Hey and Associates, Inc.

FOX LAKE MANAGEMENT STRATEGY EVALUATION REPORT AND RECOMMENDATIONS FOR FUTURE ACTION - 2008

Prepared for:

Fox Lake Inland Lake Protection and Rehabilitation District

and

Wisconsin Department of Natural Resources

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Appendix A

Fox Lake Evaluation Report: Fox Lake Alternate Stable States Model and the Roles of Lake Level, Wind, and Precipitation on Lake Ecology

CHAPTER 1: INTRODUCTION

BACKGROUND

Fox Lake is a 1,022-hectare (2,625-acre) lake located in northwestern Dodge County. In the 1980's and 1990's, Fox Lake experienced a rapid shift in water quality from a clear-water lake to one characterized by poor-water transparency, increased algae populations, loss of aquatic macrophytes, loss of wetland fringe, and declining sports fishery. In the mid 1990's, the Fox Lake Inland Lake Protection and Rehabilitation District (FLILPRD), in partnership with the Wisconsin Department of Natural Resources (WDNR) began implementation of a long-range management project to shift the lake back into a clear-water state. In 1995 a long-range management strategy for Fox Lake was developed by an advisory committee that included FLILPRD, WDNR, Dodge County, University of Wisconsin-Extension, Town of Fox Lake, City of Fox Lake, and civic and sportsman groups. The project management strategy is outlined in a report tilted, *Long Range Planning Strategy for the Rehabilitation of Fox Lake, Dodge County* (R. A. Smith and Associates, Inc. 1998). This report is intended to be an amendment to the 1998 management plan and guide the Fox lake community in the maintenance of the restoration measures achieved as part of the last decade of management.

To deal with the complex water quality problems at Fox Lake, the planning and rehabilitation process was broken down into the following components:

1. Watershed management to reduce sediment and nutrient inputs
2. Shoreline stabilization to reduce erosion
3. Aquatic plant management to restore rooted aquatic vegetation
4. Fishery Management (bio-manipulation to reduce rough fish and increase top predators)
5. Lake use management to protect sensitive areas
6. Public education

Project implementation began in 1996 with an attempted partial drawdown of the lake. Due to wetter than normal rainfall conditions, the drawdown was not successful. From 1996 through the present the WDNR has aggressively stocked the lake with top fish predators including northern pike and walleye. Rough fish removal using rotenone and commercial harvesting were conducted. Watershed management actives were implemented both in the watershed and shoreline of the lake.

In 2003, at a joint meeting of the FLILPRD and WDNR, questions were raised if the management strategy for the lake developed in 1995 was working and whether or not a new strategy was needed. Before embarking on a new management strategy, it was decided that a detailed evaluation of the existing project was needed first. It was recommended that a third party be brought in to provide an impartial evaluation of the 1995 management strategy and provide a status report on the current lake condition regarding water quality and biological community structure. The University of Wisconsin-Milwaukee Department of Biological Sciences was hired to conduct the evaluation in partnership with Hey and Associates, Inc. and the WDNR Bureau of Fishery. The evaluation includes the following components:

1. Assessment of the current fishery
2. Evaluation of aquatic plant communities
3. Status of zooplankton populations
4. Appraisal of water quality at both deep and shallow water sites on the lake
5. Measurement of sediment and nutrient inputs to the lake

The results of the project are an evaluation of the current management efforts and development of a management strategy for the next phases of the project. The project is funded in part by a grant from the WDNR Lake Protection Grant Program.

REFERENCES:

R. A. Smith and Associates, Inc. (1998). *Long Range Planning Strategy for the Rehabilitation of Fox Lake, Dodge County,* Brookfield, WI

CHAPTER 2: PROJECT GOALS AND OBJECTIVES AND SUMMARY OF PAST MANAGEMENT

PROJECT GOALS AND OBJECTIVES

Fox Lake is a 1,022-hectare (2,625-acre) lake located in northwestern Dodge County. In the 1980's and 1990's, Fox Lake experienced a rapid shift in water quality from a clear-water lake to one characterized by poor-water transparency, increased algae populations, loss of aquatic macrophytes, loss of wetland fringe, and declining sports fishery. In the mid 1990's, the Fox Lake Inland Lake Protection and Rehabilitation District (FLILPRD), in partnership with the Wisconsin Department of Natural Resources (WDNR), began implementation of a long-range management project to shift the lake back into a clear-water state.

