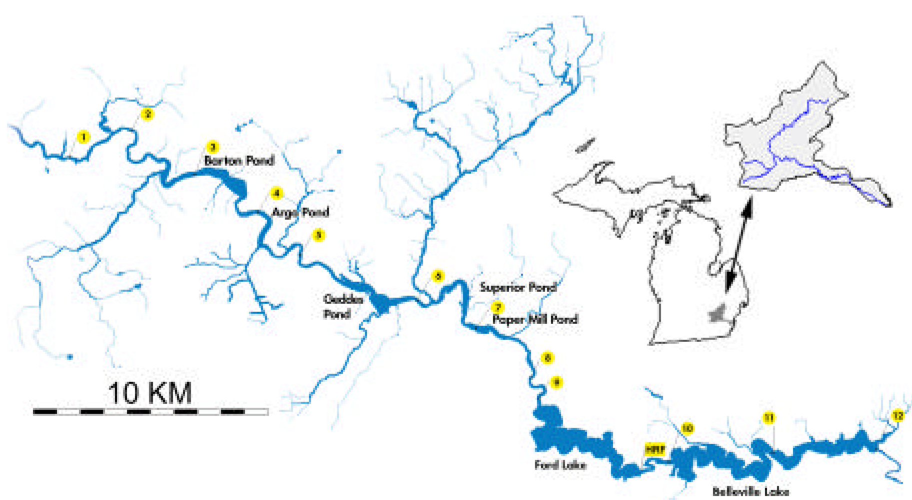
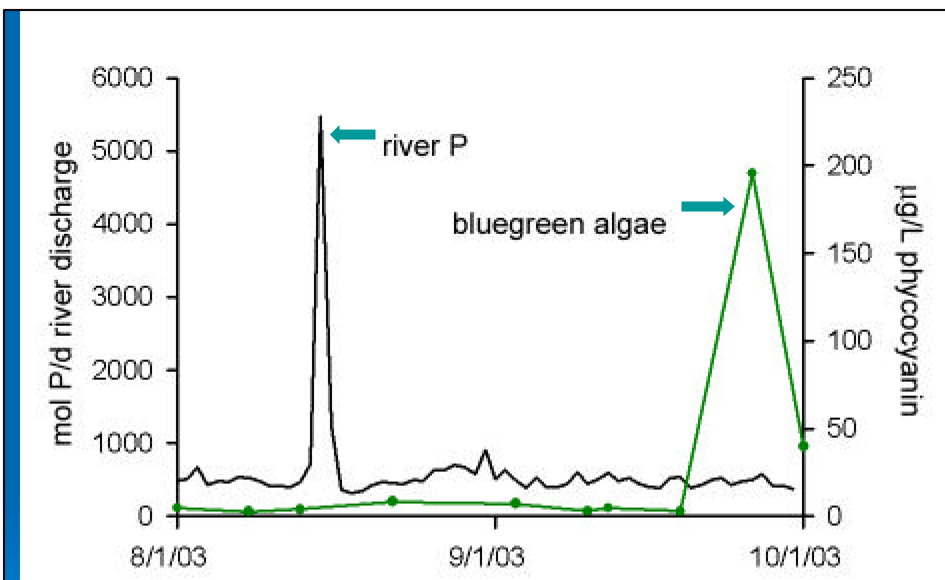
USEPA STAR Grant R830653-010

