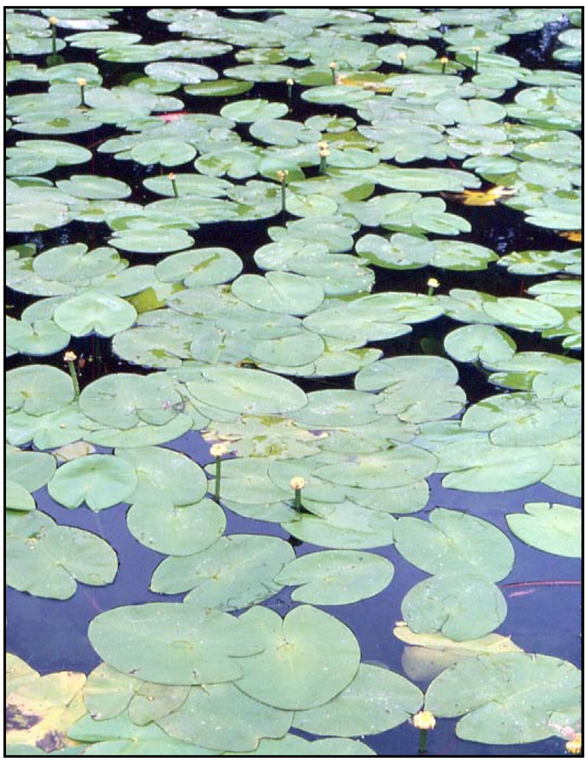
Hey and Associates, Inc.

LAKE PLANNING GRANT REPORT LPL-1227

Environmental Feasibility Report for a Lake-wide Low Dose Aluminum Sulfate Treatment on Fox Lake, Dodge County, WI



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PROJECT PURPOSE

The purpose of this project is to evaluate the use of a low dose aluminum sulfate (alum) treatment as a lake management tool to promote conditions favorable to sustain the existing biomanipulation on Fox Lake located in Dodge County, Wisconsin. The goal of a low dose alum treatment is to promote clear water conditions in the spring to promote aquatic plant growth. Aquatic plants are the key to maintaining desirable water clarity and the successful biomanipulation on Fox Lake by reducing sediment resuspension thereby reducing turbidity and internal nutrient recycling, providing competition with algae for light and nutrients, providing refugia for zooplankton enhancing their ability to filter water and provide a food source for small fish, provide habitat favorable for predatory fish reproduction and feeding, and reduce the number and impacts of resident carp population.

Shallow lake biomanipulations often show excellent initial results, as is the case with Fox Lake, but require maintenance orientated management actions to sustain in the long-term especially for eutrophic lakes where nutrient abatement has been limited[1]. In other words, shallow lake biomanipulations have not proven to be self-sustaining for nutrient rich lakes. While watershed improvements have been made in Fox Lake's watershed, internal nutrient recycling, or the internal load, is approximately 50-80% of the total nutrient budget[2] indicating alternate management will be necessary even with 100% nutrient reduction from watershed sources. Potential maintenance actions to improve the biomanipulation include: reestablish a favorable aquatic macrophyte (plant) community, reduce planktivore (plankton eating fish) biomass, reduce benthivore (bottom organism eating fish) biomass, or increase piscivore (fish that eat other fish) biomass[3]. A low dose alum treatment should be viewed as a maintenance action to promote the existing biomanipulation by reestablishing a favorable macrophyte community. This action is not intended to be used as a stand-alone lake restoration tool. A low dose alum treatment for Fox Lake is based on scientific lake response models, an existing biomanipulation, and numerous years of data collection making this a very specific management recommendation for Fox Lake. Alternate management options to maintain the clear water state will also be evaluated including no action, water level drawdown, and watershed management.

The goals of this project are:

1. Assess the feasibility of using a lake-wide low dose aluminum sulfate treatment to promote aquatic plant growth and enhance the existing biomanipulation,
2. Develop triggers for action for a low dose lake-wide aluminum sulfate treatment
3. Assess the potential for success and risk of failure, and
4. Evaluate alternate management alternatives.

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[1] Cooke GD, EB Welch, SA Peterson, and SA Nichols. 2005. Restoration and Management of Lakes and Reservoirs 3rd ed. CRC Press. Boca Raton, FL.

[2] University of Wisconsin-Milwaukee and Hey and Associates, Inc. 2008. Fox Lake Management Strategy Evaluation Report and Recommendations for Future Action. Lake Protection Grant Technical Report # LPT-244.

[3] McQueen, DJ. 1998. Freshwater food web biomanipulation: A powerful tool for water quality improvement, but maintenance is required. Lakes & Reservoirs: Research and Management 3:2:83-94.

The following report will be written in a format similar to an Environmental Assessment (EA) outlined in Wisconsin Administrative Code NR 150.

DESCRIPTION OF ACTION

Aluminum sulfate, or alum, has been used to treat drinking water supplies for over 200 years and is one of the most common chemicals used for settling solids. Traditionally alum is used in lakes as a nutrient inactivation technique by directly reducing total phosphorus and indirectly reducing chlorophyll-a concentrations. A traditional alum lake treatment has a life span of 10-20 years in deep, dimictic (mix twice per year) lakes with a dosing rate ranging from 2.5 to 28.7 g Al/m^3[4]. Alum effects on shallow lakes are somewhat shorter at 1-11 years but have proven effective at similar doses used on deeper lakes. When alum binds with phosphorus it forms a flocculent or floc that also drags suspended particles to the lake bottom. The goal of a traditional alum treatment is to seal phosphorus into the lake sediments by coating the lake bottom with the layer of floc formed by aluminum sulfate while binding phosphorus in the water column. The floc layer contains excess alum which may bind any phosphorus released by nutrient rich lake sediments during periods of anoxia (low oxygen). The long-term effectiveness of a traditional alum treatment on Fox Lake has been questioned because 1) the large amount of sediment resuspension and internal nutrient loading which would cause disruption of the alum's floc layer on the lake bottom and 2) anoxia is generally not a problem. This conclusion is supported by field investigations showing the majority of the internal loading in Fox Lake is during oxygen rich periods and caused by a combination of physical (wind) and biological (carp) processes[5]. However the goal of a low dose alum treatment does not rely on the long-term persistence of a floc layer at the water-sediment interface, but rather the chain of ecological events following a period of enhanced water clarity.

Application of aluminum sulfate to a lake can result in extremely clear water within a few hours to a few days. Floc particles settle on the bottom and carry the inorganic and organic particles previously suspended in the water column. When alum is added to water it undergoes the reaction below. The alum reacts with bicarbonate to form aluminum hydroxide, a precipitate.

$$Al_2(SO_4)_3{*}18H2O + 3Ca(HCO_3)_2 \Longleftrightarrow 2Al(OH)_3 + 6CO_2 + 3CaSO_4 + 18H_2O$$

(alum) (alkalinity as CaCO3) (precipitate) (gas) (salt)

The solubility product of aluminum hydroxide, Al(OH)3 is :

$$\frac{[Al]([OH])^3}{[Al(OH_3)]} = 1.26 * 10^{-33}$$

A low dose alum treatment does not have the goal of long-term phosphorus reduction. Rather its goal is to stimulation aquatic plant growth by temporarily clarifying the water column by removing phosphorus and settling out solids. A spring alum treatment would enhance aquatic

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[4] Cooke GD, EB Welch, SA Peterson, and SA Nichols. 2005. Restoration and Management of Lakes and Reservoirs 3rd ed. CRC Press. Boca Raton, FL.

[5] University of Wisconsin-Milwaukee and Hey and Associates, Inc. 2008. Fox Lake Management Strategy Evaluation Report and Recommendations for Future Action. Lake Protection Grant Technical Report # LPT-244.

vegetation by allowing deeper light penetration on the lake bottom. This has been cited as a negative side effect in prior alum treatments[6].

In the case of Fox Lake, it is proposed to utilize this known alum side effect as the actual lake management tool. The increased water clarity induced by the treatment would last until the available phosphorus in the water column was replenished via external loading, or a major wind event, causing resuspension of non-alum bound lake sediments and causing algae regeneration.

Based on the lake morphology and the aquatic plant community present in Fox Lake, a window of enhanced clarity would allow aquatic plants to grow over most, if not all, of the lake bottom. The treatment effect would be realized in the year of application and following years as the increased frequency and density of rooted aquatic plants enhance the existing biomanipulation by increasing water clarity, stabilizing bottom sediments, providing competition with algae, increasing top predator feeding success and reproduction, and minimizing the sediment disturbing impacts of carp.

To define a "low dose" treatment, jar experiments were conducted at the University of WI-Milwaukee using lake water collected from Fox Lake. Results of the jar experiments conducted suggest that a 0.301 g Al/m^3, or 20 gallons per acre-foot of 50% liquid alum by volume, will provide a sufficient dose to temporarily clarify the water column[7] (Figure 1). A 0.113 g Al/m^3, or 7.5 gallons per acre-foot, has been effective as a settling agent in small ponds[8]. A 0.150 g Al/m^3 or 10 gallon per acre-foot dosage rate provided water clearing, but the rate of settling was observed to be much slower than the 20+ gallon per acre-foot treatments especially when the floc was resuspended by gently stirring the jars. Controls included were a no treatment and a two hundred gallons per acre-foot or 3.010 g Al/m^3 treatment. The 3.010 g Al/m^3 dosage is just above the minimum application rate typically used for alum applications targeted at nutrient abatement[9].

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[6] The Lake and Reservoir Restoration Guidance Manual First Edition. 1988. United States Environmental Protection Agency Document # EPA 440/5-88-002, Criteria and Standards Division Nonpoint Sources Branch, Washington, D.C.

[7] Literature values are typically reported in g Al/m^3 while industry values are reported in gallons/acre-foot.

[8] Suffern, Brian. 2008. personal communication. Marine Biochemists. Mequon, WI.

[9] Restoration and Management of Lakes and Reservoirs – Third Edition. 2005. G.D. Cooke, E.B Welch, S.A. Peterson, and S.A. Nichols. Taylor and Francis Group, Boca Raton, FL.

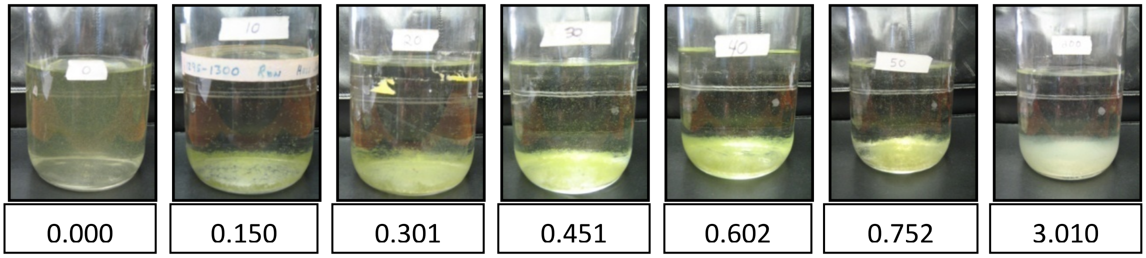

Figure 1
Results of Jar Experiments to Determine Alum Dosage
(☐ Indicates g Al/m^3 Dosage)[10]

Aluminum sulfate should be applied to Fox Lake at a dosage rate of 0.301 g Al/m^3, or 20 gallons per acre-foot of 48.5-50% liquid alum by volume with an initial concentration of 485,000-500,000 mg/l, via a barge delivery system to the top 1.2 m of the water column in areas greater than or equal to 1.2 m or 4 feet in depth. Areas in the lake less than 4 feet in depth are not as easily reachable using the barge system and tend to support aquatic plants in both turbid and clear years so treatment is not required in these areas. The total lake volume treated will be 11,113,671 m^3. Applying alum to the top 1.2 m or 4 feet of the water column should initiate settling of most suspended particles in the water column allowing sufficient light to penetrate to the lake bottom in all areas of Fox Lake to promote aquatic plant growth.

Additional calculations were made to confirm that a 0.301 g Al/m^3 dosage rate would be sufficient to bind all water column phosphorus. Assuming that the mean water column total phosphorus concentration is 0.150[11] g P/m^3, the total mass of phosphorus in the treatment area is approximately 1,667,050 g[12] while the total mass of phosphorus lake-wide is approximately 3,515,420 g. Using standard alum dosage calculations[13], it was determined that 1,456,485 g Al would be required to inactivate phosphorus or an application rate of 0.131 g Al/m^3 or 8.7 gallons per acre-foot in the treatment area and 0.276 g Al/m^3 or 18.3 gallons per acre-foot to inactivate all phosphorus in the water column. Because the alum dosage exceeds the total phosphorus in the water column, as settling occurs additional phosphorus will be bound in the underlying water column and the lake sediments.

DECISIONS THAT NEED TO BE MADE

An essential task is to develop a decision making framework to determine 1) when a low dose alum treatment on Fox Lake should occur and 2) how to judge success or failure of the action. Because Fox Lake has been a highly managed and highly monitored lake for many years, there is a large amount of data available to answer this question. It is proposed that the two most important factors to make an action decision on Fox Lake are based on 1) the status of the

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[10] Unpublished data. 2008 .Hey and Associates, Inc.

[11] A value of 0.147 g/m^3 is the maximum May value reported for 2004-2008. Mean May TP concentration for 2004-2008 is 0.094 g/m^3.

[12] Treatment area volume = 11,113 ,671 m^3; total lake volume = 23,436,155 m^3

[13] Dosage determination used Sweetwater Technologies, Inc. alum dose calculation worksheet found at http://www.teemarkcorp.com/sweetwater/calcall.htm adapted for a water column only application. Calculations can be found in Appendix A.

aquatic plant community in prior years and 2) the amount of local precipitation in the early spring months (March and April).

Fox Lake's aquatic plant community have been surveyed a number of times historically and annually since 2004 (A full summary including figures of aquatic plant data may be found in a later section of the report). A number of patterns have emerged in recent years that suggest Fox Lake is in danger of returning to the turbid water state. The year 2008 was the fourth consecutive year aquatic plant frequency has declined. Plants were found at 90% of sampling locations in 2005, but only 40% in 2008. In addition plants were found in lower densities for the third consecutive year. Shallow lake research suggests that at least 50% of the lake bottom requires coverage by aquatic plants to provide sufficient ecological benefits to promote the clear water state[14]. Because Fox Lake is currently less than the desired plant frequency threshold, a management action should occur to promote the aquatic plant community based on this data.

Figure 2 shows the correlation between aquatic plant frequency and spring (March and April) precipitation as rainfall. This simple relationship predicts 85% of the variability measured in aquatic plant frequency from 1995 to 2008. If it is assumed that the critical threshold for sufficient aquatic plant growth to sustain the clear water state is at minimum 50% of bottom coverage in the littoral zone, approximately 7.5 inches of spring precipitation should trigger a management action in any given year. Total spring precipitation for March and April 2008 for Fox Lake was approximately[15] 7.27 inches[16] resulting in an aquatic plant frequency of 40%. This result was slightly less than the model prediction which may have been due to a relatively cool spring and lower lake temperatures affecting plant growth rates and the wet preceding winter of 2007/08. It is likely that wet conditions in the spring of 2009 would further depress the aquatic plant frequency to a degree greater than model prediction because of the general downward trend in plant frequency over the last four years and especially low frequencies in 2008.

[14] Scheffer M. 1998. Ecology of Shallow Lakes. Kluwer Academic Publishers. The Netherlands.