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> ***Restore and protect the fishery, wildlife and recreational values of Fox Lake by implementing a sustainable, ecologically-based management plan that promotes increased water clarity, aquatic plant diversity and lake stability.***

To achieve the above goal, the following objectives were established:

1. Halt the degradation of the lake through the control of nonpoint source pollution.
2. Protect and enhance environmentally sensitive areas such as wetlands.
3. Reduce in-lake phosphorus concentrations to pre-1950 levels.
4. Reduce the occurrence of nuisance algae blooms.
5. Reestablish the aquatic macrophyte community.
6. Restore lost wetland areas.
7. Rehabilitate the degraded sports fishery.
8. Remove sediment deposits from in front of the Town Park, lake inlet and lake outlet.
9. Maintain and improve the economic base of the area through enhancement of recreational opportunities.
10. Develop a management plan for lake level management.
11. Control boating activities in environmentally sensitive areas.

Past Management Activities

Since 1995 several projects have been implemented to achieve the objectives on page 2-1. Management activities for the project can be broken down into the following categories:

- Fishery Management
- Watershed Management
- Shoreline Erosion Control
- Management of Lake Use
- Water level Management

Fishery Management Project

In 1995 the fishery of Fox Lake was dominated by rough fish. To re-establish a balanced fishery, the lake management project advisory committee proposed an effort to remove carp by using a combination of commercial fishing and spot chemical eradication treatments. The program was funded through a Lake Protection grant from WDNR and local funds from the Fox Lake Inland Lake Protection and Rehabilitation District. The carp control program began in 1996 and is underway today.

Adult carp removal by spot chemical treatments was conducted with the fish toxicant rotenone. The technique employed block nets (long seines) to trap spawning carp. After the seine enclosed the carp, rotenone was applied to the enclosed area. Treatment sites were typically located in shallow marshy areas with depth of 0 to 4 feet and took place in late May or early June. It is anticipated that repeated treatments for several years would knock back the carp population and allow the game and panfish population to rebound. In addition to spot chemical treatments, commercial fisherman were contracted to remove carp. The amount of rough fish removed by rotenone treatments and commercial harvesting between 1996 and 2007 are summarized in Table 2-1.

Table 2-1
Rough Fish Removed (lbs. of carp) From Fox Lake from 1996 through 2007

Year	Commercial Fishing	Rotenone Spot Treatments	Total
1996	54,000	59,688	113,688
1997	124,880	120,000	244,880
1998	49,155	159,000	208,155
1999	80,520	248,000	328,520
2000	77,700	80,000	157,700
2001	81,800	121,000	202,800
2002	375,954	30,000	405,954
2003	13,670	0	13,670
2004	66,100	0	66,100
2005	29,560	0	29,560
2006	6,080	0	6,080
2007	2,880	0	2,880
Totals	962,299	817,688	1,779,987

Northern Pike fry and walleye fingerling stocking took place to increase the predator population in the lake. Stocking was repeated every year during the project. Northern Pike fry and walleye fingerling were stocked at approximately 1,000 fry per acre and 50 fingerlings per acre, respectively. Efforts were being made to shift the panfish dominance from crappie to bluegill and yellow perch to encourage more predation on young-of-the-year carp.

In addition to the carp control program and gamefish stocking, WDNR established more stringent bag limits for northern pike, walleye, and largemouth bass. The new limits are established to allow more adults to reach spawning age. The new bag limits are as follows:

Northern Pike	32-inch length limit, bag limit 1
Walleye	20-inch length limit, bag limit 1
Largemouth Bass	18-inch length limit, bag limit 1

To document the effectiveness of the above fishery management program, the WDNR conducted annual fishery surveys and comprehensive fish surveys in 1995 and 2001.

Watershed Management

Watershed management activities included the following projects:

- Installation of barnyard runoff management practices
- Implementation of conservation tillage practices
- Installation of four weir structures to enhance wetland filtering of sediment
- Purchase of agricultural fields for conversion to wildlife and fish habitat areas
- Installation of sedimentation basins
- Installation of wildlife habitat restoration projects

Shoreline Stabilization Projects

The FLILPRD received a grant under the Beaver Dam River Priority Watershed Project for $200,000 to install shoreline protection on Fox Lake. Under the grant, 72 landowners receive cost share funds to cover up to 70% of the cost of installing shoreline protection. At total of $346,261 was invested in shore protection. Eligible landowners were identified during an inventory conducted in the summer of 1993. Implementation of this program resulted in a 1,380-ton reduction in sediment input to Fox Lake on an annual basis.

Management of Lake Use

Lake use management projects on Fox Lake fell into two categories: improved lake access, and protection of environmentally sensitive areas. To improve lake access from the Town of Fox Lake Park, a dredging project was conducted in the summer of 1998. A navigational channel 50 feet wide, 5 feet deep and 1,023 feet long was constructed. The details of the dredging project are outlined in a report titled, *Recreational Boating Facilities Program Study Report for the Town of Fox Lake Boat Launch* (R. A. Smith & Associates, Inc. and Aron & Associates, 1997).