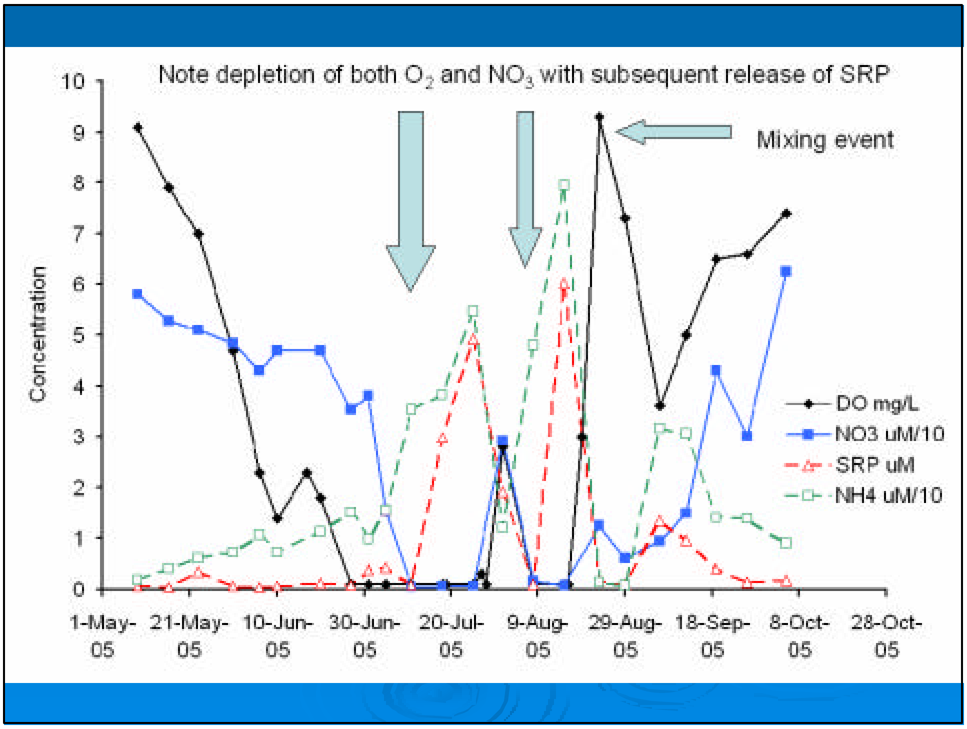
USDA/CSREES Project 2006-02523



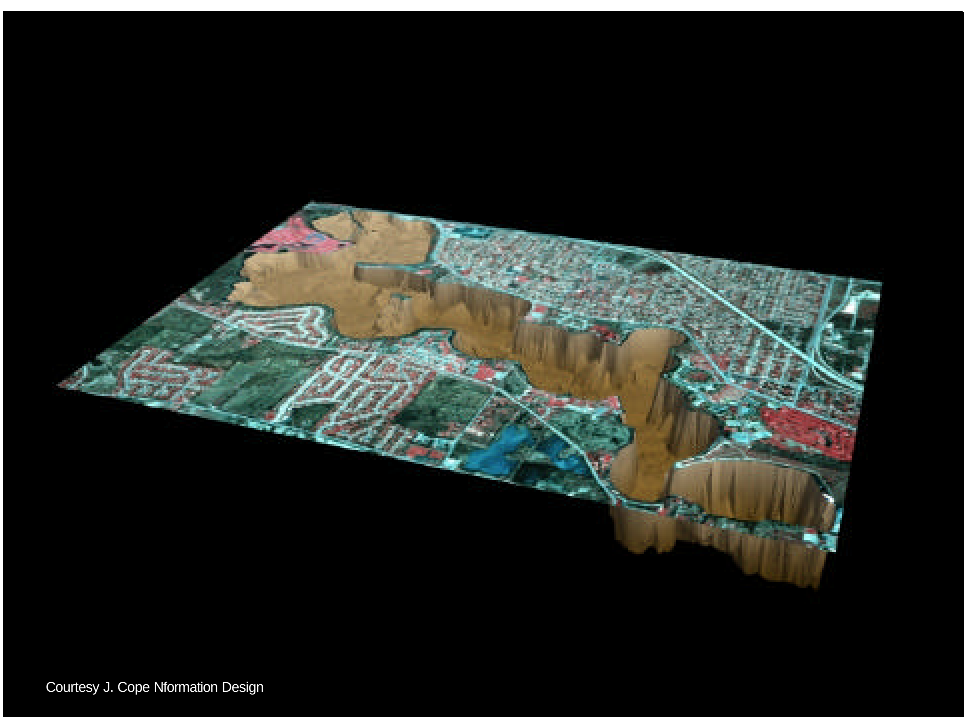
Middle Huron Project Site



Time lag = 40 days, same as flushing time



Note depletion of both O_2 and NO_3 with subsequent release of SRP
Mixing event
Concentration
10
9
8
7
6
5
4
3
2
1
0
1-May-05
21-May-05
10-Jun-05
30-Jun-05
20-Jul-05
9-Aug-05
29-Aug-05
18-Sep-05
8-Oct-05
28-Oct-05
DO mg/L
NO3 uM/10
SRP uM
NH4 uM/10

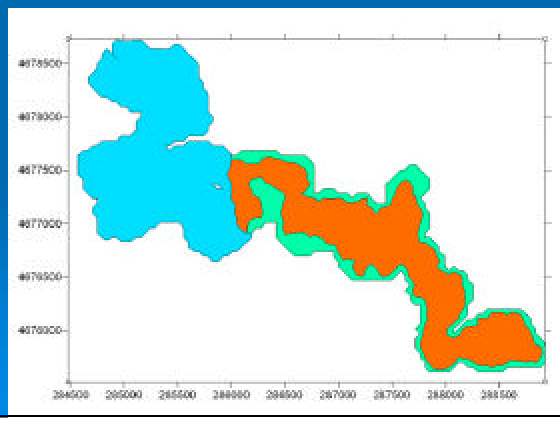


Courtesy J. Cope Nformation Design

Key features of outlet dam

- Dam operates as “run of river” constant stage height; outflow = inflow
- Turbines draw water from epilimnion
- Dam has bottom sluice gates to bypass water at peak flows

Whole lake experiments were designed based on a numerical model that characterizes the lake as a thermally stratified two-layer system at its deeper, downstream end, and as an isothermal well-mixed system at its shallower end.



- Each of the three regions was divided into 10 longitudinal sections of equal volume.
- Advective fluxes between compartments was unidirectional downstream and controlled by river discharge.
- Outlet water can be discharged from epilimnion at turbines or from hypolimnion via sluice gates.
- Oxygen consumption at sediment-water interface was based on experiments with sediment cores.
- Vertical diffusion between epilimnion and hypolimnion was modeled as “piston velocities” calibrated against summer 2005 data.