[15] Precipitation includes snowfall converted to rainfall (snowfall total ÷ 10 = converted rainfall total).

[16] FLILP&RD. 2008. Kathleen Rydquist (District Coordinator) pers. com.

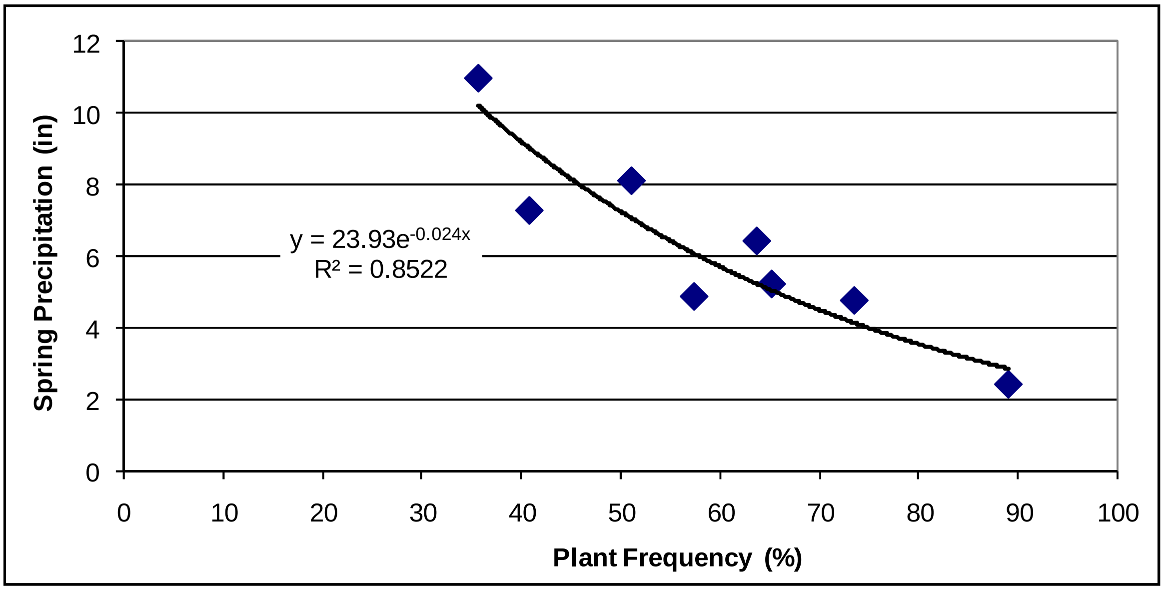

Figure 2
Aquatic Plant Frequency versus Spring Precipitation (March and April) for Fox Lake 1995-2007
Source: Hey and Associates, Inc., WDNR, and NOAA

From 2004-2008 spring precipitation is coupled to water clarity on Fox Lake, but prior to 2004 there is no relationship between precipitation and water clarity (Figure 3). These results suggest that prior to 2004 other forces were driving water clarity on Fox Lake such as wind events or water level management, but currently precipitation impacts are very important affecting the initial establishment of aquatic plants thereby limiting water clarity (plants stabilize sediment and provide competition for algae). From 1989 to 2003, with the exception of 1995, aquatic plants were largely lacking in Fox Lake providing one possible explanation for the lack of correlation between precipitation and Secchi depth.

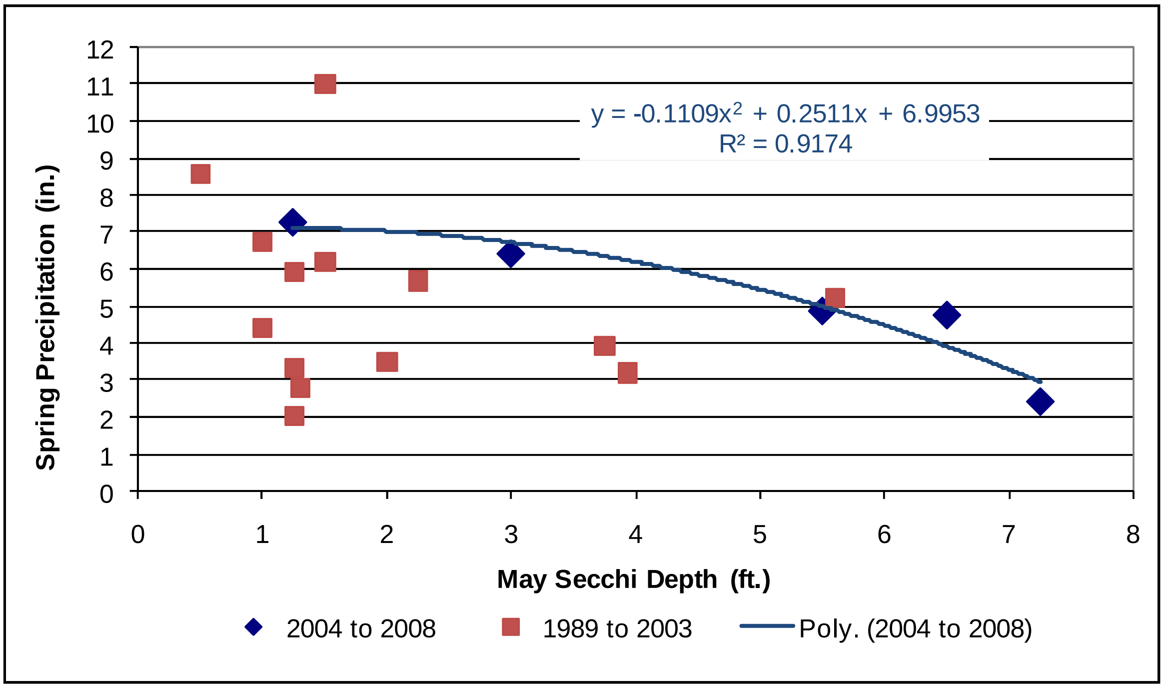

Figure 3
Relationship between Spring Precipitation and May Secchi Depth 1989-2008

The relationship between spring precipitation and aquatic plant frequency was the first of two predictive models developed for Fox Lake. The second model below shows the relationship between spring water clarity, or Secchi depth, and aquatic plant frequency (Figure 4).

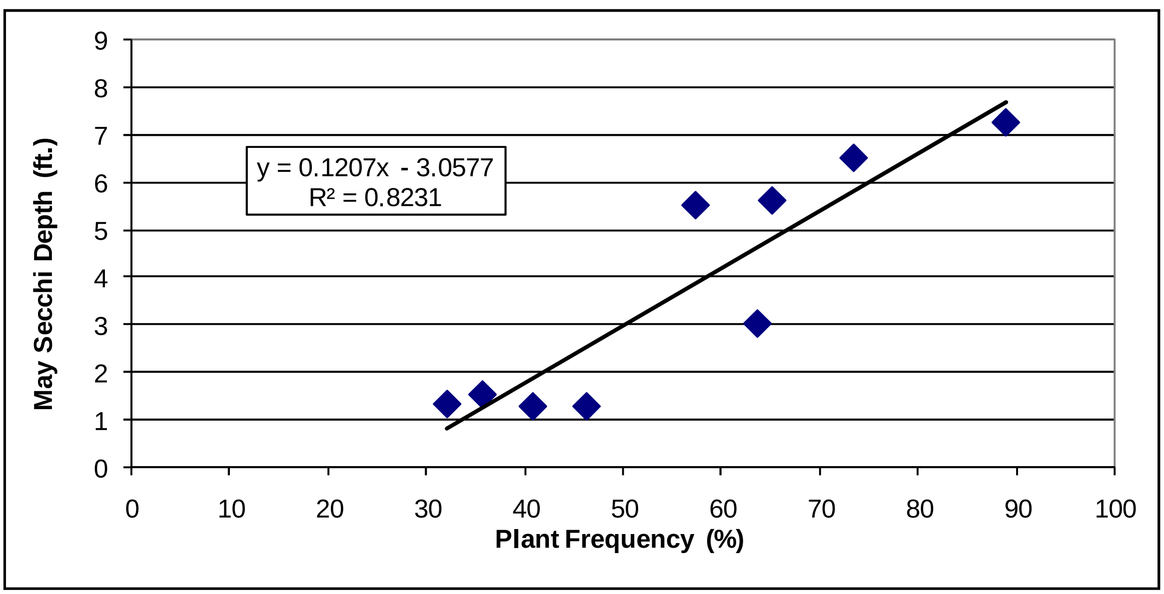

Figure 4
May Secchi depth versus Aquatic Plant Frequency for Fox Lake 1995-2008
Source: Hey and Associates, Inc., WDNR, and UW-Milwaukee

Combined, the precipitation and water clarity models may be used to assess the effectiveness of the low dose alum treatment. The precipitation model acts as a control model and will not be affected by the alum treatment. The water clarity model will be affected by the alum treatment because the spring water clarity will be artificially increased. As a result, if the actual plant frequency measured post-treatment matches the precipitation model, the treatment would be considered unsuccessful. If the plant frequency matches the water clarity model, the treatment would be considered successful.

While the precipitation and water clarity models can be used to assess the effectiveness of the low dose alum treatment, they are not helpful in determine when to do the treatment. Planning, financing, permitting and implementing a low dose alum treatment will take several months. If the Fox Lake community waits until the spring conditions exist to determine wither or not to proceed it may be too late. To determine the trigger for determining to proceed with a treatment requires a decision the prior fall. As will be discussed latter in this report, the prior year's plant community health is also a factor in determining the response the following year**. It is proposed that the trigger for planning a following spring low dose alum treatment be that the rooted aquatic plant community experience two or more years of decline and the plant community drops below a 50% frequency of occurrence.**

BACKGROUND

Fox Lake is a large, popular recreational lake located in Dodge County, Wisconsin. It has been the subject of on-going lake improvement projects jointly sponsored by the Fox Lake Inland Lake Protection and Rehabilitation District (ILP&RD) and the Wisconsin Department of Natural Resources (WDNR) since the 1960's. Past activities on Fox Lake include installation of agricultural non-point source practices, stabilization of eroding lake shorelines, restoration of wetlands, lake level drawdown for enhancement of rooted aquatic plants, modification of the dam outlet to better control high water levels, establishment of no-wake zones in all sensitive aquatic plant areas, and fishery restoration. The fishery restoration is a biomanipulation that included rough fish removal using rotenone and mechanical harvesting, stocking of game fish, and restrictive size and bag limits on game fish. Each of these management activities was intended to improve water quality, improve water clarity, and promote aquatic plant growth.

Over the last 50 years, Fox Lake experienced a gradual decline in water quality as indicated by reduced water transparency, increased algae populations, loss of aquatic macrophyte beds, loss of wetland fringe, and a declining sports fishery. Sediment core sampling indicates that during the last forty years, the trophic status of Fox Lake has progressed from a mesotrophic condition to a eutrophic one. Recent evidence from aquatic plant surveys and Secchi depth monitoring suggests that Fox Lake has shifted from a turbid water state dominated by algae to a relatively clear water state dominated by aquatic plant growth.

The abundant plant growth in Fox Lake prompted the Fox Lake ILP&RD to seek funding for an aquatic plant management plan to facilitate recreational lake uses, maintain fish habitat, and monitor exotic plants. An interim plan was developed and implemented in 2006 and a long-term plan was adopted in 2007 spanning 2007-2012. Both projects were funded under the WDNR Lake Planning Grant Program. Navigation lanes and individual riparian homeowner chemical treatments around piers were the management actions taken. Protection is an additional focus of the plan which requires an annual comprehensive point-intercept survey at nearly 900 locations on the lake.

While many of the factors leading up to Fox Lake's current state are unknown, it is likely that the combination of carp eradication, predatory fish stocking, improved water level management, and favorable climate conditions all played a role in achieving the current clear water state. It must also be restated that, based on scientific knowledge of shallow lakes, Fox Lake's current clear water status is likely unstable. Nutrient concentrations alone would predict Fox Lake to exist in a persistent turbid water state with limited, if any, chance for a successful biomanipulation; however, the combination of top-down management of the fishery and bottom-up enhancement of the aquatic plant community has overcome the impacts of high nutrient concentrations. For these reasons it is important to seek out management options which could potentially counteract a shift back to the turbid water state due to loss of aquatic plants.

In 2008, the "*Fox Lake Management Strategy Evaluation Report and Recommendations for Future Action*" was submitted to the Fox Lake ILP&RD and Wisconsin Department of Natural Resources. The study recommended a low dose aluminum sulfate (alum) treatment to promote spring water clarity and submergent aquatic plant growth due to declines from 2005 to 2008. A number of simple predictive models were generated in the 2008 Evaluation Report and addendum to help understand the interactions between seasonal water clarity, spring precipitation, and the frequency of aquatic plants. The relationship between the data models and the proposed action will be included in a later section of the report.

The Fox Lake ILP&RD and WDNR have demonstrated a long-term commitment to managing Fox Lake as evident by consistent participation in the WDNR Self-help program, receiving 12 lake planning grants since 1990, and several lake protection grants for fishery management and project evaluation, an active partner in the Beaver Dam River Priority Watershed Project through installation of shoreline protection, wetland restoration projects and agricultural runoff control systems, and installation of a sanitary sewer system the lake and construction of a regional wastewater treatment plant. In addition, Fox Lake ILP&RD currently funds aquatic plant surveys to monitor frequency and density annually. Currently one watershed assessment is underway to identify pollution sources on Drew Creek. Two other watershed assessment projects have been submitted to the WDNR for lake planning grant funding to identify pollution sources in the Cambra Creek and Alto Creek watersheds.

ENVIRONMENTAL SETTING

The current environmental setting is a product of Fox Lake's status as a shallow lake, a large agriculturally dominate watershed, and by the lake management strategy implemented over the last decade on Fox Lake known as a biomanipulation.

Because Fox Lake is a shallow lake, it is prone to switch between alternate stable states. The large, agricultural watershed results in a nutrient rich or eutrophic to hyper-eutrophic state and high levels of in-lake productivity.

Biomanipulation is a lake management technique used to promote a well balanced lake ecology or trophic structure for fish, zooplankton, aquatic plants, algae, and other organisms by selectively promoting or minimizing particular species or species groups.

A conceptual lake model incorporating alternating stable states, trophic status, and the effects of biomanipulation has been developed for Fox Lake. Each of these topics will be explained in the following paragraphs as a context for each component of the remainder of this section summarizing the physical, chemical, and biological setting for Fox Lake.

“Alternate Stable States” refers to a model used to explain the often rapid shift that occurs in shallow lakes from the clear water, macrophyte (plant) dominant state to a turbid water, algal-dominant state (Figure 5). Figure 6 illustrates the relative biomass of each ecological component of the lake biota in the clear and turbid water state. For productive lakes such as Fox Lake, the desired condition is the clear water state; however, the probability of a lake to exist in the plant dominant or algal dominant state is dependent on its trophic status.