To protect environmentally-sensitive areas on Fox Lake, the Town and City of Fox Lake has revised its boating ordinance. Under the new ordinance, several areas on the east end of the lake were zoned as no-wake zones to protect rooted aquatic plants.

Water Level Management

For several decades the Town and City of Fox Lake, who own the outlet dam, were operating the lake level above the state-established maximum level. It was determined that these higher than normal lake levels were having an adverse affect on aquatic vegetation, especially riparian wetlands. As part of the lake management project, operation of the dam was returned to authorized ranges with a summer normal level of 89.75 feet, winter level of 89.25 feet, and a maximum of 90.50 feet. Alternate summer and winter water level requiems have been discussed; however, no consensus has been reached to date. The limited available data ranging from 1985 to 2005 indicates that lake levels have been managed within the desired limits since at least 2002. Data is not available from 1996-2000.

REFERENCES:

R. A. Smith & Associates, Inc. and Aron & Associates (1997). *Recreational Boating Facilities Program Study Report for the Town of Fox Lake Boat Launch, Brookfield, WI.*

R. A. Smith and Associates, Inc. (1998). *Long Range Planning Strategy for the Rehabilitation of Fox Lake, Dodge County,* Brookfield, WI

CHAPTER 3: PHYSICAL DESCRIPTION OF THE LAKE

HISTORY OF THE LAKE

Fox Lake is a 1,022-hectare (2,625-acre) lake. The lake is located within the municipal boundaries of the Town of Fox Lake and City of Fox Lake. While a natural glacial lake, Fox Lake was enlarged in 1845 by the construction of a dam and saw mill on the lake outlet, known as Mill Creek. The construction of the dam artificially raised the lake elevation approximately 11 feet and created several thousand acres of new lake and shallow literal zone. The first recorded settlement in Dodge County was established by Jacob Brower on the north side of Fox Lake in 1838.

Lake Characteristics

Table 3-1 outlines the physical characteristics of Fox Lake.

Table 3-1
Physical Characteristics of Fox Lake

Parameter	Size
Surface Area (open water)	1,022 hectare (2,525 acres)
Surface Area (with fringe wetlands)	1,898 hectare (4,690 acres)
Maximum Depth	5.6 meters (19 feet)
Mean Depth	1.5 meters (5 feet)
Volume	23 million cubic meters (19,307 acre-feet)
Shoreline Length	28.8 Kilometers (17.9 miles)

Source: WDNR

Fox Lake is divided into two main basins, a western deeper basin and a shallow eastern basin (Figure 3-1). The mean depth of the lake is 1.5 meters (5 feet), with 14.6 % of the lake less than 0.9 meter (3 feet). The lake has a maximum depth of 5.6 meters (19 feet) which is located in the western basin. Fox Lake does not strongly stratify. Occasionally weak stratification will take place allowing a narrow zone near the bottom sediments of the deep area to go anoxic. Stratification of Fox Lake is discussed in more detail in Chapter 5 of this report.

The Lake has extensive riparian wetland areas along the eastern and southern shorelines and the inlet area of Cambra Creek on the northwest end of the lake. Riparian wetland adjacent to the lake that is influenced by normal lake levels are estimated at 876 hectares (2,165 acres).