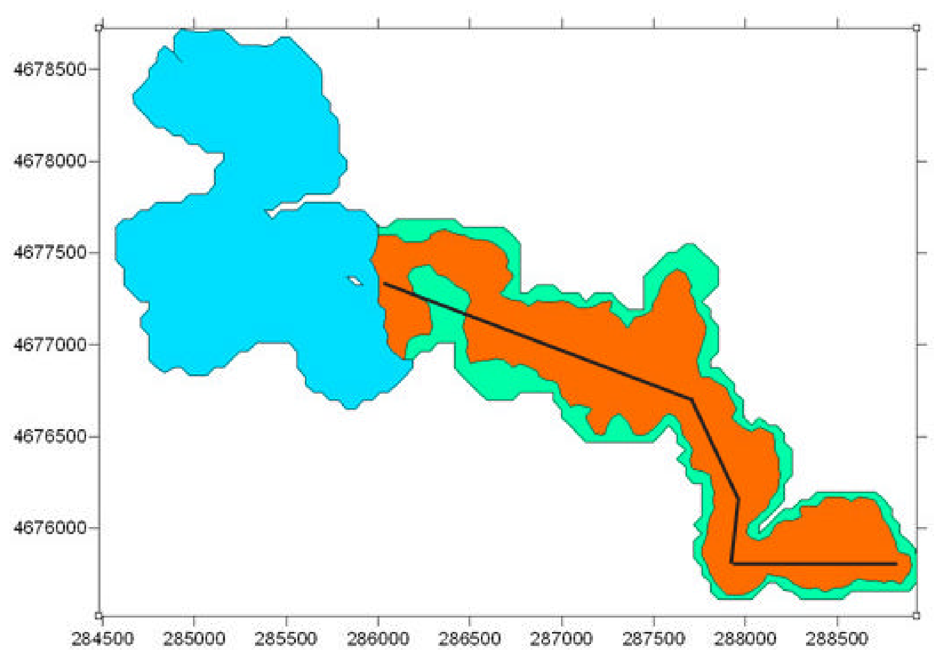
→ Simulation results predicted that hypolimnetic discharge at 300,000 $m^3\ d^{-1}$ could prevent anoxia.

Hypotheses for Whole Lake Experiments

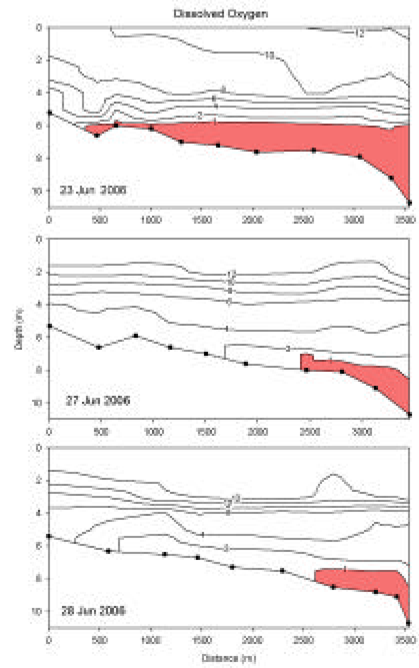
• Ford Lake will export less P and NH_4 if deep water remains oxic. This should have a beneficial effect on Belleville Lake water quality.

• Ford Lake will grow diatoms during summer if deep mixing can be achieved.

• If diatoms consume lake nutrients (N and P), bluegreens will have less resource and will be less successful.

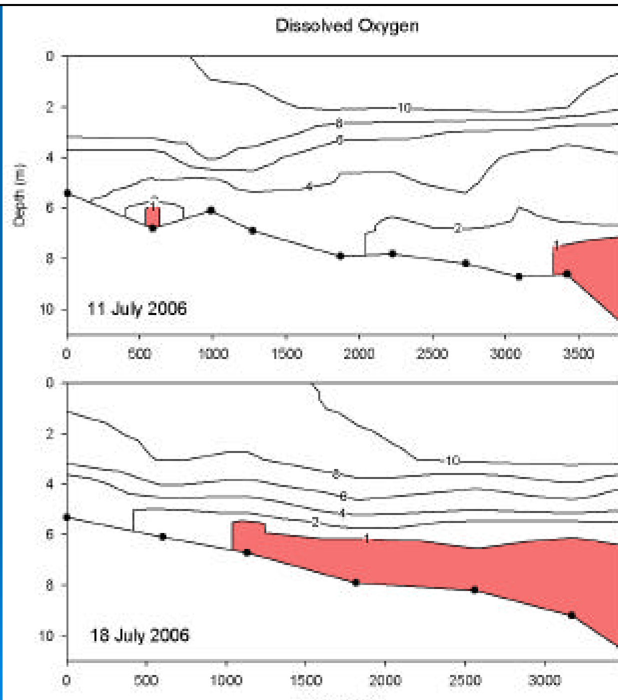


Experiment 2006-1: Calibration. Longitudinal transect. Outlet dam is at right margin of figure. Release 300,000 m ³/d (123 CFS) from 22 to 30 June 2006. Note contraction of hypoxic region (red), consistent with model prediction.