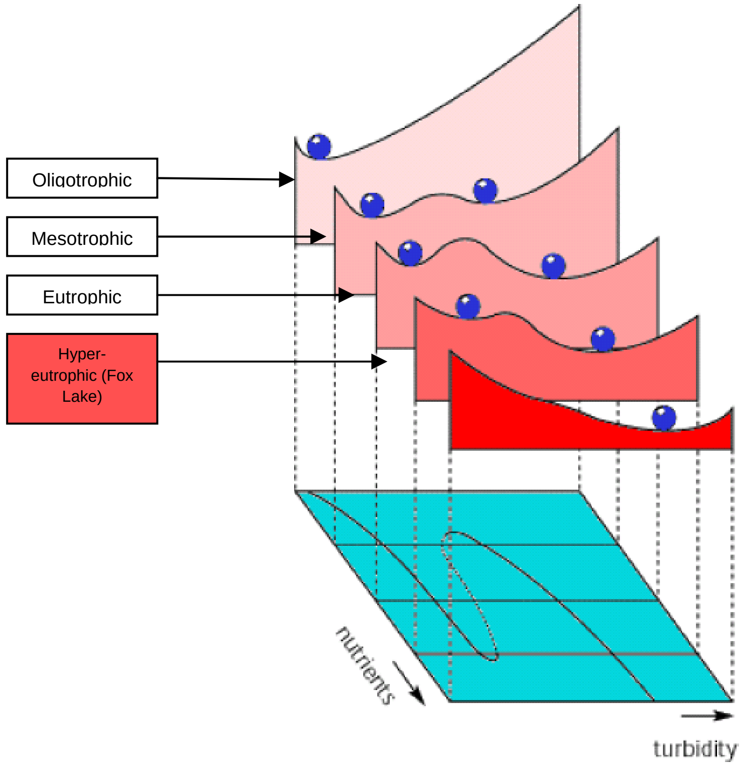

Figure 5
Alternate Stable States Model[17]

Trophic state is a common term used to describe lake biological productivity and is based on a combination of nutrients, water clarity, and chlorophyll-a[18] measurements. Measurements for nutrients, water clarity, and chlorophyll-a are converted to a numeric scale from 0-100, or trophic status index, and are assigned to one of four categories. These categories are assigned because most lakes within each category will share common characteristics. Eutrophic refers to a nutrient rich condition that is very biologically productive with many plants, algae, and fish. The eutrophic condition is usually caused by watershed degradation associated with land use changes and nutrient delivery, but do occur naturally if lakes have very large watershed areas. Hyper-eutrophic lakes are the most productive and can be thought of as an extreme eutrophic state. In contrast, oligotrophic lakes are nutrient poor and very unproductive. They are usually found in more pristine landscapes. Mesotrophic lakes are intermediate in terms of productivity

[17] Adapted from Scheffer, M., S. H. Hosper, M. L. Meijer, B. Moss & E. Jeppesen, 1993. Alternative equilibria in shallow lakes. Trends Ecol. Evol. 8: 275-279.

[18] Chlorophyll-a is an indicator of algal biomass.

falling between eutrophic and oligotrophic lakes. They may be found in a variety of landscapes and may have internal buffering mechanisms that reduce the impacts of nutrient addition. Table 1 summarizes characteristics of lakes with each trophic state.

Table 1
Trophic Status Characteristics
Source: WDNR

TSI	Classification and Description
< 30	Oligotrophic: Clear water, many algal species, oxygen throughout the year in bottom water, cold water, oxygen-sensitive fish species in deep lakes. Excellent water quality.
30-40	Mesotrophic: Deeper lakes still oligotrophic, but bottom water of some shallower lakes will become oxygen-depleted during the summer.
40-50	Moderately Eutrophic: Water moderately clear, but increasing chance of low dissolved oxygen in deep water during the summer.
50-60	Eutrophic: Decreased clarity, fewer algal species, oxygen-depleted bottom waters during the summer, plant overgrowth evident, warm-water fisheries (pike, perch, bass, etc.) only.
60-70	Eutrophic: Blue-green algae become dominant and algal scums are possible, extensive plant overgrowth problems possible.
70-80	Hyper-eutrophic: Heavy algal blooms possible throughout summer, dense plant beds, but extent limited by light penetration (blue-green algae block sunlight).
> 80	Hyper-eutrophic: Algal scums, summer fishkills, few plants, rough fish dominant. Very poor water quality.

Typical goals to manage shallow lakes via biomanipulation, the current management strategy on Fox Lake, to achieve the clear water state require total phosphorus <100 ug/l or a TSI score ~65[19,20]. Based on the total phosphorus level fluctuation on Fox Lake from 1990-2008 which range from 100-200 ug/l, it is unlikely that the biomanipulation will remain stable.

Biomanipulation is defined as the deliberate alteration of an ecosystem by adding or removing species. For a lake, the effect of successful biomanipulation is to decrease the impacts of nutrients on the production of algal biomass creating greater than predicted water clarity. Top predators are promoted via stocking to increase predation on planktivorous fishes. Planktivorous fishes are unable to consume zooplankton which in turn increases their consumption of algae. Top predators also consume young common carp limiting their increase in population size. Meanwhile adult carp are also removed via direct harvest. Sediment resuspension by carp decreases lowering turbidity and nutrients in the water column. Aquatic plants are promoted by increased water clarity providing refugia for top predators and zooplankton, provide direct competition with algae for nutrients, support periphyton (attached algae) that compete with planktonic (water column) algae, further stabilize bottom sediments,

[19] Scheffer, M. H. Hosper, M L Meijer, B Moss & E Jeppesen, 1993. Alternative equilibria in shallow lakes. Trends Ecol. Evol. 8: 275-279.

[20] Hosper H and ML Meijer. 1993. Biomanipulation, will it work for your lake? A simple test for the assessment of chances for clear water, following drastic fish-stock reduction in shallow, eutrophic lakes. Ecological Engineering Vol. 2, no. 1, pp. 63-72.

and promote reproduction of top predators. As a result, the initial management actions of stocking top predators and removing common carp are perpetuated by the ecological structuring effects of the aquatic plant community[21]. The above biomanipulation scenario generally is consistent with the results of the management efforts on Fox Lake.

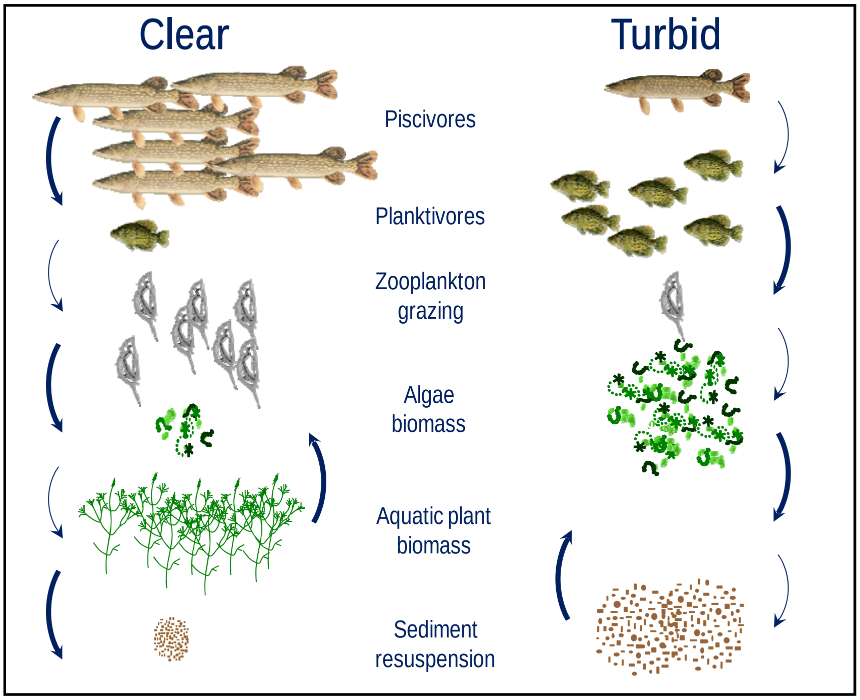

Figure 6
Species Composition in Clear and Turbid Water States[22]

To fully incorporate alternate stable states, trophic status, and biomanipulation factors in a management strategy for Fox Lake, a model for Fox Lake accounting for dominant physical and biological factors illustrated in the "Fox Lake Management Strategy Evaluation Report and Recommendations for Future Action – 2008" was proposed. It is important to note that a basic assumption of the lake model is that Fox Lake will tend towards the turbid water state in any given year largely due to its high nutrient levels and requires the effects of the biomanipulation or favorable environmental conditions to reach the clear water state. The low nutrient and chlorophyll-a levels measured post-restoration project implementation are likely a product of a successful biomanipulation and do not reflect a reduction in external nutrient loads. As a result, the lake will likely return to pre-restoration conditions in terms of nutrient levels if the effects of the biomanipulation are lost.

The alternate stable states model for Fox Lake is presented in Figure 7. The black circles show the starting point or likelihood to shift towards clear or turbid water in any given year based on 1) the frequency aquatic plants in the prior year related to how many plants overwintered and will be able to grow quickly in the current year and 2) the conditions related to spring precipitation

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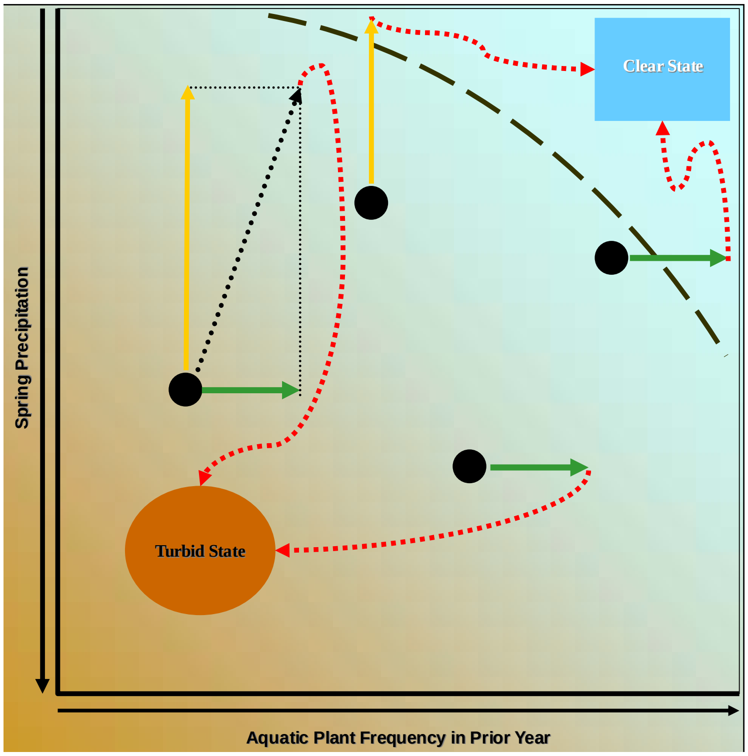
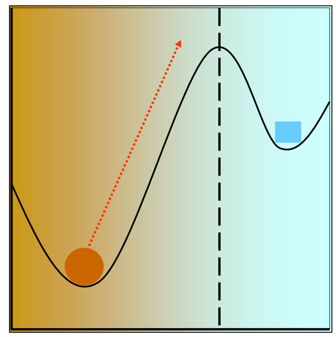
[21] McQueen DJ, MRS Johannes, JR Post, TJ Stewart, and DRS Lean. 1989. Bottom-up and top-down impacts on freshwater pelagic community structure. Ecological Monographs. 59(3) pp. 289-309.

[22] Hanson, M., M. Butler. 1994. Responses to food web manipulation in a shallow waterfowl lake. Hydrobiologia 279/280: 457-466.

and water clarity determining whether the water is clear enough this year to allow overwintering from last year and to allow existing plants to grow from seed or rysomes (roots).



(a) Conditions affecting annual dominant stable state



(b) Hyper-eutrophic alternate stable state model

Figure 7
Alternate Stable States Model for Fox Lake[23,24]

The green arrows in the model are a reference to the influence of aquatic plants and a healthy zooplankton community promoting the clear water state or how much can the lake's natural biology helps clean the water. The yellow arrows are in reference to climate factors or management actions which would promote greater water clarity such as a lack of wind and runoff. The black arrows are the net sum of the influences of environment and biology. In both cases, only positive influences are illustrated. Negative impacts would be associated with gravitating towards the turbid water state. The red arrows indicate the eventual outcome of the interaction for any given year for Fox Lake. This model also incorporates the potential influence of catastrophic events that could quickly push the lake into the turbid state such as extreme nutrient or turbidity loading, collapse of aquatic plant community, or a drastic increase in the carp population.[25]

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[23] Scheffer, M., S. H. Hosper, M. L. Meijer, B. Moss & E. Jeppesen, 1993. Alternative equilibria in shallow lakes. Trends Ecol. Evol. 8: 275-279.

[24]Byers JE, K Cuddington, CG Jones, TS Talley, A Hastings, JG Lambrinos, JA Crooks and WG Wilson. 2006. Using ecosystem engineers to restore ecological systems. Trends in Ecology & Evolution Volume 21, Issue 9, Pages 493-500.

[25] Carpenter SR, JF Kitchell, and JR Hodgson. 1985. Cascading trophic interactions and lake productivity. Bioscience 35:634-639.

Physical Setting

Fox Lake is a 2,625-acre shallow lake located within the municipal boundaries of the Town of Fox Lake and the City of Fox Lake. Fox Lake is a natural glacial lake that was enlarged in 1845 by the construction of a dam on the lake outlet, Mill Creek. Table 2 outlines the physical characteristics of Fox Lake.

Table 2
Physical Characteristics of Fox Lake[26]

Parameter	Size
Surface Area (open water)	2,625 acres
Surface Area (with fringe wetlands)	4,690 acres
Maximum Depth	19 feet
Mean Depth	5 feet
Maximum Fetch	2.1 miles
Volume	19,307 acre-feet
Shoreline Length	17.9 miles

Land use in the watershed is dominated by agriculture and wetlands as indicated in Table 3.

Table 3
Land Use/Land Cover for Fox Lake Watershed[27]

Land Use/Land Cover Type	Subbasin (%)		
	Alto Creek	Cambra Creek	Drew Creek
Industrial and Commercial	0.0	0.3	1.2
Cropland and Pasture	84.0	80.7	94.5
Residential	0.0	1.6	0.0
Wetlands	14.1	17.2	1.3
Forest	1.9	0.0	1.4
Other	0.0	0.1	1.6

Water Quality and Water Clarity

Fox Lake is a shallow, well mixed eutrophic lake characterized by high nutrient levels, prolific algal growth, and poor water clarity. In general, Fox Lake exhibits many of the characteristics expected of shallow lakes such as periods of limited anoxia and uniform distribution of most

[26] Wisconsin Department of Natural Resources. 1993. A Nonpoint Source Control Plan for the Beaver Dam River Priority Watershed.

[27] Hey and Associates, Inc. 2008. Fox Lake Management Strategy Evaluation Report and Recommendations for Future Action. Lake Protection Grant Technical Report # LPT-244.

water quality measurements for most of the year including nutrients. Data suggests the lake seasonally alternates between nitrogen and phosphorus limitation in terms of algae production, but it is likely that light attenuation also plays a role as indicated by very low water clarity in some years.

In-lake total phosphorus concentrations ranged from 100 ug/l to greater than 200 ug/l during the summer months from 1990-2008 on Fox Lake. These nutrient levels correspond to TSI scores ranging from 65-70 suggesting the clear water state is unstable and unlikely to persist at current nutrient levels without active management to promote the successful biomanipulation.

Oxygen depletion in the winter and summer months occurs over the deeper hole and likely in the deeper (>15 feet) areas of the lake. The winter anoxia is limited by the use of an in-lake aeration system and does not reach levels dangerous to aquatic life. The anoxia in the summer months is temporary and natural lake mixing caused by wind maintains sufficient dissolved oxygen in the water column.