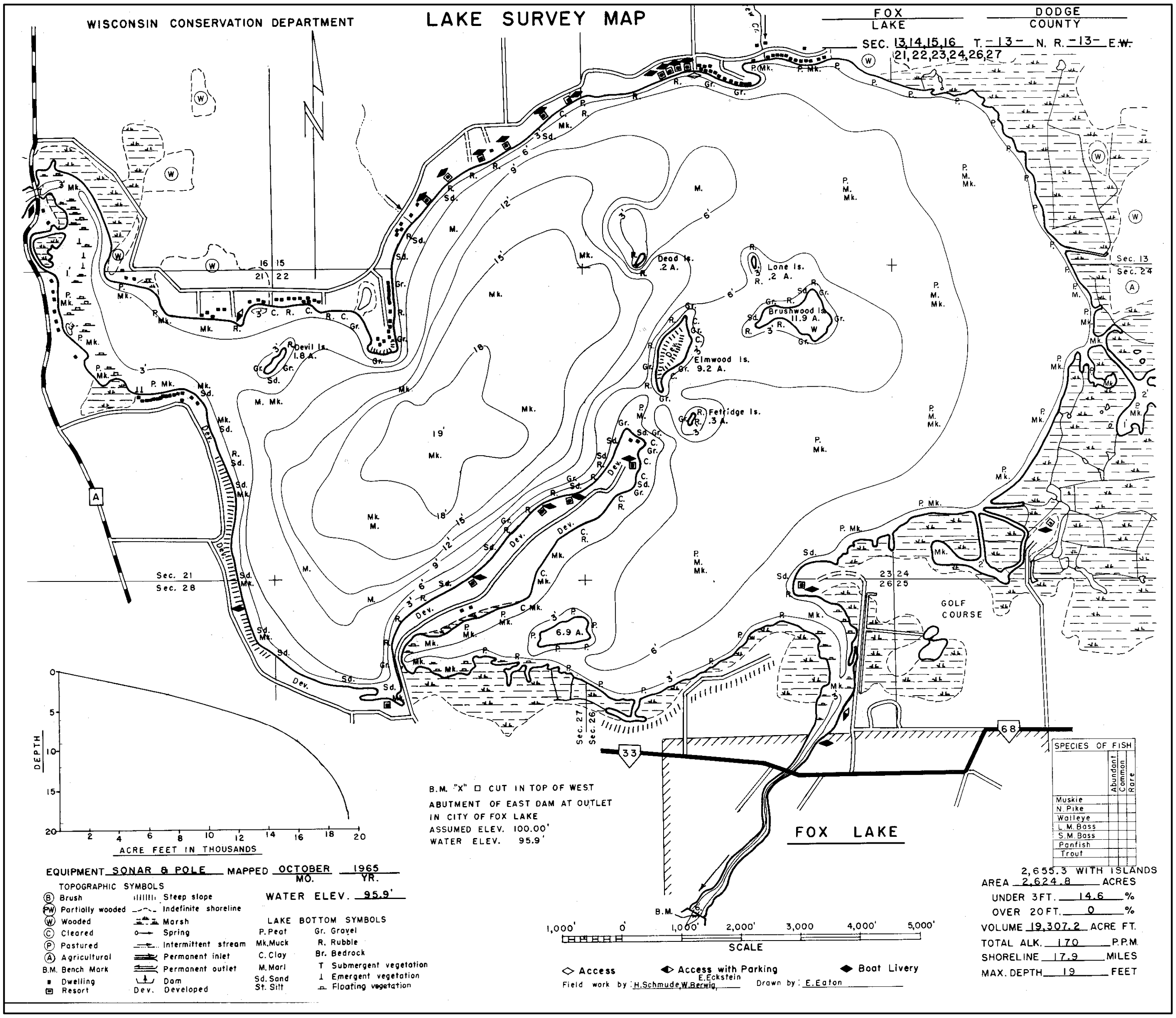

Figure 3-1
Hydrographic Map of Fox Lake, Dodge County

CHAPTER 4: FOX LAKE WATERSHED DESCRIPTION

The Fox Lake watershed is approximately 35,600 acres in size, draining areas of Dodge, Fond du Lac, Green Lake and Columbia Counties. The Fox Lake watershed was recently studied in depth as part of the Beaver Dam River Priority Watershed Project sponsored by the Wisconsin Department of Natural Resources Nonpoint Source Pollutant Abatement Program. The watershed project focuses on the control of upland pollutant sources of crop erosion, streambank and shoreline erosion, and barnyard waste runoff. The findings of the study are documented in, *A Nonpoint Source Control Plan for the Beaver Dam River Priority Watershed Project* (WDNR, 1993). A map of the subbasins is shown in Figure 4-1.

The watershed is made up of four sub-watersheds outlined in Table 4-1.

Table 4-1
Fox Lake Sub-watersheds

Sub-watershed	Acres	Square Kilometers	Percent of Total
Alto Creek	13,693	55.4	38%
Cambra Creek	14,900	60.3	42%
Drew Creek	3,894	15.7	11%
Fox Lake Direct Drainage	3,087	12.5	9%
Total	35,574	55.6	100%

Source: A Nonpoint Source Control Plan for the Beaver Dam River Priority Watershed Project (WDNR, 1993).

The watershed is comprised of rolling hills and plains interspersed with wetlands. While the original vegetation consisted of prairie grasses, marshland, and shrubs, today greater than 70% of the watershed is in agricultural land use. The geology of the area consists of bedrock, sandstone, and dolomite formations overlain by glacial deposits of clay, silt, sand, and gravel.

SOILS

Soils in the Fox Lake area are made of a combination wetland (hydric) soils in the lowland areas and glacial soils on the glacial moraines that form the upland features.

Wetland soils adjacent to the lake on the west, north, and east shores are predominantly Houghton-Pella (H-P) association. H-P soils are characterized as deep, very poorly drained, and poorly drained organic soils with a silty sub-soil. They are usually formed in decomposed sedges and reeds or in silty material and glacial drift. H-P soils are common in depressions on glacial lake plains, moraines, and between drumlins. Both H-P soils are nearly level with moderate to rapid permeability. These soils have good potential for corn, carrots, mint, oats, hay, vegetable crops, or pasture. Un-drained they also provide excellent wildlife habitat. Drainage is a problem for H-P soils as they are subject to blowing and burning if overly dried.