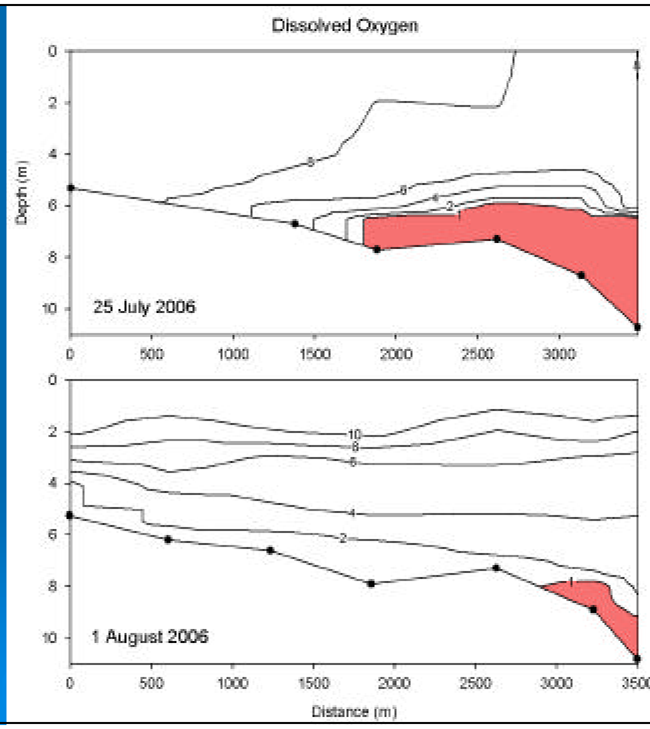
Experiment 2006-2: Calibration

Test whether a lower rate of discharge can produce beneficial effects with less loss of hydroelectric capacity. Release half as much water as in 2006-1 (150,000 m ³/d) from 14 to 21 July 2006. Note expansion of hypoxic region (red), also consistent with model prediction.



Experiment 2006-3: Calibration

Repeat Experiment 2006-1. Release 300,000 m³/d from 28 July to 4 August 2006. Hypoxic region contracts, consistent with model prediction.



Occurrence and Toxicity of Cyanobacteria: The Selective Withdrawal Experiment

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STAR

CSREES

Selective Withdrawal Experiments

- Objective
  - Test selective withdrawal of hypolimnetic water as management solution without harming lake recreation or water quality of downstream lakes
- Method
  - Reduce discharge of epilimnetic water
  - Discharge at appropriate rate from base of dam

Hypotheses

1) Selective withdrawal will destabilize water column by weakening thermal gradient and deepening the mixed water layer
2) Resulting in:
   a) Increased volume/duration of diatom blooms
   b) Reduce volume of blue-green algae
   c) Reduced toxicity of *Microcystis*

Results

- Destratification
- Deeper lake mixing
- Summer diatom bloom
- Dramatic reduction in cyanobacteria biovolume

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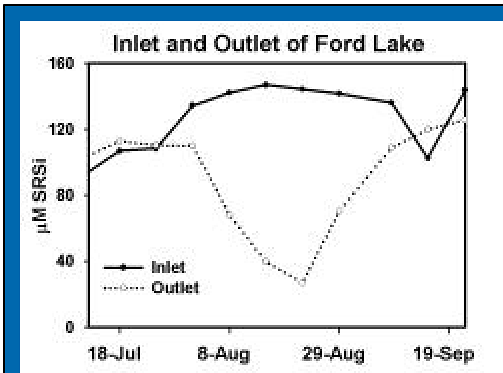
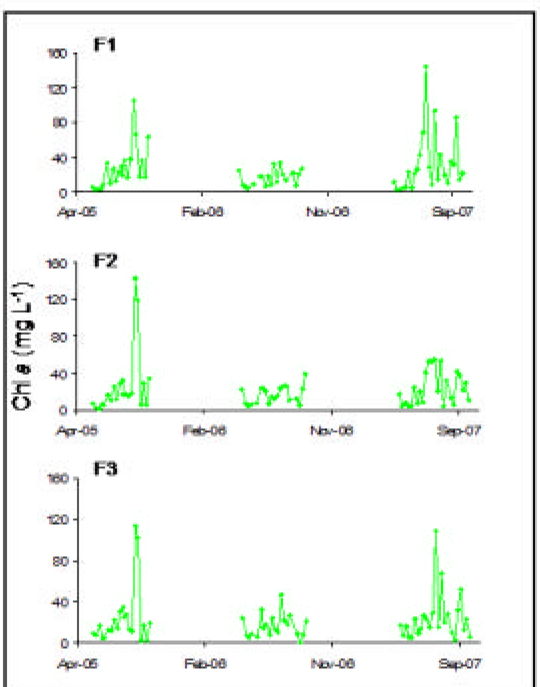


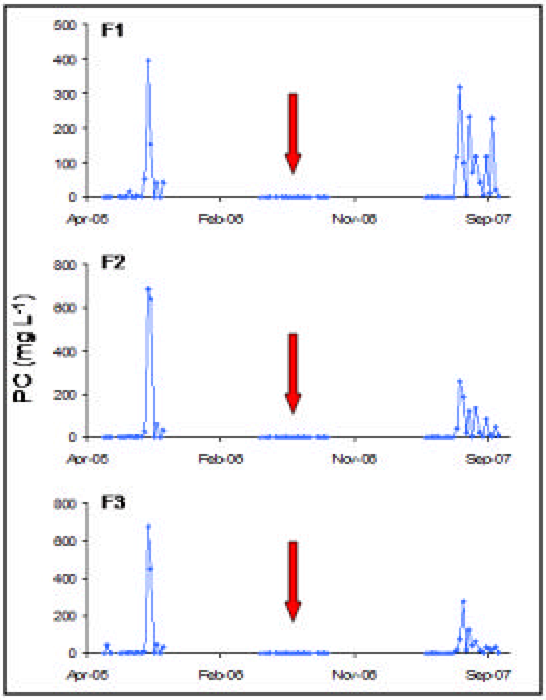
Evidence of dramatic SRSi uptake by diatoms in Ford Lake in 2006