Long-term patterns in water clarity, measured as Secchi depths, indicate that Fox Lake has exhibited worsening water clarity since 2005. This may be indicative of either:
1) a direction shift towards the turbid water state that was dominant for many years prior to 1995 or 2) patterns related to cyclical annual variations in water clarity within the clear-water state. Prior to the clear-water year in 1995, the water clarity was consistently poor throughout the growing season. From 1996-2007 water clarity was high in spring and throughout the growing season in some years and poor in others (Figure 8). Clear water years were identified statistically using Secchi depth data in 1995, 2001, 2004, 2005, 2006, and 2007. Turbid water years were identified for the remaining years including 2008. The statistical procedures used to classify years as clear or turbid are included in Appendix A.

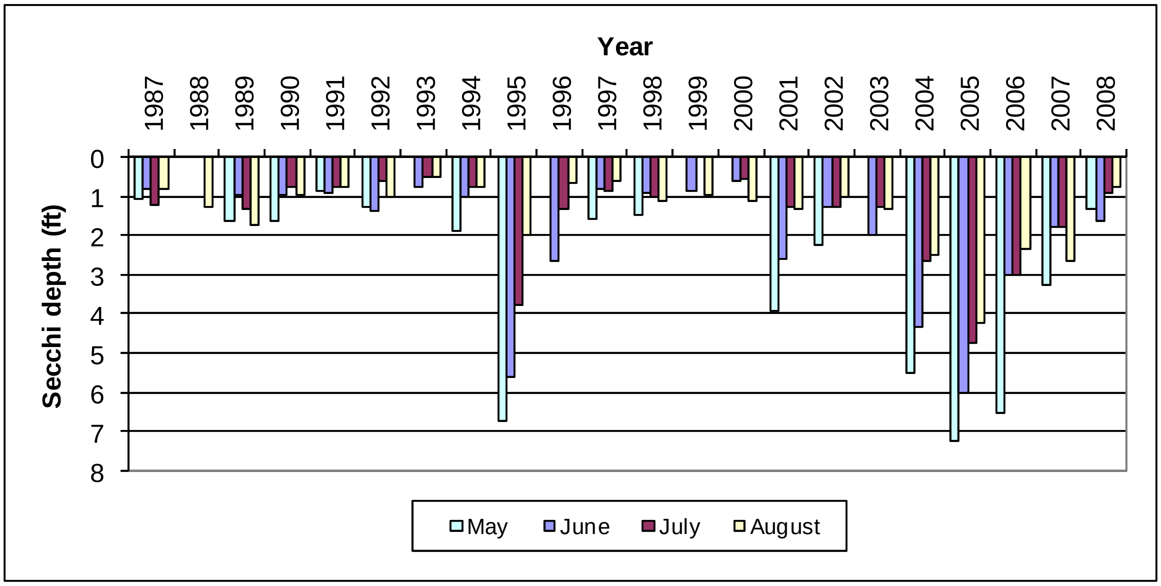

Figure 8
Secchi Depth on Fox Lake (1987-2008)[28]

The summer growing season mean trophic state index (TSI) scores are summarized in Figure 9. They show Fox Lake is a borderline eutrophic hyper-eutrophic lake with consistently high values for all three indicators. The years with the lowest Secchi depth TSI scores on record coincide with the reestablishment of aquatic plants illustrating their role in the maintenance of water clarity in Fox Lake.

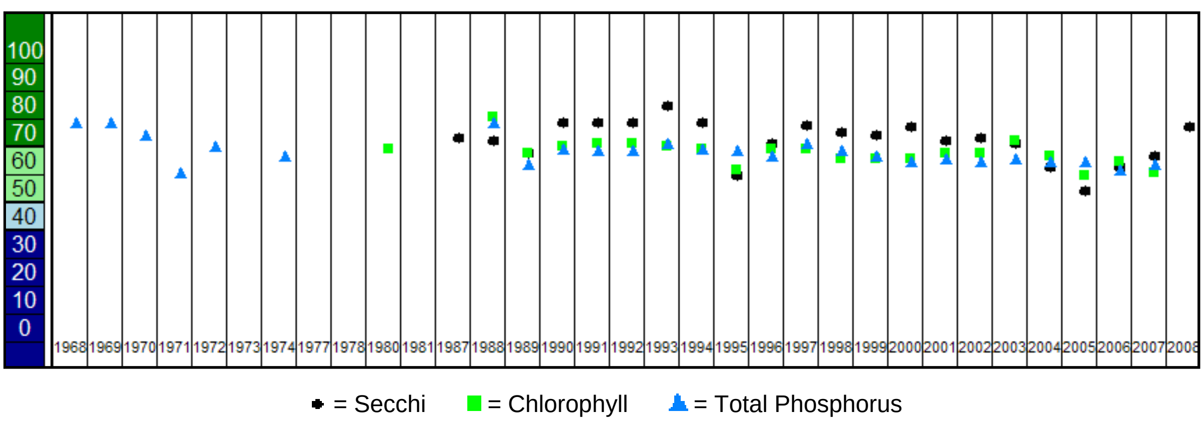

Figure 9
Trophic State Index Scores (1968-2008)[29]

[28] Wisconsin Department of Natural Resources Self-help Lake Monitoring Data

[29] Wisconsin Department of Natural Resources Self-help Lake Monitoring Data

Existing Biological Community

Aquatic Plants

<u>*Survey Methods*</u>

Historically, the plant community on Fox Lake was surveyed using a transect-based method. In 2006, the methodology was changed to a comprehensive point-intercept survey to provide a better overall picture of the aquatic plant community. Point-intercept surveys, now the DNR standard for most surveys in Wisconsin, contain many more survey points than transect-based surveys, but do not sample as intensively at each location (i.e. one rake toss versus four rake tosses). As a result, comparisons between 2006, 2007, and 2008 are excellent as are comparisons between surveys conducted prior to 2006; however, comparing post-2006 data to pre-2006 data are likely not as precise as comparisons between years where the collection method was identical.

The lake-wide aquatic plant point-intercept survey was conducted at predetermined sampling locations using the WDNR provided coordinates and approved field sampling methodology. Sampling points were uploaded into a hand-held Garmin GPS unit using software provided by the Minnesota Department of Natural Resources called DNR Garmin v.5.1.1. A long-handle rake or rake head attached to a rope was dragged along the bottom of the lake to collect plants up to a depth of 14 feet. All plants were identified to genus or species and assigned density ratings. The density of aquatic plants is important because it is the primary determinant of many recreational uses. The values assigned for aquatic plant density are “0” for no plants on the rake head, “1” for a few plants, “2” for a moderate amount of plants, and “3” for dense plants (Figure 10).

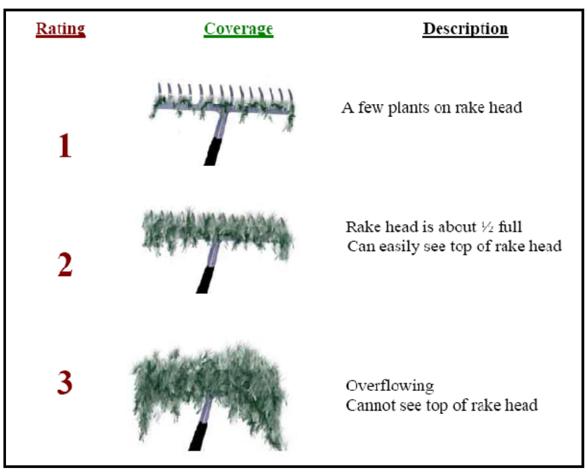

Figure 10

Density Ratings for Aquatic Plant Sampling

Plant Frequency

Plant frequency refers to the number of sampling locations where plants were collected. Plant frequency is important because plants prevent sediment resuspension dually reducing solids or turbidity and nutrients in the water column. Recent aquatic plant surveys have shown that the aquatic plant frequency in Fox Lake expanded from 1998-2005 and declined from 2006 to 2008 (Figure 11).

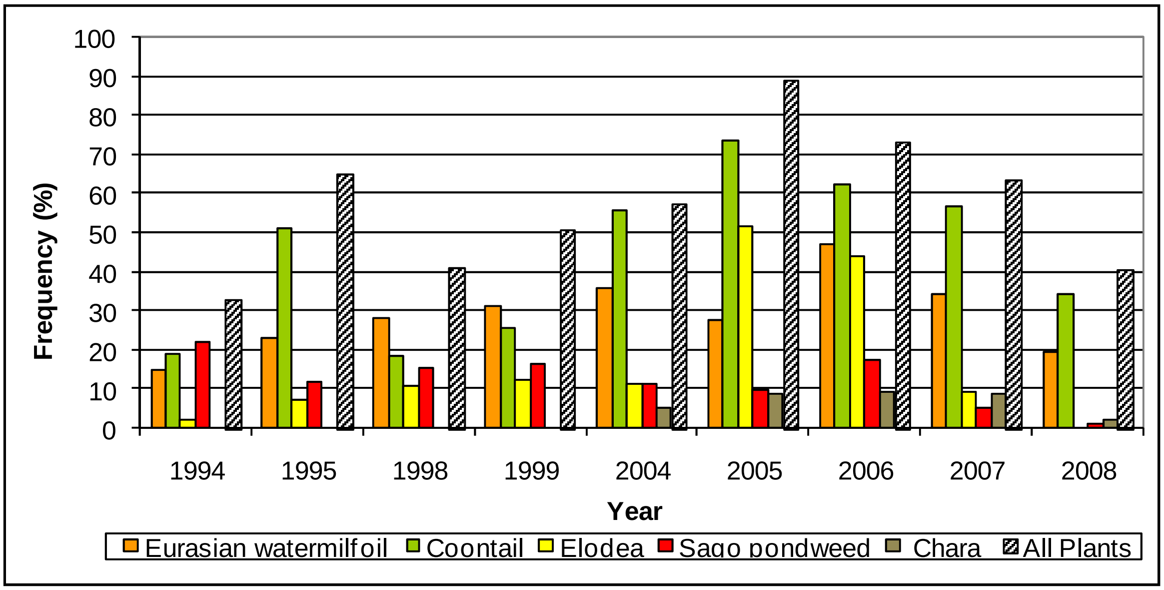

Figure 11
Frequency of Occurrence for Selected Aquatic Plants[30]

Figure 12 shows the lake-wide distribution and density of aquatic plants in 2008. Frequency is indicated by the presence or absence of a colored dot at each sampling location. When compared to 2006 and 2007 years, it is obvious plants have declined in large areas of the lake most notably in the Jug and near the marsh located on the eastern shoreline of the lake (Figure 13).

The most dramatic changes in species frequencies are the sharp rise and fall of Elodea from 2004-2008, Chara and Sago pondweed's decline from 2006 to 2008, and Coontail's decline from 2005 to 2008. This may be ecologically significant because Elodea, Chara, and coontail are low growing and may be sensitive to subtle changes in light availability along the lake bottom. Research has shown that "meadow forming species" such as Chara and Elodea reduce sediment resuspension by reducing the impact of waves on the lake bottom as do "canopy forming" plants such as Coontail and Eurasian water-milfoil[31].

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[30] Hey and Associates, Inc. 2008. Fox Lake Management Strategy Evaluation Report and Recommendations for Future Action. Lake Protection Grant Technical Report # LPT-244.

[31] James, WF, J W Barko, and MG Butler. 2001. Shear stress and sediment resuspension in canopy- and meadow-forming submersed macrophyte communities. APCRP Technical Notes Collection (ERDC TN-APCRP-EA-03), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

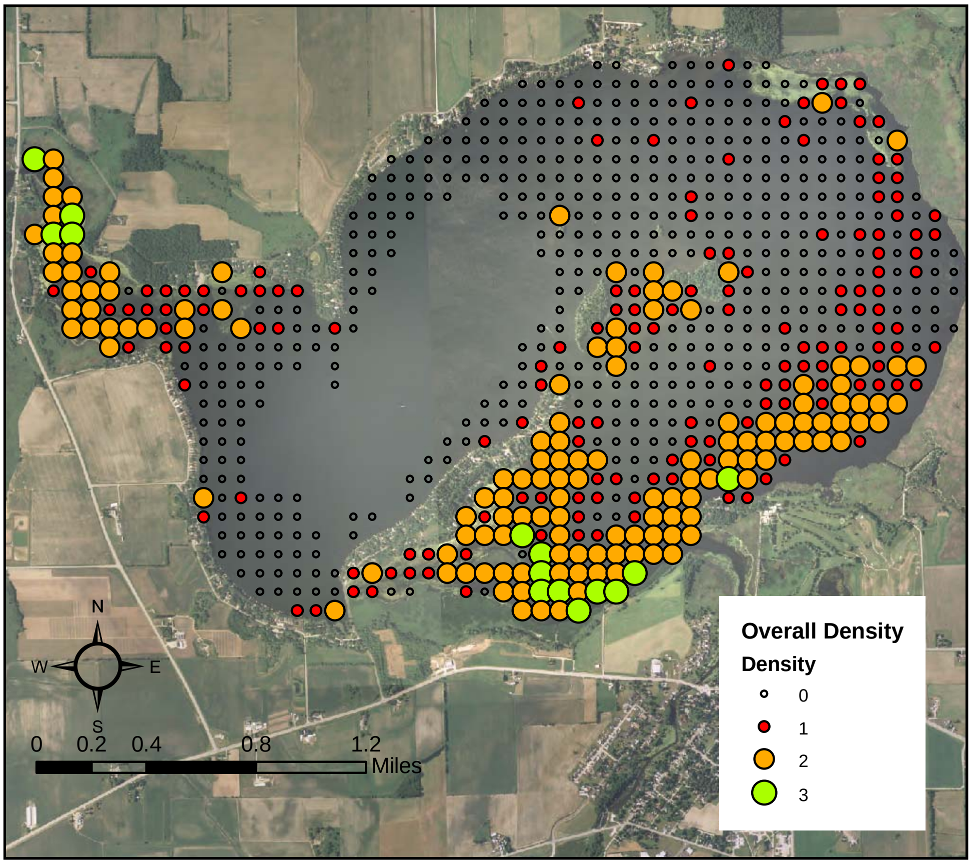
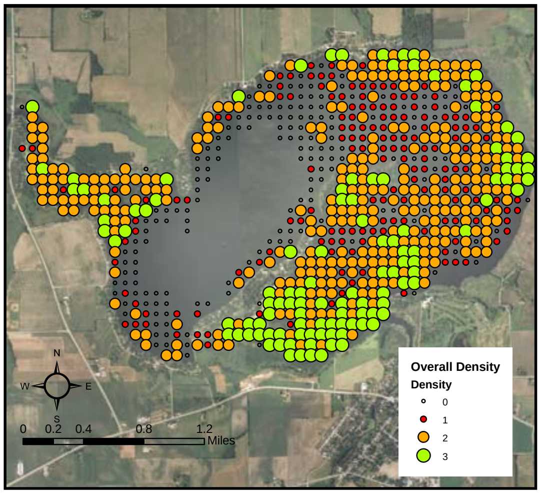
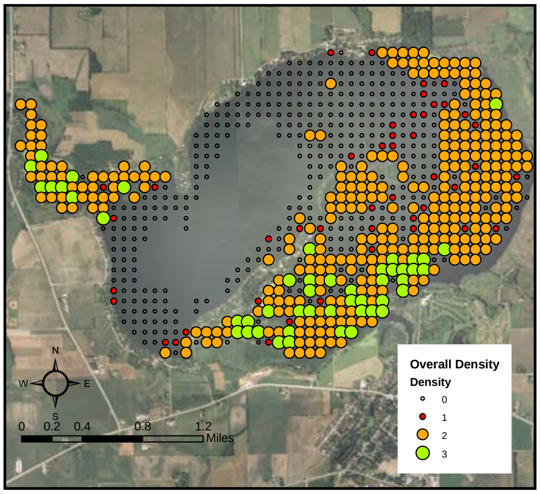


Figure 12
Overall Plant Density 2008



(A) 2006



(B) 2007

Figure 13
Overall Plant Density 2006 (A) and 2007 (B)

Plant Density

Plant density is an estimate of the plant biomass present at each sampling location. Plant density is quantified using the scale shown in Figure 10. Figures 12 and 13 show overall[32] plant densities on Fox Lake from 2006 to 2008. They show that the number of green and orange dots which indicate relatively dense plant growth have declined since 2006.