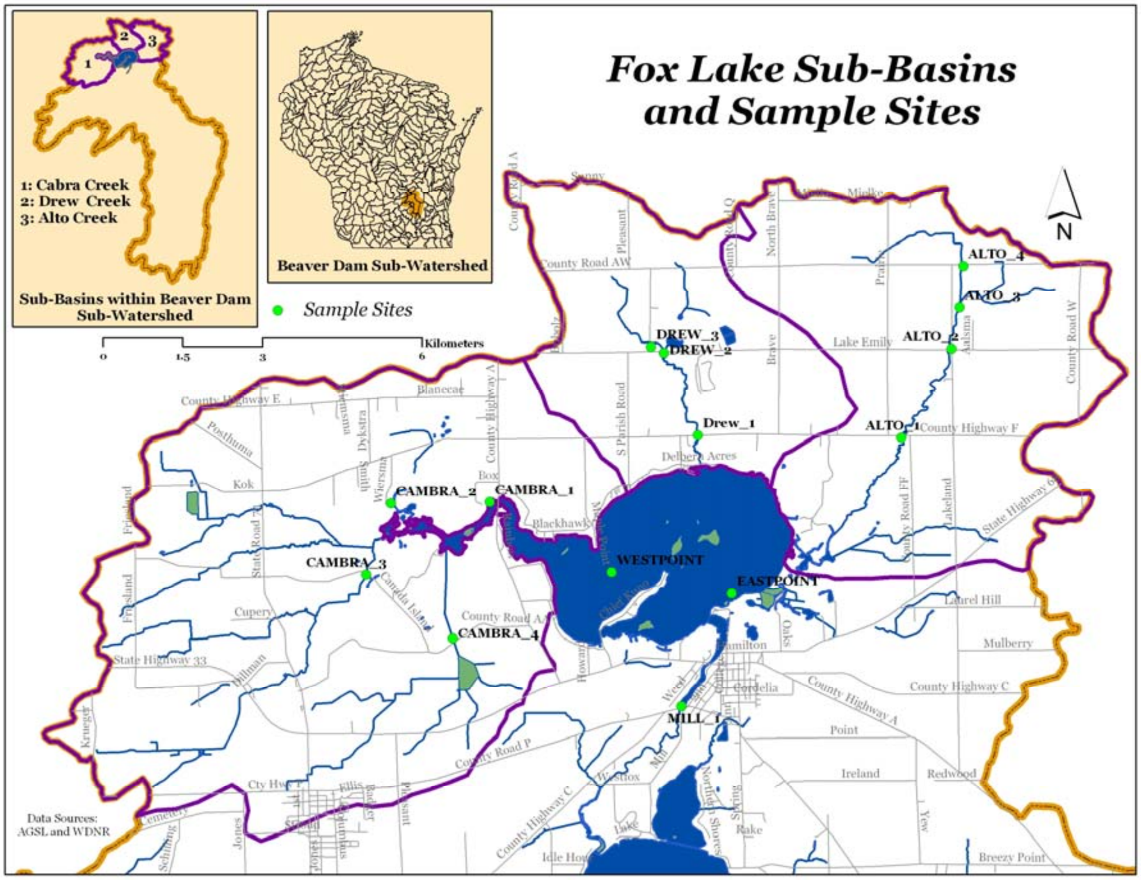

Figure 4-1
Fox Lake Subbasins including Direct Lake Drainage

Source: University of WI-Milwaukee

The wetland soils to the south of the lake are St. Charles-LeRoy-Lomira association. These soils are characterized as deep, nearly level to sloping, well drained, and moderately drained soils with a silty and loamy sub-soil. They are typical in loess and glacial till and found on ground moraines and drumlins. These soils have good to fair potential for all of the cultivated crops common to Dodge County. Activities common to the St. Charles-LeRoy-Lomira association include: corn, grains, legumes, dairy farming, woodlands, pasture, or wildlife habitat. These sites also have good potential for sanitary facilities and building development.

Both of the aforementioned wetland soils are relatively easy to restore to wetlands from other uses by reducing drainage via blocking or removing drain tiles.

The upland soils that surround much of Fox Lake are Plano-Mendota (P-M) association. These soils are characterized by nearly level to sloping, well drained, and moderately well drained with a silty and loamy subsoil, and are formed in loess and glacial till. P-M soils are found on ground moraines and drumlins with long, even slopes. Permeability is moderate with high water capacity. These soils have good potential for corn, grains, legumes, dairy farming, pasture, or wildlife habitat. They also have good potential for sanitary facilities and fair potential for building development.