Lower levels of SRSi across all lake stations in 2006 compared To 2005 & 2007

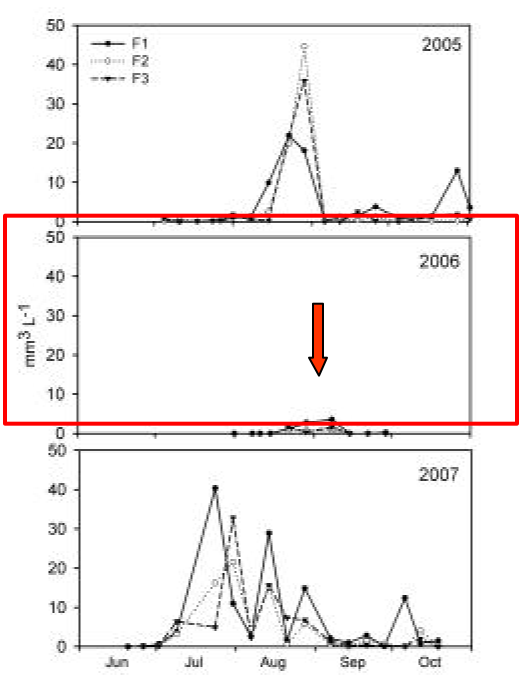
Station	Year	Mean	ANOVA (P-Value)
F1	2005	103.43 uM	0.0027
	2006	84.37 uM	
	2007	118.77 uM	
F2	2005	100.37 uM	0.0027
	2006	80.91 uM	
	2007	115.10 uM	
F3	2005	99.78 uM	0.0010
	2006	80.45 uM	
	2007	112.66 uM	



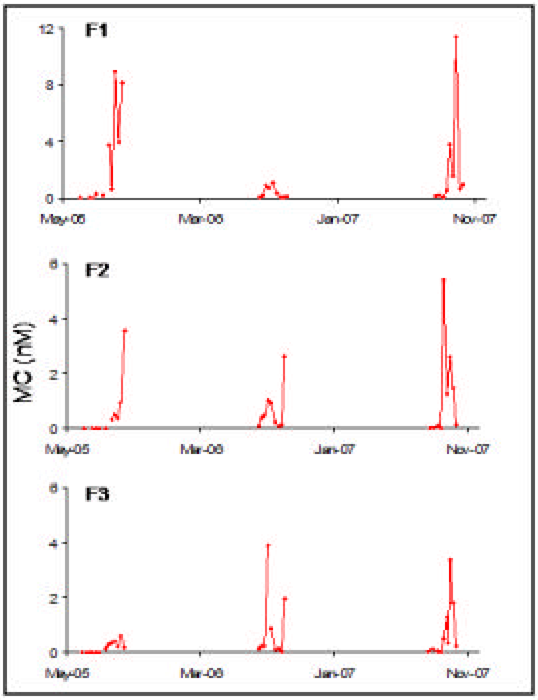
Chlorophyll *a* concentrations, June–October 2005-2007, sites F1, F2, & F3



Phycocyanin concentrations, June–October 2005-2007, sites F1, F2, & F3



Aphanizomenon biovolume, June–October 2005-2007, sites F1, F2, & F3



Microcystin toxin concentrations, June–October 2005-2007, sites F1, F2, & F3

Hypotheses Revisited

1) Selective withdrawal will destabilize water column by weakening thermal gradient and deepening the mixed water layer ✓

2) Resulting in:
   a) Increased volume/duration of diatom blooms ✓
   b) Reduce volume of blue-green algae ✓
   c) Reduced toxicity of *Microcystis* ×

Next Steps

- Reduced toxicity of *Microcystis* ×
- Laboratory experiments
  - Isolate properties that select for toxic strains of *Microcystis*
  - Determine what conditions influence the expression of microcystin toxin