To better visualize and quantify the changes in density at specific locations in Fox Lake, the data was re-plotted to indicate density change from year to year. The following equation shows how density change was calculated for each sampling point:

Density 2008 – Density 2007 = Net Change from 2007 to 2008

The range of the potential total change in density is +3 to -3. A positive value indicates plants are gaining density, a negative value indicates plants are losing density, and a zero value indicates no change. A value of "-3" means that in the first year of sampling a value of "3" or very full rake was collected and in the following year a "0" or no plants were collected. The scale roughly represents the changes in rake fullness shown in Figure 10. Figure 14 shows that most sites in the lake lost density or stayed the same from 2007 to 2008 (indicated by white or red coloration).

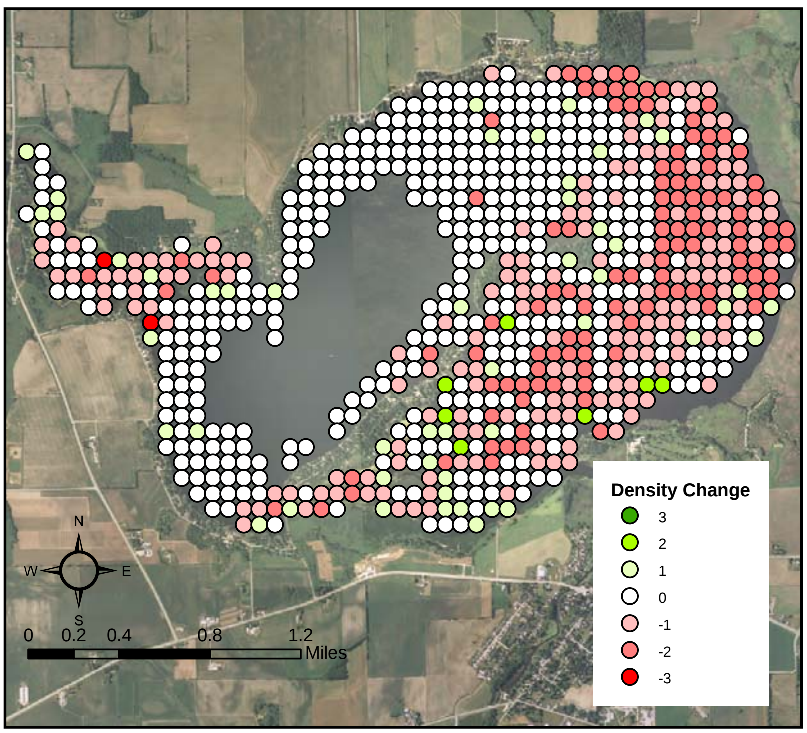
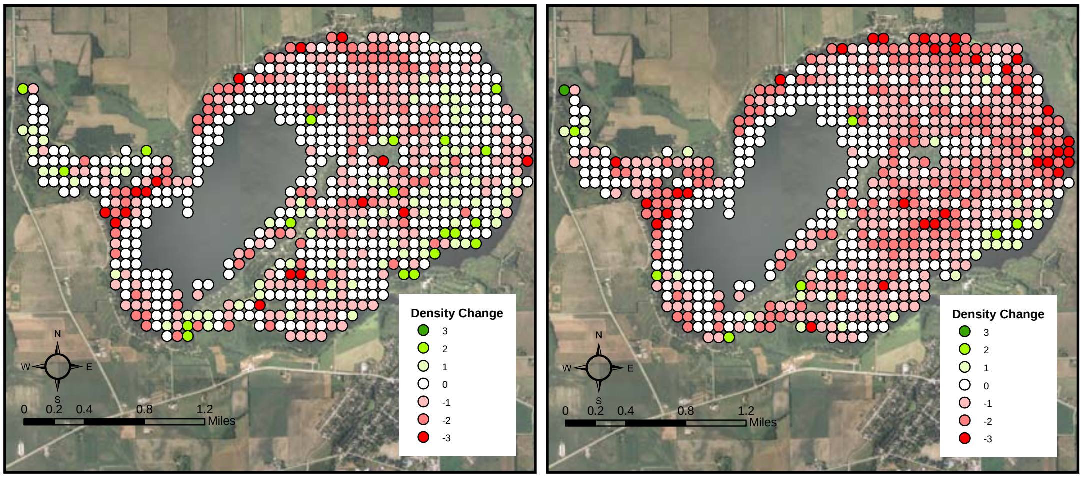


Figure 14
Overall Aquatic Plant Density Change from 2007 to 2008

32 Overall plant density is the rake fullness for all species present.

Figure 15 shows changes from 2006 to 2007 and 2006 to 2008. They also show a decline from 2006 to 2007 in plant density at most points on the lake. When the density change from 2006 to 2008 is plotted directly, large-scale loss of plant density is obvious on a near lake-wide scale.



(A) 2006 to 2007 (B) 2006 to 2008

Figure 15

Overall Aquatic Plant Density Change from 2006 to 2007 (A) and 2006 to 2008 (B)

Figure 16 shows how the plant density has changed at one-foot depth intervals from 2006 to 2008. It is a summary of the lake-wide data discussed in the previous paragraph and shows a near uniform loss of plant density at most depths. The scale roughly corresponds to rake fullness shown in Figure 10.

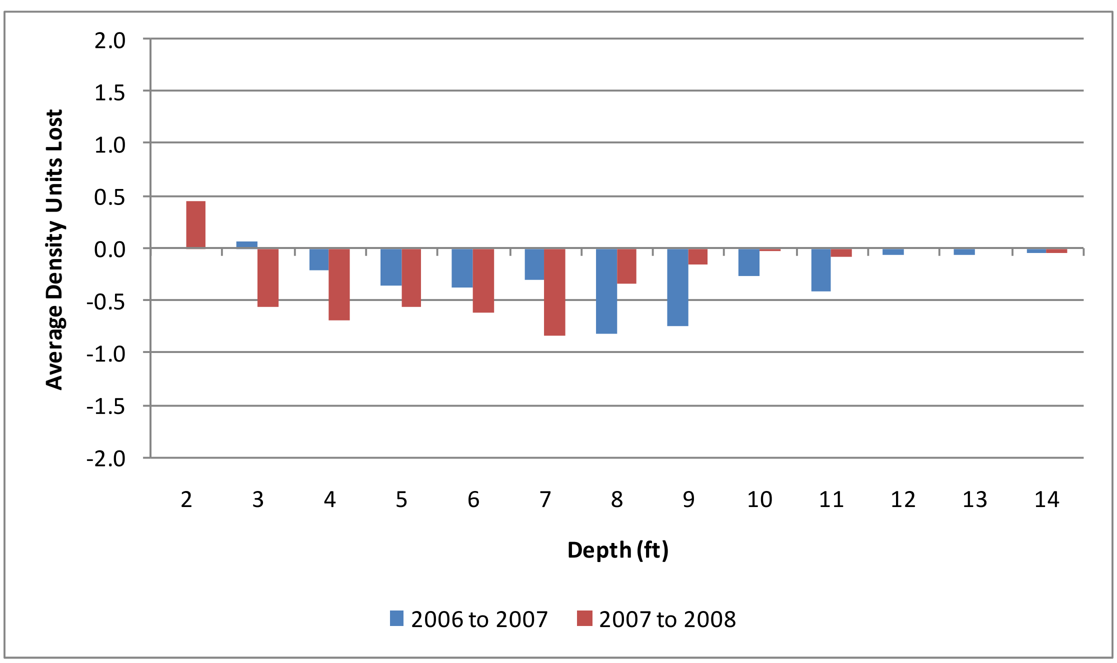


Figure 16

Mean Change in Aquatic Plant Density by Depth for 2006 to 2008

(>0 Denotes Gain in Plant Density, <0 Denotes Loss in Plant Density, 0 = No Change)

To further summarize density data, the overall density was summed for all sites sampled in each of 2006, 2007, and 2008 as a qualitative estimate of lake-wide biomass. The results are shown in Figure 17 and Table 4.

Table 4
Biomass Loss in Fox Lake from 2006 to 2008

Year	2006	2007	2008
Total Biomass (Density Units)	1,100	807	435
Biomass Units Lost (%)	-	26.6	46.1

Table 4 shows a 26.6% loss in density units from 2006 to 2007 and an additional loss of 46.1% from 2007 to 2008. In total 60.4% of the biomass present in 2006 has been lost in 2008 in terms of density units. This data indicates that the plant community is in a serious decline. Figure 17 illustrates that most of the loss of rooted aquatic plants has taken place in water 4 feet and deeper.

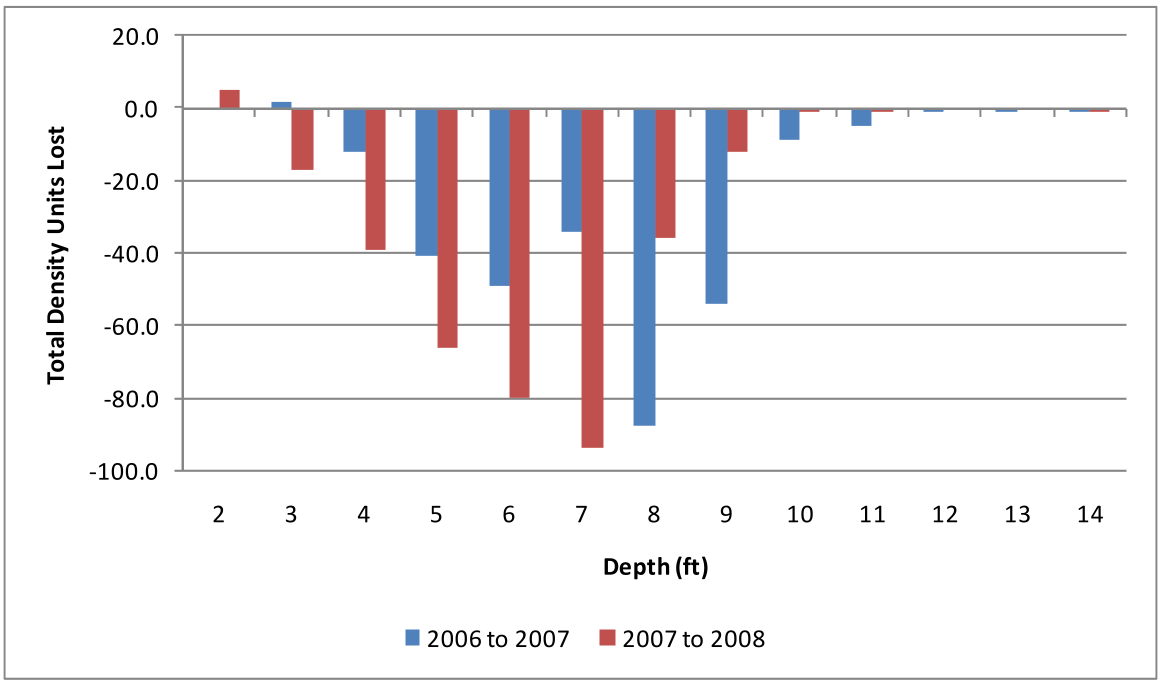


Figure 17
Total Density Change in Aquatic Plant Density by Depth for 2006 to 2008
(>0 Denotes Gain in Plant Density, <0 Denotes Loss in Plant Density, 0 = No Change)

Community Characteristics

Characteristics of the aquatic plant community can be used to compare Fox Lake to itself and to other lakes to asses change. The primary indicators of change used on Fox Lake are the Floristic Quality Index (FQI), the number of plant species collected, and the maximum rooting depth.

The quality of the aquatic plant community also appears to be in decline based on the FQI score. A number of native plant species found in prior years were not recorded in 2008 (species summaries will be included in the next section). The maximum rooting depth (MRD) fell to 10 feet in 2008 from 12-14 feet in the previous three years (Figure 18). This is likely a result of poor water clarity throughout the growing season (Figure 8). The total number of plant species found during the survey was consistent from 2004-2007 but declined in 2008.

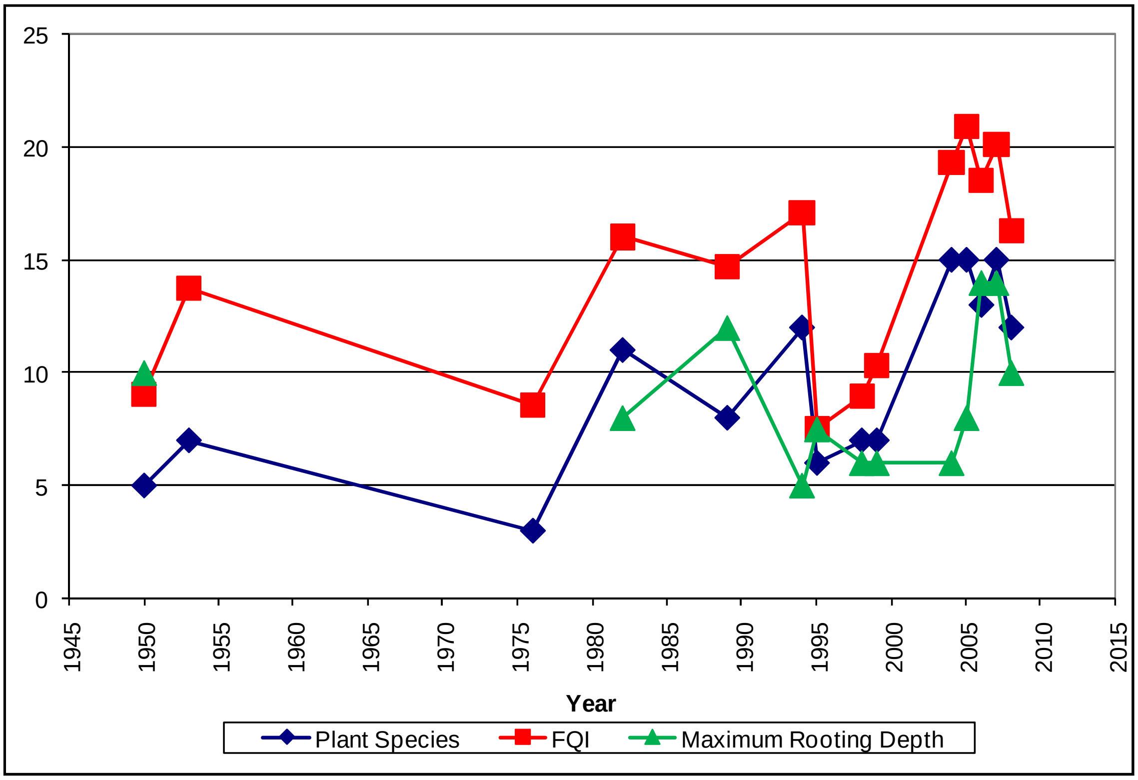


Figure 18
Lake-wide Aquatic Plant Community Trends

Fishery

Annual fall electrofishing surveys have been conducted from 2002-2007. Numbers were standardized by total effort in the form of time spent shocking. The total effort expended was approximately 2 hours per survey. The stations that were sampled included: 1) Inlet of Cambra Creek south, 2) North side of Chief Kuno Trail, 3) South side of Chief Kuno Trail, 4) South shore of the Jug to outlet, 5) Elmwood Island, 6) Green Bell tavern to Maple Point with approximately a 20-minute sampling run at each station.