LAND USE AND LAND COVER

The Fox Lake Watershed lies primarily within the boundaries of the City of Fox Lake, the Town of Fox Lake, Fox Lake Township, and Trenton Township in Dodge County. Portions of the watershed also lie within Columbia, Fond du Lac County, and Green Lake County. A land use analysis using WISCLAND GIS data was performed on the Fox Lake watershed. "WISCLAND" is the Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data, a partnership of public and private organizations seeking to facilitate landscape GIS data development and analysis. The WISCLAND data depicts land use conditions in Wisconsin in 1999.

The terms "land use" and "land cover", or LULC, are often used simultaneously to describe maps that provide information about the types of features found on the earth's surface (land cover) and the human activity that is associated with them (land use). In some cases, a hybrid approach results in both land cover and land use being mapped together. These maps are produced from remotely sensed data (satellite images and aerial photography) at scales that are amenable to planning, environmental assessment, and development studies.

The percent LULC for the Alto Creek, Cambra Creek, and Drew Creek subbasins--including the direct drainage to the lake--are summarized in Table 4-2. The direct drainage areas not associated with a tributary were not included in the analysis.

Table 4-2
Land Use/Land Cover for Fox Lake Watershed
Source: University of WI-Milwaukee

Land Use/Land Cover Type	**Subbasin (%)**		
	Alto Creek	**Cambra Creek**	**Drew Creek**
Commercial and Services	-	0.13	1.24
Cropland and Pasture	84.00	80.74	94.48
Deciduous Forest Land	1.90	-	1.36
Forested Wetlands	-	9.14	-
Industrial	-	0.17	-
Lakes	-	0.02	0.03
Nonforested Wetlands	14.10	8.05	1.25
Other Built-Up Land	-	0.12	1.64
Residential	-	1.64	-
Total	100	100	100

The LULC analysis clearly shows that the dominant forms of LULC in the watershed are agriculture and wetlands.

REFERENCES:

Wisconsin Department of Natural Resources (WDNR) (1993). *A Nonpoint Source Control Plan for the Beaver Dam River Priority Watershed Project*

CHAPTER 5: LAKE WATER QUALITY

INTRODUCTION

The term water quality is relative in nature. Like art, the quality is in the eye of the beholder. A fisherman may enjoy a productive lake with abundant plant beds that provide habitat for fish, while a swimmer may enjoy clear water and a sandy lake bottom. To remove some of the subjectivity in the analysis of water quality information, the Wisconsin Department of Natural Resource (WDNR) and University of Wisconsin-Extension (UWEX) have established a series of indexes that rank lakes from very poor to excellent based on individual parameters. The indexes are based on a study of over 600 lakes in the state of Wisconsin. Where applicable, this report will use the WDNR and UWEX indexes to understand how Fox Lake relates to other lakes in Wisconsin. For monitoring parameters lacking established index values, Fox Lake will be compared to the General Use Standards in Wisconsin (Table 5-1) or to the values presented in "*Limnological Characteristics of Wisconsin Lakes*" (Lillie and Mason 1983).

Table 5-1
Wisconsin Water Quality Standards

Parameter	General Use Standard
Maximum Temperature	89° F
pH	6.0 minimum – 9.0 maximum
Dissolved oxygen	minimum 5.0 mg/l
Un-ionized Ammonia Nitrogen	maximum 0.02 mg/l

Source: SEWRPC

Aging Process of Lakes

Lakes naturally progress through a series of predictable conditions as they gradually fill in with sediment from the surrounding landscape called eutrophication (Figure 5-1). The state of eutrophication is known as its trophic status. Trophic status is a lake's level of primary productivity or how many aquatic plants and algae are present. Because trophic status and water quality are closely related, our expectations for lakes change dramatically as they age.

The first trophic state a lake belongs to over its aging process is **oligotrophic** which means the water is very clear, there is little productivity in the littoral zone (few aquatic plants), and the fishery is dominated by a few, large predatory species. As a lake ages, it becomes more productive because it grows shallower and is filled with more nutrients. The second classification for lakes is mesotrophic.

Mesotrophic lakes are an intermediate stage between the oligotrophic and eutrophic states. They are characterized by moderate levels of productivity, some accumulated organic matter on the lake bed, a good fishery, and occasional algal blooms. The last phase of a lake's aging is called eutrophic.

Eutrophic lakes are highly productive with frequent algal blooms, go through periods of oxygen depletion and fish-kills, and support abundant rough fish such as the Common Carp. Eventually, lakes will fill in enough where they will be too shallow and productive to be considered a lake and turn into a wetland. At its natural pace, the eutrophication process may take thousands of years. Many activities undertaken by humans can accelerate the eutrophication process since they accelerate soil loss via erosion. This is called **cultural eutrophication** and it shortens the aging process down to a few hundred years.