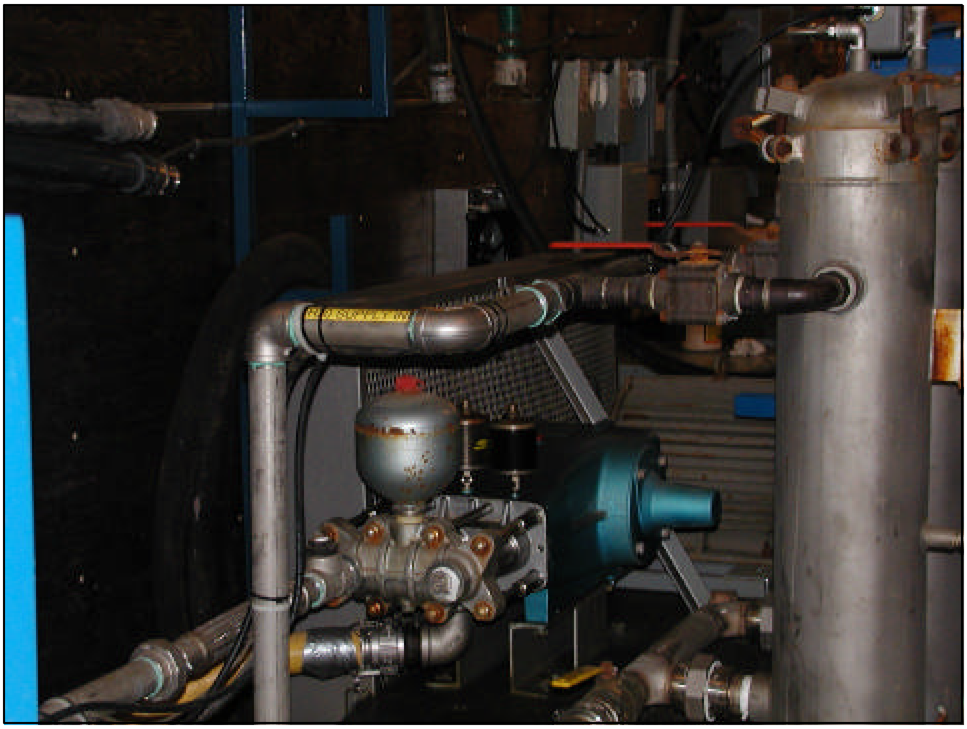
Conclusions

- Selective withdrawal a viable management option under certain conditions
- Environmental sustainability can only be determined by additional experiments and testing management theory over longer periods of time
- The question of socio-political sustainability exists in a different sphere and will require evaluations by local/municipal governments in the context of their other commitments and priorities

Results of oxygen injection experiments: 2007

In July 2007, total river discharge into Ford Lake fell below 300,000 $m^3\ d^{-1}$. As a result, selective discharge became an ineffective option and the hypolimnion became anoxic.

We experimented with a novel method of hypolimnetic oxygen injection with the trade name DynamOx. Hypolimnetic water is pumped to shore, where it is supersaturated with pure oxygen at elevated pressure and then returned to depth. The supersaturated water is discharged through capillary tubes, maintaining laminar flow long enough for the oxygen to dissipate into bulk solution before forming gas bubbles.



Unfortunately, the action of pressurizing the fluid raised its temperature, and the added oxygen increased its buoyancy so that it floated upward and did not remain at the bottom.

→ Experimental objective was not achieved

→ Engineering improvement: chill the compressed water

→ Future plan: test redesigned system on smaller lake with stronger thermal gradient so that the oxygenated water is less likely to float

Was 2007 a waste of time?

No:

• we understand the specific engineering challenges that must be overcome.

• 2007 served as another “control” year, demonstrating that nuisance algae will plague Ford Lake each summer unless successful interventions are performed.

What about 2008?

Another control year?

Try to replicate results of 2006?

Turn attention to another lake?

What lies ahead?

Plans for real-time data loggers in 2008
Township plans to install *in situ* instruments during spring 2008 that can telemeter temperature and oxygen data to a shore base, with real time on-line access.

The advent of high quality real time data means that scientific understanding can be advanced by attempting to replicate and improve on the experiments of 2006.

The plan is to commence hypolimnetic discharge of 300,000 $m^3 d^{-1}$ in June **before anoxia develops** and to continue it until August, if hydrological conditions permit.

Operational Considerations

Simulation models indicate that under experimental conditions, the combined flow from hypolimnetic discharge and residual epilimnetic discharge through the turbines will have composite dissolved oxygen greater than 5 mg per liter.

This concentration is regarded to be protective of downstream biota and is specified in the operating permit.

Operational Considerations

Of course, water released at the sluice gates could have less than 5 mg/L oxygen because it is the same as the bottom of the lake.

But there is intense turbulent gas exchange with the atmosphere before the water enters the river channel.

In 2006 there was never any fish mortality associated with the discharge experiments.

Research Question (Easy)

How much oxygen will have to diffuse into 300,000 m^3 of water each day to guarantee that it exceeds 5 mg/L in bulk concentration, assuming a starting concentration of 1 mg/L?

1200 KG = 2640 LB

Research Question (harder):

Estimate expected diffusion of atmospheric oxygen into the discharge water within the dam spillway, before entering Huron River channel.

The rate of diffusion depends on estimated "boundary layer thickness" or "transfer velocity" in the turbulent spillway.

Reliable estimates demand direct measurements.

Note, however, that the experiments in 2006 produced no negative environmental effects, only beneficial ones. Similarly, no negative effects should be expected in 2008 if the experiments go as planned.