Figure 19 illustrates the improvement of the fish community since 2000 with greatly increased numbers of walleye, bluegill, largemouth bass, and yellow perch. A second increase in overall fish abundance in 2005 coincides with the establishment of aquatic plants.

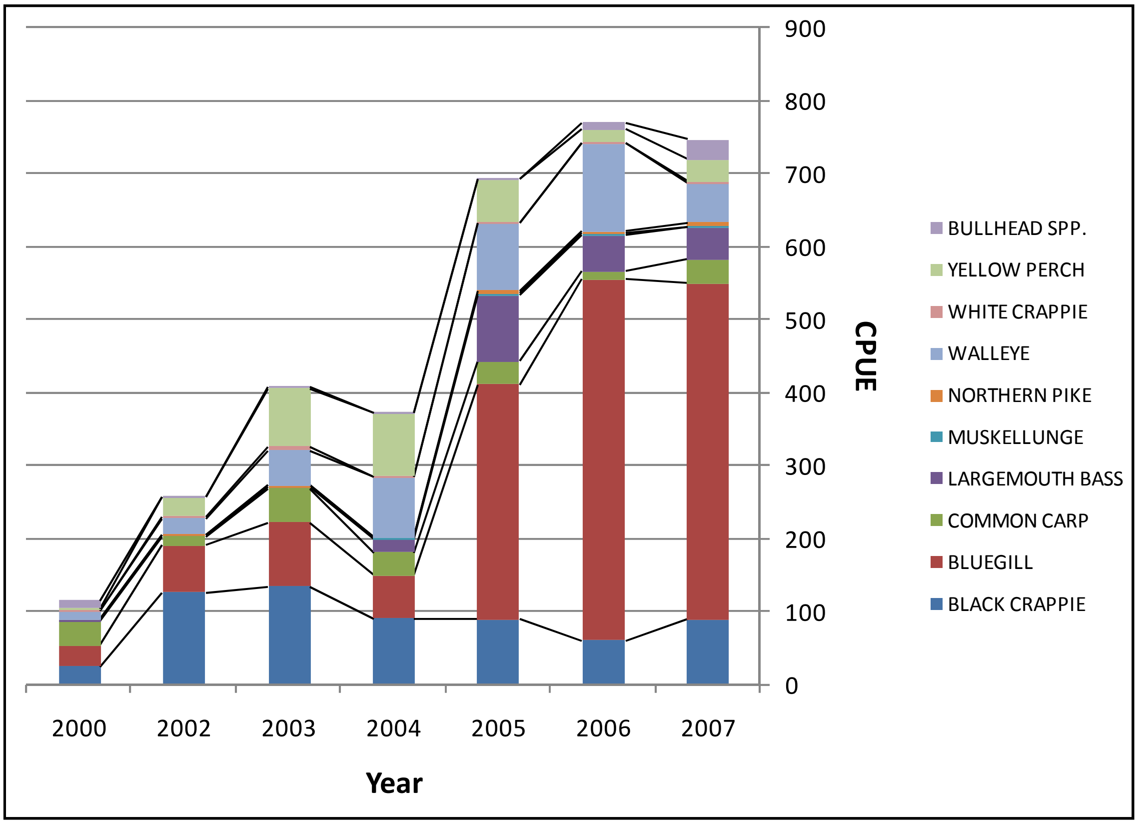


Figure 19
Improvement of the Fish Community Since 2000

Zooplankton

A comparison of the "clear-water" years of 1995 and 2005 reveal that both years exhibited high *Daphnia* abundance in the April and May period. In 1995, *Daphnia* abundance remained high through August but a similar trend was not seen in 2005 (Figure 20). However, in 2005 the vegetation-dwelling cladoceran, *Diaphanosoma*, became abundant during late August and September. It is possible that the increase in *Diaphanosoma* may be linked to the increase in the availability of macrophytes in Fox Lake. As such, the presence of another large-bodied filter feeder (i.e. *Diaphanosoma*) may have contributed to help maintain the clear-water state during the late summer period. This temporal substitution between pelagic-dwelling *Daphnia* and vegetation-dwelling *Diaphanosoma* could be a potential mechanism for maintaining the biological control of algal abundance under the eutrophic conditions in Fox Lake in late summer.

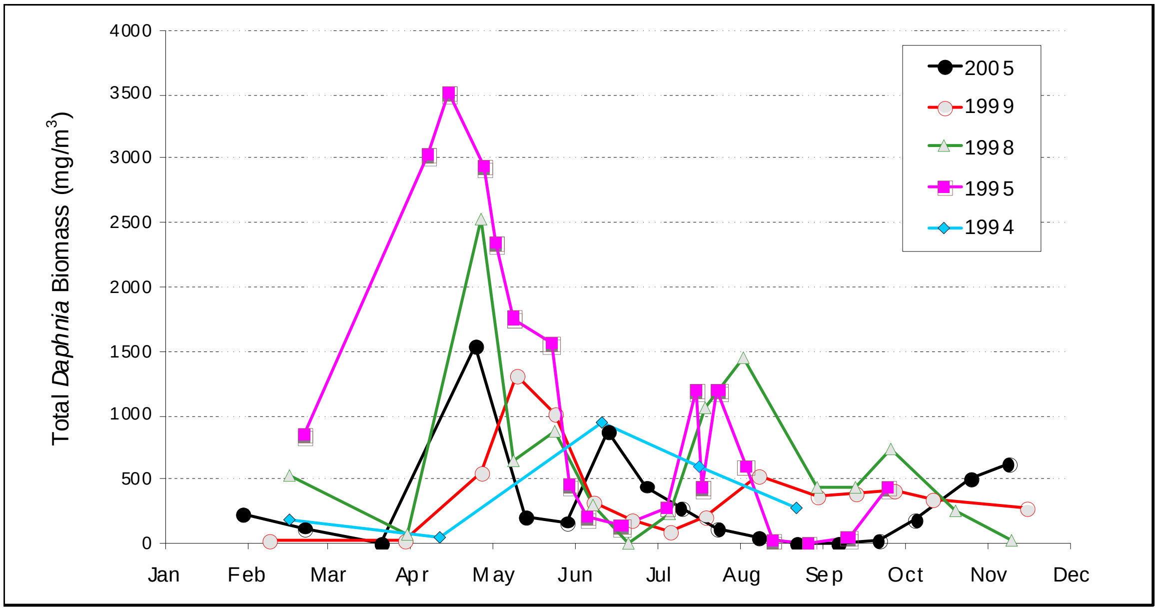


Figure 20

Seasonal Trends in the Biomass Density of Large-bodied Daphnia in Fox Lake Wisconsin between 1994 and 2005[33,34]

Wildlife

Fox Lake and Alto Creek have been classified as Areas of Special Natural Resource Interest (ASNRI) by the Wisconsin Department of Natural Resources. ASNRI waters or portions of waters are inhabited by any endangered, threatened, special concern species or unique ecological communities identified in the Natural Heritage Inventory (NHI). In the Fox Lake Area the NHI has identified the following important communities:

- Shrub-carr
- Southern sedge meadow
- Southern Dry-mesic Forest
- Southern Mesic Forest

Several wildlife species utilize the above habitats for reproduction, nurseries, and feeding. Several key species that inhabit the Fox Lake area include: ducks, herons, egrets and swans, a variety of song birds, reptiles such as frogs, salamanders and snakes, and typical upland animals of southern Wisconsin, including rabbit, fox, raccoon, squirrel and muskrat. The Government Marsh, along the eastern edge of the lake and Cambra Creek are heavily used by duck hunters in the fall of the year.

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[33] Asplund, T. and P. Garrison. 2002. The Effectiveness of the Partial Drawdown on Fox Lake, Dodge County, Wisconsin. Wisconsin DNR, Madison. [PUB-SS-963 2002].

[34] Hey and Associates, Inc. 2008. Fox Lake Management Strategy Evaluation Report and Recommendations for Future Action. Lake Protection Grant Technical Report # LPT-244.

Threatened and Endangered Species

As stated above, Fox Lake and Alto Creek have been classified as Areas of Special Natural Resource Interest (ASNRI) by the Wisconsin Department of Natural Resources. ASNRI waters or portions of waters are inhabited by any endangered, threatened, special concern species or unique ecological communities identified in the Natural Heritage Inventory (NHI). Endangered, threatened, special concern species in the Fox Lake area (T-13-N, R-13-E) include:

- Blanchard's Cricket Frog (frog) (endangered)
- Great Egret (bird) (threatened)
- Banded Killifish (fish) (concern species)
- Black-crowned Night-heron (bird) (concern species)

UNITS OF GOVERNMENT, INDUSTRIES, ORGANIZATIONS, AND OTHER PARTIES AFFECTED BY THE PROPOSED ACTION

Town of Fox Lake, City of Fox Lake, Fox Lake Inland Lake Protection and Rehabilitation District, local tourism, Fox Lake Homeowners Association, local residents, and lake users. The proposed action would likely enhance the local economy by attracting fishermen and other recreational enthusiasts to the Fox Lake area.

EXISTING DATA SOURCES

Existing sources of data on the water quality and ecological balance of Fox Lake include the following:

- Quarterly water quality monitoring by Wisconsin Department of Natural Resources (WDNR) Bureau of Research in 1970's.
- One year water quality monitoring by Aqua-Tech in 1982-83.
- Fox Lake: Water Quality and Management Study, by the Water Resource Management Workshop, University of Wisconsin - Madison (1984).
- WDNR Long Term Trend Program monitoring from 1986 to the present.
- Aquatic Macrophyte surveys by WDNR in 1986 and 1994, 1995, 1998.
- Aquatic Macrophyte surveys by Hey and Associates in 2004, 2005, 2006, 2007, and 2008.
- Various fishery surveys by WDNR, including a carp capture and recovery survey and two comprehensive fish surveys.
- Carp enclosure study (1993-94)

- A priority watershed inventory of barnyard runoff, and upland, streambank and lake shoreline erosion sources as part of the Beaver Dam River Priority Watershed Project.

- Inventory of shoreline erosion (R. A. Smith & Associates, Inc. 1993).

- Water quality appraisal report for the priority watershed project.

- Bottom sediment core sampling by WDNR Bureau of Research.

- Expanded Self-Help Monitoring by the Fox Lake Protection and Rehabilitation District.

- Evaluation of Alternative Stable States in Fox Lake, Dodge County, WI (WDNR, 1996)

- Exploration of the Use of Biomanipulation to Improve Water Quality in Fox Lake (WDNR, 1996).

- Fox Lake Management Strategy Evaluation Report and Recommendations for Future Action. Lake Protection Grant Technical Report # LPT-244. (University of Wisconsin-Milwaukee and Hey and Associates, Inc.

PROBABLE ENVIRONMENTAL IMPACTS

Beneficial Consequences

Physical Setting

The proposed action will likely result in improved in-lake habitat for fish, zooplankton, and wildlife improving the physical setting of Fox Lake. The proposed spring alum treatment would strip solids from the water column during turbid springs, allowing rooted aquatic plants to achieve a completive advantage. Once rooted plants are dominant, data from 2004 and 2005 indicate that biological interactions of plants, zooplankton and fish have the potential to keep the lake in a clear water state.

Water Quality and Water Clarity

Beneficial consequences to water quality and water clarity resulting from the proposed action would be removal of organic and inorganic solids and a temporary reduction in water column phosphorus. This would result in greatly enhanced water clarity and temporary removal of all planktonic algal biomass via floc settling. Short-term reduced chlorophyll-a levels would be the result of loss of water column nutrients.

Improved water clarity should result from the expansion of the aquatic plant community and reduced sediment resuspension. The relationship between May water clarity as measured by Secchi depth and aquatic plant frequency is shown in Figure 21. It shows that if the water clarity is improved in May to a depth of 8 feet, approximately 90% of the lake bottom would be expected to be covered by aquatic plants.

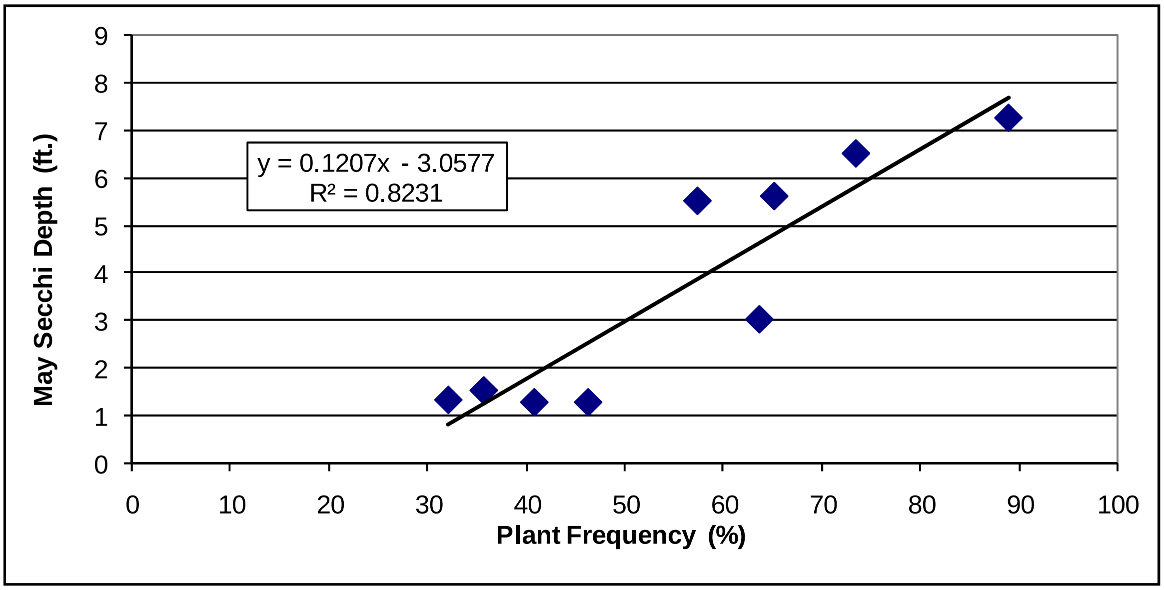

Figure 21
May Secchi depth versus Aquatic Plant Frequency for Fox Lake 1995-2008[35]

In shallow lakes, as the density of aquatic plants increases, increased total phosphorus levels do not result in increased algal biomass as indicated by chlorophyll-a (see Figure 22)[36]. Aquatic plants act to increase the shear stress required to move particles off the lake bottom by waves reducing the impacts of wind events and other disturbances[37,38,39]. Limiting suspended particles reduces turbidity and increases water clarity.