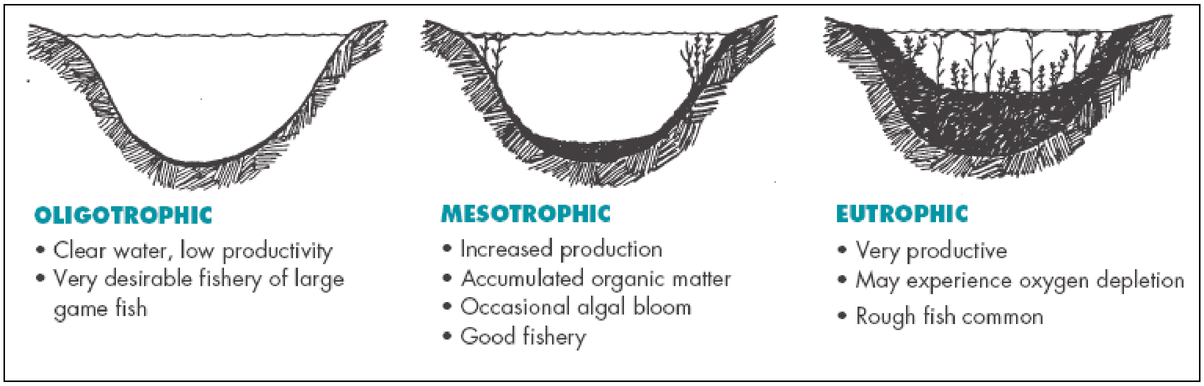

Figure 5-1
Aging Stages of Lakes and their Attributes
Source: University of WI-Extension and SEWRPC

METHODS

All field data were collected monthly from February through November 2005 (Table 5-2). Data were collected using traditional grab methods with a Kremmler bottle to collect samples from surface and deep water sites. A second set of data were collected using an YSI 6600 probe to measure temperature, dissolved oxygen, turbidity, conductivity and pH. Two lake sampling sites were located at the lake's deepest point or mid-lake at the surface (1m) and bottom (3m) while a third was located in the Southeast Bay. The mid-lake site is located at 43^{o} 34' 55" N 88^{o} 56' 07" W and the Southeast Bay site is located at 43^{o} 34' 42" N 88^{o} 54' 28" W (Figure 5-2).

Table 5-2
Parameters Measured on Fox Lake

Parameters Measured	
Specific conductance	pH
Water temperature	Dissolved oxygen
Turbidity	Secchi-disk transparency
Nitrate / Nitrite	Ammonia
Total phosphorus	Total nitrogen
Chlorophyll a	Dissolved phosphorus

RESULTS

The monitoring results are summarized in the following subsections. Figure 5-3 illustrates how to read a boxplot. When interpreting boxplots, it is important to understand that sites with more overlap are more similar. Sites with minimal or no overlap are less similar.