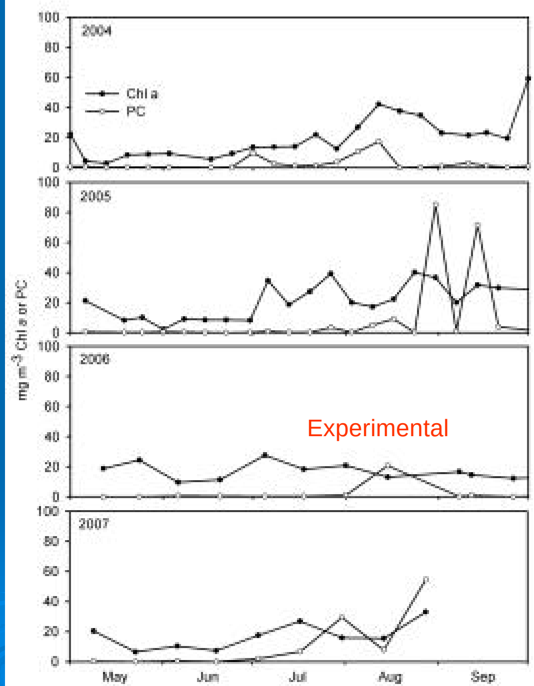
The improvement to Ford Lake in 2006 has been well documented.

What happened in Belleville Lake?

Were the experiments beneficial, deleterious, or neutral?

Effects of Ford Lake experiments on Belleville Lake

Year	Chl	Chl	PC	PC
	mean	med	mean	med
2004	20.6	20.5	2.6	0.8
2005	20.7	20.1	10.7	0.6
2006	**17.0**	**16.6**	**2.2**	**0.3**
2007	17.0	15.9	11.2	2.1

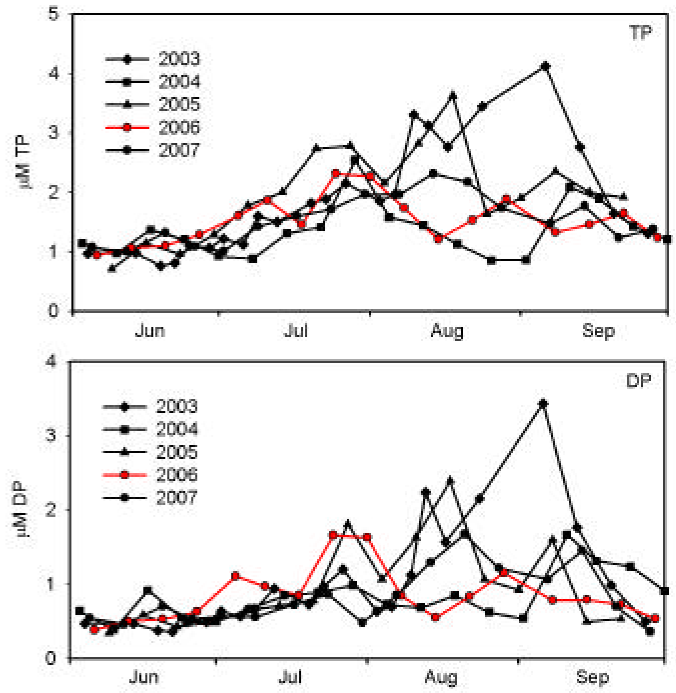


Conclusion:

Belleville Lake had lower abundances of bluegreen algae in 2006 than in other years.

Why?

Huron River below Ford Lake dam



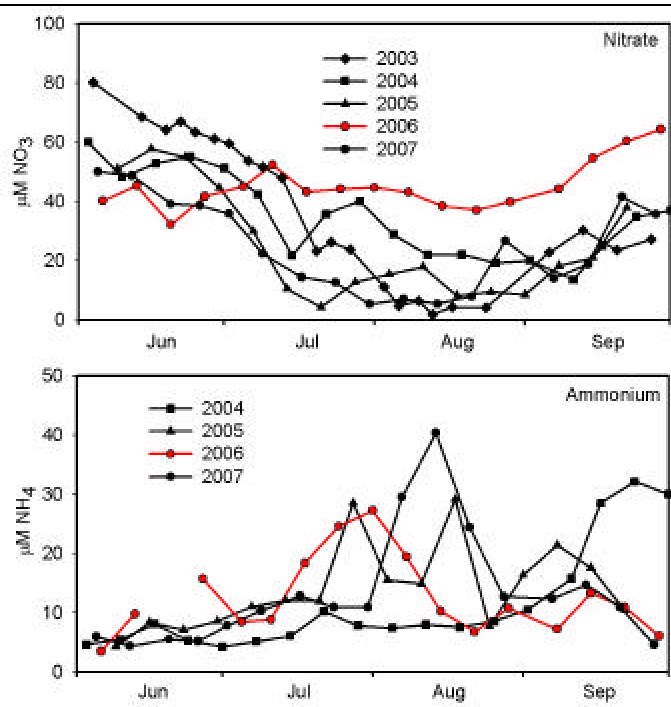
Belleville Lake received less phosphorus in 2006 compared to most other years because Ford Lake was exporting less P late in the summer.