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[35] Hey and Associates, Inc. 2008. Fox Lake Management Strategy Evaluation Report and Recommendations for Future Action. Lake Protection Grant Technical Report # LPT-244.

[36] Bayley S. E., I. F. Creed, G. Z. Sass, and A. S. Wong. 2007.Frequent regime shifts in trophic states in shallow lakes on the Boreal Plain: Alternative "unstable" states?. Limnology and Oceanography, 52(5), 2002–2012.

[37] James, WF, J W Barko, and MG Butler. 2001. Shear stress and sediment resuspension in canopy- and meadow-forming submersed macrophyte communities. APCRP Technical Notes Collection (ERDC TN-APCRP-EA-03), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

[38] Dieter, C.D. 1990.The importance of emergent vegetation in reducing sediment resuspension in wetlands. Journal of Freshwater Ecology. 5:467-473.

[39] James, W.F. and J.W. Barko. 1994. Macrophyte Influences on Sediment Resuspension and Export in a Shallow Impoundment. Lake and Reservoir Management. 10(2):95-102.

Biological Community

Aquatic Plants

Promoting aquatic plant growth will enhance the existing biomanipulation because abundant aquatic vegetation in shallow lakes moderates the impacts of nutrients on algae production (Figure 22) and minimizes turbidity and internal nutrient loading[40]. These are essential components to manage Fox Lake because the large amount of internal nutrient loading is likely due to physical and biological sources such as wind and common carp.

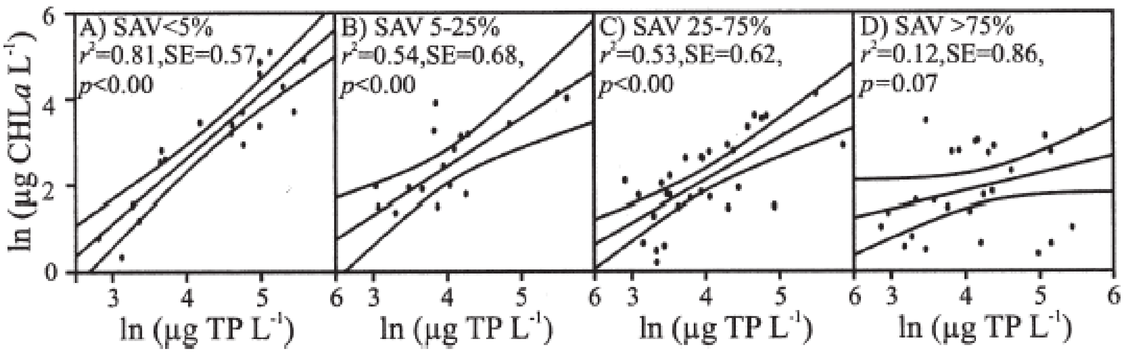

Figure 22
Effects of Submergent Aquatic Vegetation (SAV) Cover on the Relationship between Total Phosphorus (ug/l) and Chlorophyll-a (ug/l) in Alberta's Shallow Lakes[41]

The primary purpose of the proposed action is to promote aquatic plant frequency and density in Fox Lake. There is a strong positive correlation between May water clarity[42] and the frequency of aquatic plants in Fox Lake (Figure 21). This model illustrates the importance of the spring clear water phase in the establishment of aquatic plants. A greatly increased biomass of *Ceratophyllum* and especially *Elodea canadensis* was reported post-alum treatment on Wapato Lake, WA[43]. Elodea increased four-fold in biomass from minimal coverage to 70-90% from pre- to post-alum addition. Elodea was one of the plants to show the greatest increase in density and distribution during the clear water years on Fox Lake and would be likely to have a similar response to an alum treatment. Although the 2008 distribution of Elodea was severely limited, populations persist in both the lake and in Drew Creek and Alto Creek[44].

Over the range of nutrient concentration and turbidity where alternate stable states occur, the vegetation dominated state can only be reached if the initial aquatic plant biomass is high

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[40] James, WF, J W Barko, and MG Butler. 2001. Shear stress and sediment resuspension in canopy- and meadow-forming submersed macrophyte communities. APCRP Technical Notes Collection (ERDC TN-APCRP-EA-03), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

[41] Bayley S. E., I. F. Creed, G. Z. Sass, and A. S. Wong. 2007. Frequent regime shifts in trophic states in shallow lakes on the Boreal Plain: Alternative "unstable" states?. Limnol. Oceanogr., 52(5), 2002–2012.

[42] May Secchi depth is used in the analysis because the historic record lacks consistent data for prior months.

[43] Welch EB and GD Cooke. 1999. Effectiveness and longevity of phosphorus inactivation with alum. Journal of Lake and Reservoir Management 15(1):5-27.

[44] Hey and Associates, Inc. 2008. Unpublished field data.

enough. In many lakes this will apply to the amount of biomass invested in overwintering structures such as seeds, spores, rhizomes, or tubers required to allow for a successful return of non-wintergreen aquatic vegetation[45]. In the case of Fox Lake, this applies largely to Eurasian water-milfoil and Coontail being coupled to the abiotic conditions leading to spring water clarity sufficient to allow the overwintered, propagating root crowns to initiate growth prior to the establishment of algal or sediment induced turbidity[46]. When the biomass of overwintering structures or the water clarity falls below a critical threshold value, the resulting spring vegetation will be too sparse to clear up the water sufficiently to prevent transition to the turbid water state as summer progresses[47].

Fishery

Changes in the fishery were previously noted, especially the increase in key species post-establishment of widespread aquatic vegetation in 2005. Assuming the low dose aluminum sulfate creates the desired effect of promoting aquatic vegetation, there will likely be a response of the fish community similar to the initial vegetation response in 2005 with large year classes of bluegill and largemouth bass.

While fall electrofishing is not the ideal means to assess northern pike populations, a numeric increase from 1.0 CPUE in 2002 to 5.5 CPUE in 2007 indicates at least some improvement. The increases in largemouth bass from 2.0 CPUE to 44.0 CPUE over the same time period is also significant. Each improvement is coincident with the reestablishment of aquatic vegetation likely due to the dependence on littoral vegetation for spawning and enhanced survival of juveniles due to food availability and habitat. Both species are predators of YOY common carp providing a limit to overall carp abundance and filling an essential role in the long-term success of the biomanipulation.

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[45] Ecology of Shallow Lakes. M. Scheffer (1998) ISBN 0-412-74920-3

[46] Smith, C. S., and J. W. Barko. 1990. Ecology of Eurasian watermilfoil. *Journal of Aquatic Plant Management* 28: 55-64; Van Driesche, R., et al., 2002, Biological Control of Invasive Plants in the Eastern United States, USDA Forest Service Publication FHTET-2002-04; Madsen, J.D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies. J. Aquatic Plant Management 29:94-99.

[47] Ecology of Shallow Lakes. M. Scheffer (1998) ISBN 0-412-74920-3

Figure 23 illustrates the impact of piscivorous fish on carp populations.

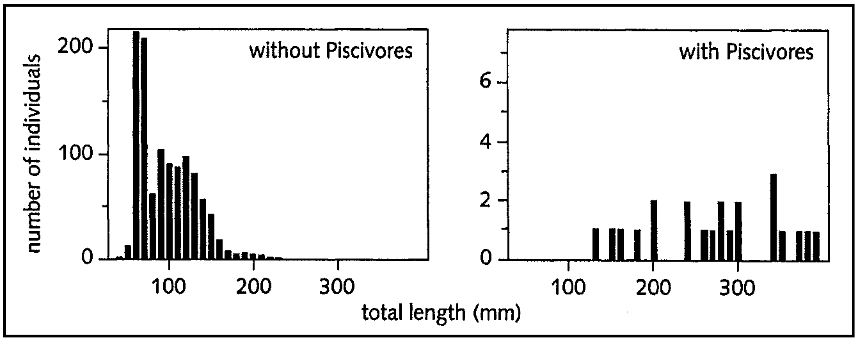

Figure 23
Effect of Piscivorous Fish on Carp Population Structure[48]

The impact on the fishery will be improved bluegill and largemouth bass populations and increased predation on common carp. Carp reduce macrophyte biomass in three ways. Bioturbation is the uprooting of aquatic macrophytes when feeding; direct consumption is feeding on tubers and young shoots; and, indirectly, by increasing turbidity which in turn limits the available sunlight[49,50]. Carp have been shown to decrease water quality by increasing turbidity and increasing the amount of nutrients in the water column through bioturbation[51,52]. Carp also act as "nutrient pumps" when they consume the nutrient rich benthic sediments and then excrete those nutrients back into the water column in a form that is available to other organisms[53]. Carp may also facilitate sediment resuspension by their mode of feeding. In this case they create small holes along the lake bottom allowing relatively low wind energy to overcome natural sediment erosion resistance (Figure 24).

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[52] Lyche A, BA Faafeng, and Å Brabrand. 1990. Predictability and possible mechanisms of plankton response to reduction of planktivorous fish. Hydrobiologia. Volume 200-201, Number 1, pp 251-261.

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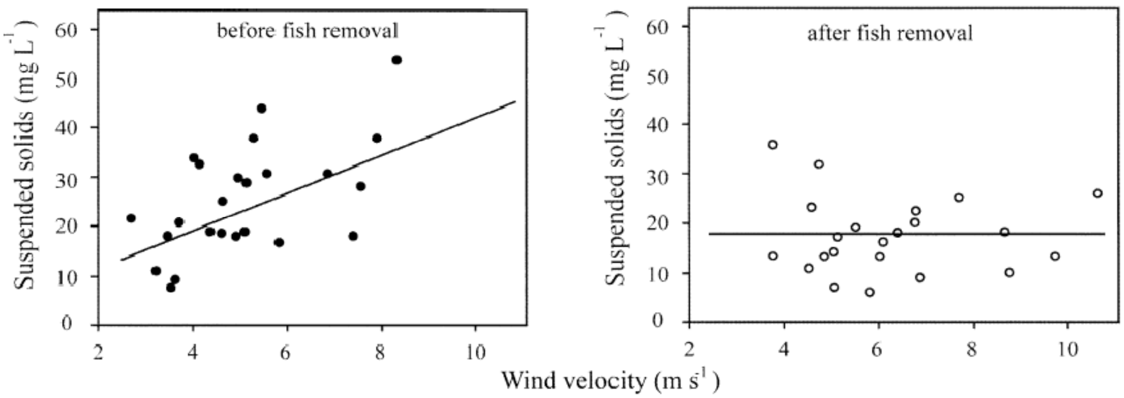

Figure 24
Impacts of Benthivorous (Bottom Feeding) Fish on Total Suspended Solids[54]

Zooplankton

Daphnia are large bodied Cladocerans that consume large amounts of algal biomass often resulting in higher than expected water clarity. They are indirectly managed in biomanipulation projects in shallow lakes by 1) increasing top-down predation on planktivorous fish thus reducing zooplankton predation via a trophic cascade and 2) promoting aquatic plant growth to provide daytime refugia, a phenomenon known as "diel horizontal migration[55]", from planktivorous fish. Promoting aquatic plant growth would provide additional refugia opportunities for *Daphia* and likely increase their persistence in Fox Lake if plant beds of sufficient size were established. Research suggests that plant beds in excess of 1000 ft^2 provide the greatest benefit to zooplanktons[56]. This pattern has been established in previous studies on Fox Lake where clear-water years with abundant aquatic plants exhibit increased zooplankton densities through much of the summer months.

Wildlife

Promoting aquatic plants and an improved fishery will benefit herbivorous and predatory waterfowl.

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[54] Scheffer Ma, R Portielje, and L Zambrano. 2003. Fish facilitate wave resuspension of sediment Limnol. Oceanogr., 48(5) 1920–1926.

[55] Burks, R. L., D. M. Lodge, E. Jeppesen, and T. L. Lauridsen. 2002. Diel horizontal migration of zooplankton: costs and benefits of inhabiting the littoral. Freshwater Biology 47, 343–365.

[56] Torben Lauridsen, Leif Junge Pedersen, Erik Jeppesen and Martin Sønergaard 1996 The importance of macrophyte bed size for cladoceran composition and horizontal migration in a shallow lake JOURNAL OF PLANKTON RESEARCH VOLUME 18 NUMBER 12 PAGES 2283-2294.

Threatened and Endangered Species

In the Fox Lake area there in one identified endangered and one threatened species[57]:

- Blanchard's Cricket Frog (frog) (endangered)
- Great Egret (bird) (threatened)

Both species benefit during periods of abundant rooted aquatic plants which help provide habitat for aquatic insects and fish which provide food for these organisms.

Adverse Consequences

Physical Setting

No adverse consequences on the physical setting of Fox Lake are anticipated due to a low dose alum treatment. In-lake habitat will be much improved if the treatment is effective at promoting aquatic plants.

Water Quality and Water Clarity

A potential adverse effect on the water quality of Fox Lake would be an unusually large wind event to follow the alum application. This would temporarily resuspend the floc and limit light penetration. Some re-suspended floc could build up on windward shorelines. Re-suspended floc would settle to the lake bottom after a wind event due to its specific gravity which is heavier than water.

Fox Lake is a well buffered, high pH, hardwater lake. Annual pH values range from 7.0 to 9.0. There are no anticipated problems associated with acidification anticipated from the action. Lakes with alkalinity ranging from 0-50 mg/l may experience acidification and require buffer addition. Alkalinity for lakes in the southern portion of Wisconsin generally exceeds 90 mg/l[58].

Biological Community

In general the chemical effects of high dose alum treatments are short-lived on the biological community. Toxicity of free Al is limited to less than an hour in most cases because of the rapid binding of alum to both phosphorus and dissolved organic matter. Floc formation is also rapid in most cases with settling taking approximately one hour to reach the lake bottom. In the case of Fox Lake with a high pH, the acidic conditions required for persistent Al exposure are nonexistent. While continuous exposure experiments under controlled conditions are useful to determine worst case scenarios, they do not provide a realistic test of the impacts of alum under field conditions.

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[57] Wisconsin Natural Heritage Inventory

[58] Lillie RA and JW Mason. 1983. Limnological characteristics of Wisconsin lakes. Technical Bulletin No. 138. Wisconsin Department of Natural Resources.

Aquatic Plants

No reports of adverse impacts on aquatic plants due to alum treatments were found. Dense aquatic plant growth was found to inhibit alum effectiveness in some cases[59].

Fishery

There have been no reported issues related to Al toxicity associated with alum treatments in well buffered lakes with pH >6.5. Fish may escape the local effects of an alum application due to the nature of the treatment method. Because alum treatments take a number of days to complete and the free alum is only in the water for a few hours, fish are generally able to avoid exposure.

Zooplankton

Field studies on the effects of alum treatments on zooplankton have shown a temporary reduction in abundance and diversity, but recovery is generally rapid and complete[60,61].

Threatened and Endangered Species

In the Fox Lake area there in one identified endangered and one threatened species[62]:

- Blanchard's Cricket Frog (frog) (endangered)
- Great Egret (bird) (threatened)

Years of research and use of alum in drinking water treatment has demonstrated that aluminum sulfate is non toxic when used in the method proposed.

Risk or Uncertainty

There is no risk to the aquatic community or human health posed by a low dose alum treatment.

A measure of uncertainty as to the longevity of the treatment exists. A strong, prolonged wind event post-treatment may resuspend floc from the lake bottom. This would temporarily reduce water clarity until the floc re-settled to the lake bottom.

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[59] Welch EB and GD Cooke. 1999. Effectiveness and longevity of phosphorus inactivation with alum. Journal of Lake and Reservoir Management 15(1):5-27.

[60] Shumaker RJ, WH Funk, and BC Moore. 1993. Zooplankton response to aluminum sulfate treatment of Newman Lake, Washington. Journal of Freshwater Ecology 8:375-387.

[61] Gibbons MV, FD Woodwick, and HL Gibbons. 1984. Effects of a multi-phase restoration, particularly aluminum sulfate application, on the zooplankton community of a eutrophic lake in eastern Washington. Journal of Freshwater Ecology 2:393-404.

[62] Wisconsin Natural Heritage Inventory

Alternatives to Proposed Action

No Action

Taking no action would eventually result in Fox Lake reverting to the turbid water state. Based on Secchi depths, Fox Lake may already have shifted to the turbid water state in 2008. Fox Lake is an altered ecosystem due to the construction of the dam on Mill Creek, widespread agriculture in the watershed, the addition of exotic species, and groundwater contamination. Occasional management actions are required to maintain Fox Lake in a desirable condition.

Water Level Management

Water levels on Fox Lake have been an issue of great deal of past discussion. Through the 1980's and early 1990's the City and Town of Fox Lake, who own the outlet dam, operated the lake above state mandated levels to improve navigation in shallow areas. Many believe that high water levels during this period contributed to degradation of the marsh fringe around the lake. Since 1995 the water level on Fox Lake has been managed according to the Public Service Commission order of 889.25 feet above sea level in fall and winter and 889.75 during spring and summer. Figure 25 shows that sufficient aquatic plant growth can occurs in Fox Lake as spring water levels are kept at the current levels.

One option hat has been proposed to deal with the loss of rooted aquatic plants in water deeper than 4 feet is to lower the lake in the spring of the year to allow light to penetrate to these deeper regions. A drawdown of one to two feet has been proposed. While this option would bring light to deeper areas of the lake, it would also expose nearshore macrophyte beds which are the remaining refuge of aquatic plants on the lake (Figure 12). Research indicates that lake level drawdown has a negative effect on Coontail and Eurasian water-milfoil, the dominant aquatic plant species in Fox Lake[63]. A WNDR project using water level drawdown as a management tool on Fox Lake in 1996 was unsuccessful at promoting submergent aquatic plant growth[64]. Following the drawdown in 1996 Fox Lake saw a significant increase in water column phosphorus levels as exposed sediment were oxidized by exposure to the air[65]. While a spring drawdown on Fox Lake could have a significant impact on riparian emergent vegetation (wetlands) it is likely this drawdown would do more damage to the existing submerged plant community in shallow areas than it will benefit deeper water plants.

Many of the lake residents on Fox Lake do not have sufficient water depth to navigate to the deeper parts of the lake at their current levels making this a socially unacceptable management tool.

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[63] Cooke GD, EB Welch, SA Peterson, and SA Nichols. 2005. Restoration and Management of Lakes and Reservoirs 3rd ed. CRC Press. Boca Raton, FL.

[64] Asplund, T. and P. Garrison. 2002. The Effectiveness of the Partial Drawdown on Fox Lake, Dodge County, Wisconsin. Wisconsin DNR, Madison. [PUB-SS-963 2002].

[65] University of Wisconsin-Milwaukee and Hey and Associates, Inc. 2008. Fox Lake Management Strategy Evaluation Report and Recommendations for Future Action. Lake Protection Grant Technical Report # LPT-244

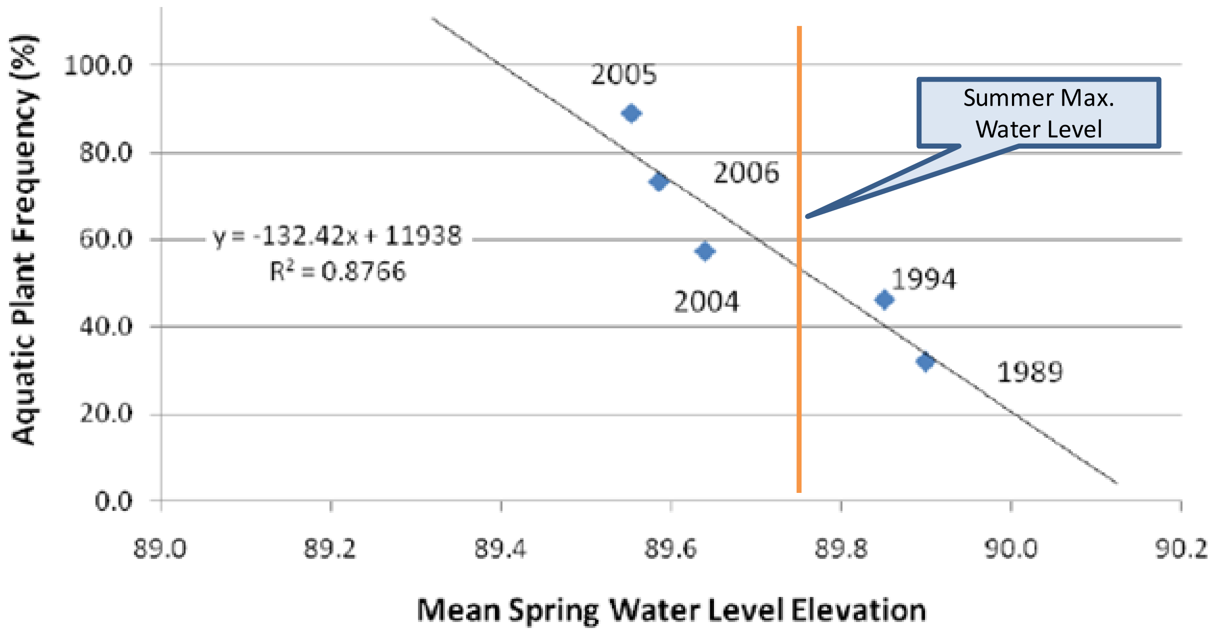

Figure 25
Mean Spring Water Level versus Aquatic Plant Frequency

Watershed Management

Watershed management is a long-term goal for Fox Lake. Many nonpoint source pollution abatement practices have been installed in the lake's watershed as part of the Beaver Dam River Priority Watershed Project, including shoreline protection, stream buffers, wetland restoration, barn yard runoff management systems, and conservation tillage. Today several projects are currently underway to identify the remaining nutrient sources in the watershed for future management. Research has shown first that biomanipulation projects success depends on nutrient (total phosphorus) values beneath the 100 ug/l level which are not currently being met on Fox Lake. Other research has shown that the effects of watershed nutrient abatement are not realized immediately and it may take many years for a lake to naturally shift to a stable clear water state[66]. Prior studies have estimated that the majority of the nutrient loading in Fox Lake is due to internal sources suggesting that external nutrient management in the watershed will not produce short term improvements in Fox Lake.

Fishery Management

Fishery management is ongoing on Fox Lake. Figure 26 shows the history of carp removal on Fox Lake. Local angling groups and the WDNR also have stocked the lake in the past routinely and as part of the biomanipulation project. Recent commercial harvesting has been minimal due to poor fishing success and resale market conditions. Fishery management is a key component of the current biomanipulation project and needs to be continued.

[66] Scheffer M. 1998. Ecology of Shallow Lakes. Kluwer Academic Publishers. The Netherlands.

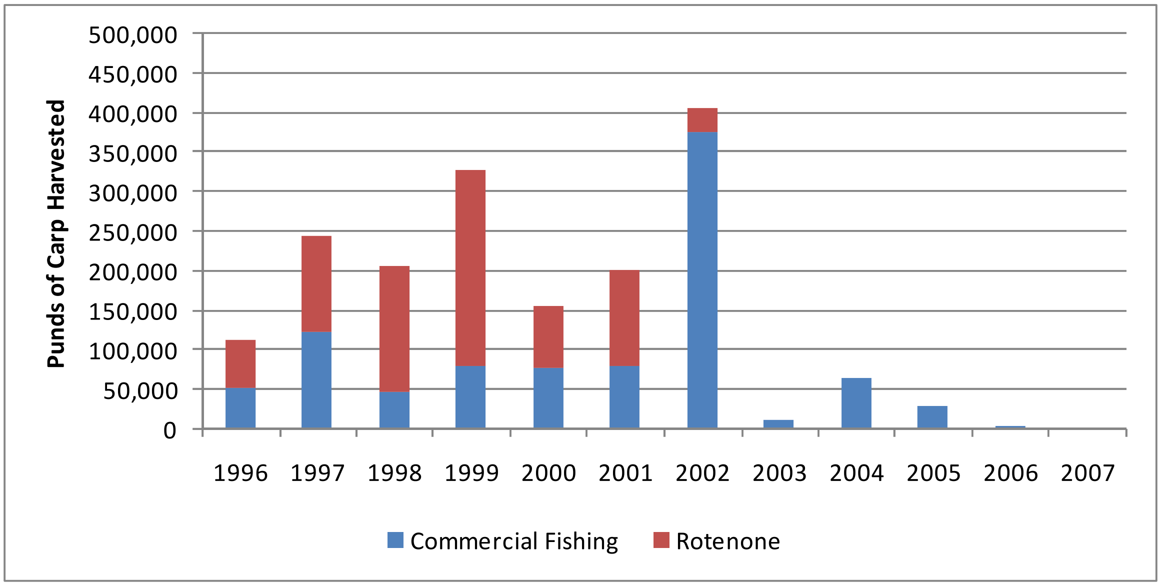

Figure 26
Carp removal on Fox Lake 1996-2007

Significance of Precedent

Because of the unique ecological circumstances and large amount of supporting data used in the decision making process, this action sets very limited precedence. Most lakes will not meet the physical criteria or the data standards applied to Fox Lake--notably 1) a near 3000-acre shallow lake, 2) an existing biomanipulation project , 3) abundant data including aquatic plant surveys and water clarity data extending into the late 1980's, 4) local support for the action, and 5) a diverse history of intense carp management.

Significance of Controversy over Environmental Effect

The low dose alum treatment is supported by the local lake district. An aquatic plant management plan is currently in place for Fox Lake to manage an over abundance of aquatic plant growth.

PUBLIC INVOLVEMENT

The proposed action has been discussed at several public meetings and voted into the 2009 budget of the FLILP&RD by majority vote at the August 2, 2008 annual meeting.

RECOMMENDED ACTIONS

The recommended action is to conduct a low dose alum treatment in the spring of 2009 as a maintenance measure in support of the existing biomanipulation. Data suggests 1) that Fox Lake existed in the turbid water state in 2008 (Appendix A) and 2) that this action will increase aquatic plant growth by enhancing water clarity resulting in a trophic cascade. The trophic cascade will in turn reduce sediment resuspension thereby reducing turbidity and internal nutrient recycling, provide competition with algae for light and nutrients via aquatic plants and their attached periphyton, provide refugia for zooplankton enhancing their ability to filter water and provide a food source for small fish, provide habitat favorable for predatory fish reproduction and feeding, and reduce the number of and impacts of the resident carp population.

APPENDIX A

CLASSIFICATION METHODS AND CONFIRMATORY TESTS FOR CLEAR VERSUS TURBID WATER YEARS

STATISTICAL METHODS TO DETERMINE CLEAR VERSUS TURBID YEARS

A summary of all available Secchi depth data was compiled for 1989-2008. Data for May, June, July, and August was compiled as monthly averages by year. The monthly averages for each year were classified using the hierarchical clustering technique included in SYSTAT v10.2. The linkage selection for clustering was “linkage” and the distance selection was “Euclidean”. The results are shown in Figure A-1 where two groups are clearly identified in black and red. The “black” group represents the clear water years versus the “red” group which represents the turbid water years.

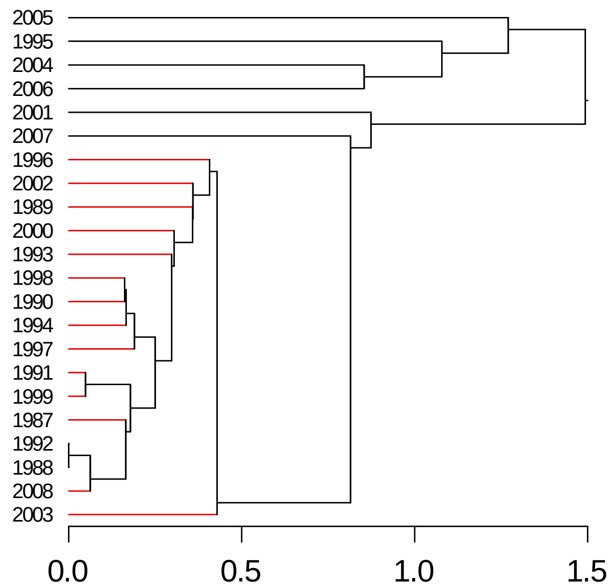

Figure A-1

Hierarchical Clustering Dendogram for Fox Lake Secchi Depth Data 1998-2008

Figure A-2 shows the same Secchi depth data summarized as box plots separated by clear versus turbid water years on a monthly basis. The distribution of the box plots clearly shows a dramatic difference in water clarity. The data was further analyzed using a Kruskal-Wallis rank-sum analysis of variance. Each month a statistically significant ($p<0.05$) difference was found in the Secchi depth values comparing the clear versus turbid state (Table A-1).

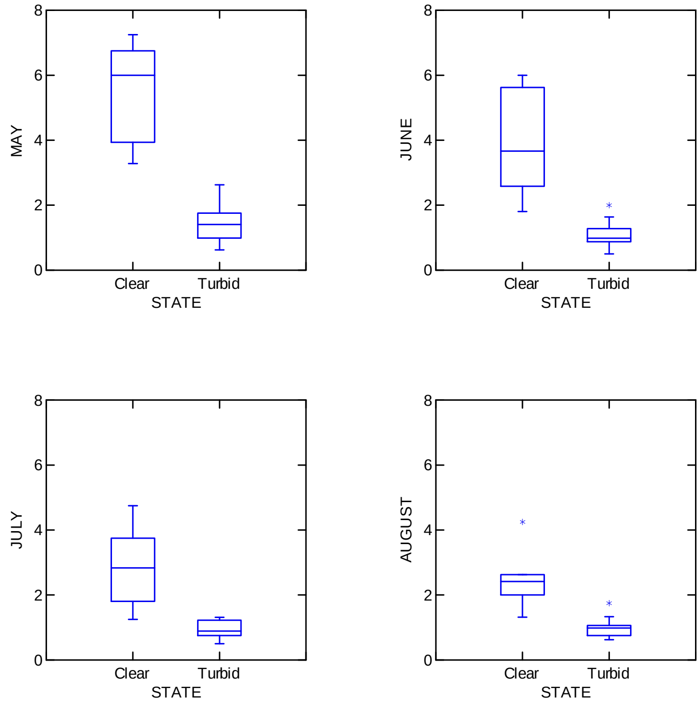

Figure A-2

Boxplots of Monthly Secchi depth Data for Fox Lake 1987-2008

Table A-1

Significance of Kruskal-Wallis Test Results of Monthly Secchi depth Data for Fox Lake 1987-2008
(p-value <0.05 indicates difference between clear and turbid water state)

Month	May	June	July	August
cases	22	21	20	17
p-value	0.000	0.001	0.001	0.002