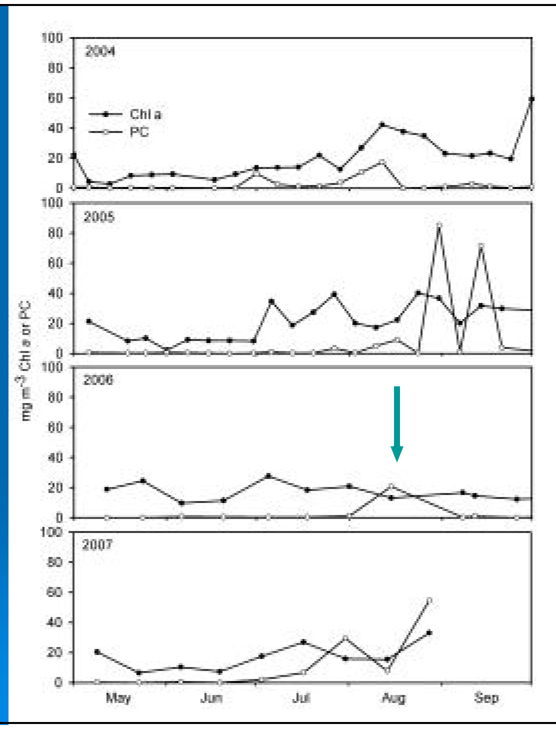
Why? Because Ford Lake did not develop widespread anoxia and therefore did not release P from large areas of its mud. P released in Ford Lake is invariantly exported down to Belleville Lake in August and September.

What else?

Bluegreen algae prefer ammonia as a nitrogen source. Nitrate gives different, non-nuisance algal species a competitive advantage.

Huron River below Ford Lake dam





River flow as a master variable for Ford Lake water quality

The volume of river discharge is the key factor in interannual variations of the spring (April to May) diatom bloom and the vernal clear water phase (May to June) in Ford Lake (Ferris and Lehman 2007; Lehman et al. 2007). Fluvial discharge is also critical in determining whether there is sufficient flow to undertake effective selective withdrawal manipulations.

Emerging Question:

Ann Arbor has enacted an ordinance that bans phosphorus from lawn fertilizer.

The action was based on theory that predicts a 22% decrease in non-point source P loading to the Huron River.

How can we know if the action will produce the desired effect?

Report to the Minnesota Legislature: Effectiveness of the Minnesota Phosphorus Lawn Fertilizer Law

March 15, 2007

Minnesota Department of Agriculture
Pesticide and Fertilizer Management Division

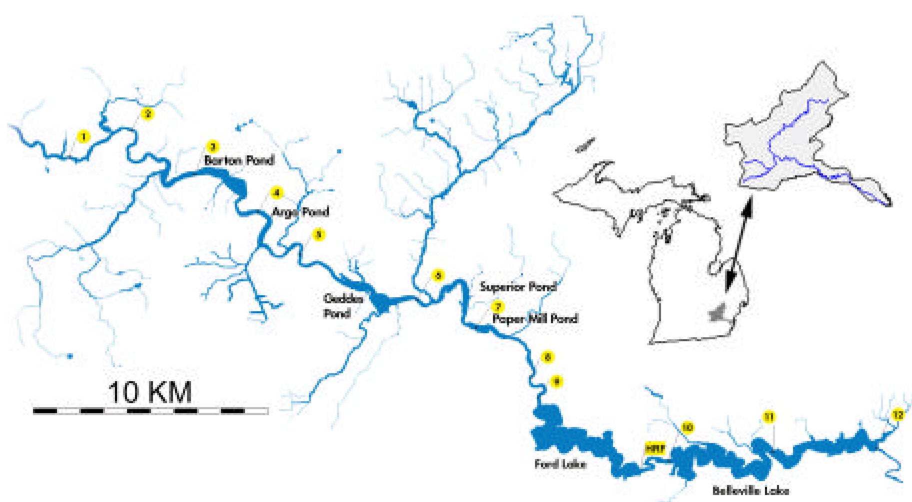
Has the law improved water quality?

- *Changes in water quality resulting from the law have not been documented at this time.*
- *Existing phosphorus runoff data from Twin Cities streams are too variable in years following phosphorus lawn fertilizer restrictions to indicate short-term trends in water quality.*
- *Measuring water quality changes associated with the law is made difficult by the variability of runoff data and the number of phosphorus runoff sources that need to be accounted for.*

No discernable water quality trends could be determined due to the high variability of the data. High variability in short-term water quality data is not surprising due to the complexities already noted. Many years of watershed monitoring data often are required before statistically valid trends in water quality can be determined.

Nutrient Budgets and River Impoundments: Interannual Variation and Implications for Detecting Future Changes (J.A. Ferris and J.T. Lehman)

In press: *Lake and Reservoir Management* (June 2008) Volume 24(2)



Historical Huron River water chemistry data set: 2003-2005 (pre-ordinance)

- Weekly samples during summer
- TP, DP, SRP plus many more analytes
- Characterized the magnitudes of seasonal and interannual variability
- Question: how much sampling effort would it take to have a 75% probability of detecting a 25% change in TP or DP if it is really there?

Assume weekly sampling from May to September

Answer:

- **Total P: 2 years**
- Dissolved P: 3 years
- SRP: 8 years

What if a careful study does not detect the predicted decrease?

The statistical model necessarily makes a tradeoff between the probability of accepting the hypothesis if it is false (10%) and rejecting it if it is true (25%).

There is also the question of compliance by citizens.

Advice from MHP: Can compliance be measured?

Thank you.

Citizens and elected officials of Ypsilanti Charter Township for cooperation and facilitation of the research.

D. Swallow and Van Buren Township for collecting samples from Belleville Lake.

Julie Ferris and Kahli McDonald for analyses and algal sample counts.

More info→ http://www.umich.edu/~hrstudy