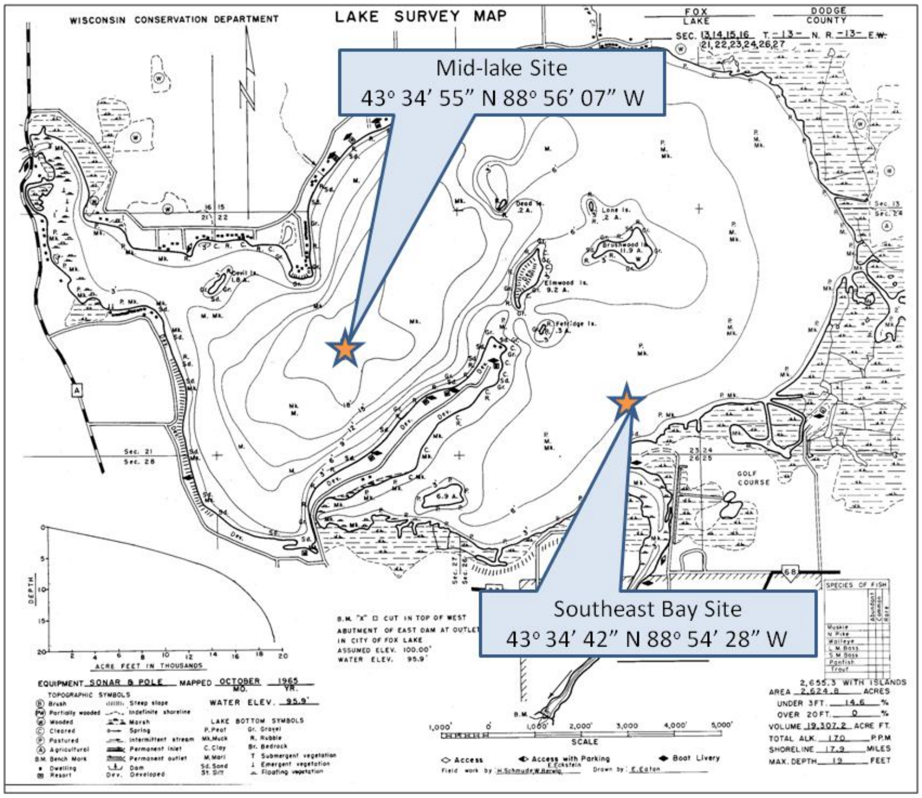

Figure 5-2
Location of Lake Monitoring Sites

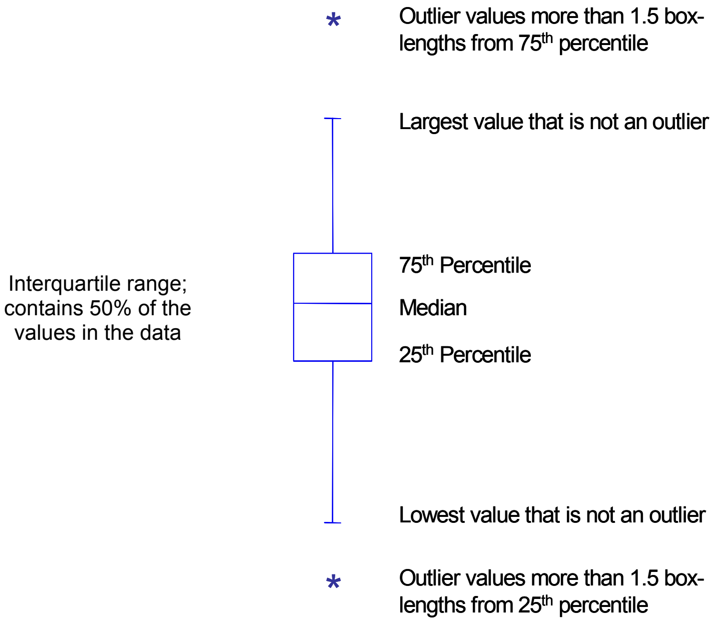

Figure 5-3
How to Read a Boxplot

Thermal Stratification

Thermal stratification is the result of temperature differences in the water column (Figure 5-4). Water reaches its maximum density at 4° C. It is lighter at both warmer and colder temperatures. Density variances at different temperatures within a lake can be sufficient to prevent mixing of warm and cold water. This density difference forms a barrier between the shallow and deep water of a lake that is known as thermal stratification or the thermocline. The phenomenon is common in lakes with a maximum depth greater than 6 m, but may also occur in shallower lakes as well. Since Fox Lake's maximum depth is ~6 m, lake morphology alone may not predict whether stratification is occurring.

As summer approaches, the surface waters of a lake warm, expand, and become lighter than the lower waters. A barrier begins to form between the lighter, warmer surface water and the heavier, cooler bottom water. A noticeable drop in temperature marks the barrier as depth increases to the thermocline.

The zone of transition between warm and cold water, on either side of the thermocline, is known as the metalimnion. It separates the warmer, lighter surface water known as the epilimnion from the colder, heavier bottom layer of water called the hypolimnion. During the spring and fall there is a relatively uniform temperature from the top to the bottom of the lake. However, in stratified lakes, in mid summer, the temperature profile has warmer water at the surface of the lake and cooler water at the bottom. The thermocline becomes a physical barrier in the lake. The barrier is easily crossed by fish, but prohibits the exchange of water between the epilimnion and hypolimnion.

The thermocline becomes most noticeable in mid to late summer. This stratification period lasts until air temperatures cool the surface of the lake and wind action is able to disrupt the thermocline. As the surface water temperature cools, it becomes denser, sinking and mixing under wind action to erode the thermocline until the entire water volume of the lake is of uniform temperature. The phenomenon that follows summer stratification is known as fall turnover.

As the water temperature cools below 4° C, it becomes less dense and floats on the more dense warmer water. Eventually, the water near the surface is cooled to 0° C at which temperature ice begins to form on the lake surface, sealing it off to the atmosphere for about four months. Winter stratification occurs as the cooler, lighter water and ice remain close to the lake surface, separated from the relatively warmer, heavier water near the bottom of the lake.

The arrival of spring brings warmer weather and the reversal of the stratification process, known as spring turnover. As the surface waters warm, they become denser and begin to approach the temperature of the warmer, lower water until the entire volume of the lake reaches the same temperature. Wind action serves to mix the lake until it reaches a uniform temperature of 4° C. Beyond this point, the surface waters continue to warm, become lighter, and float on top of the cooler water. This begins the summer stratification process over again.

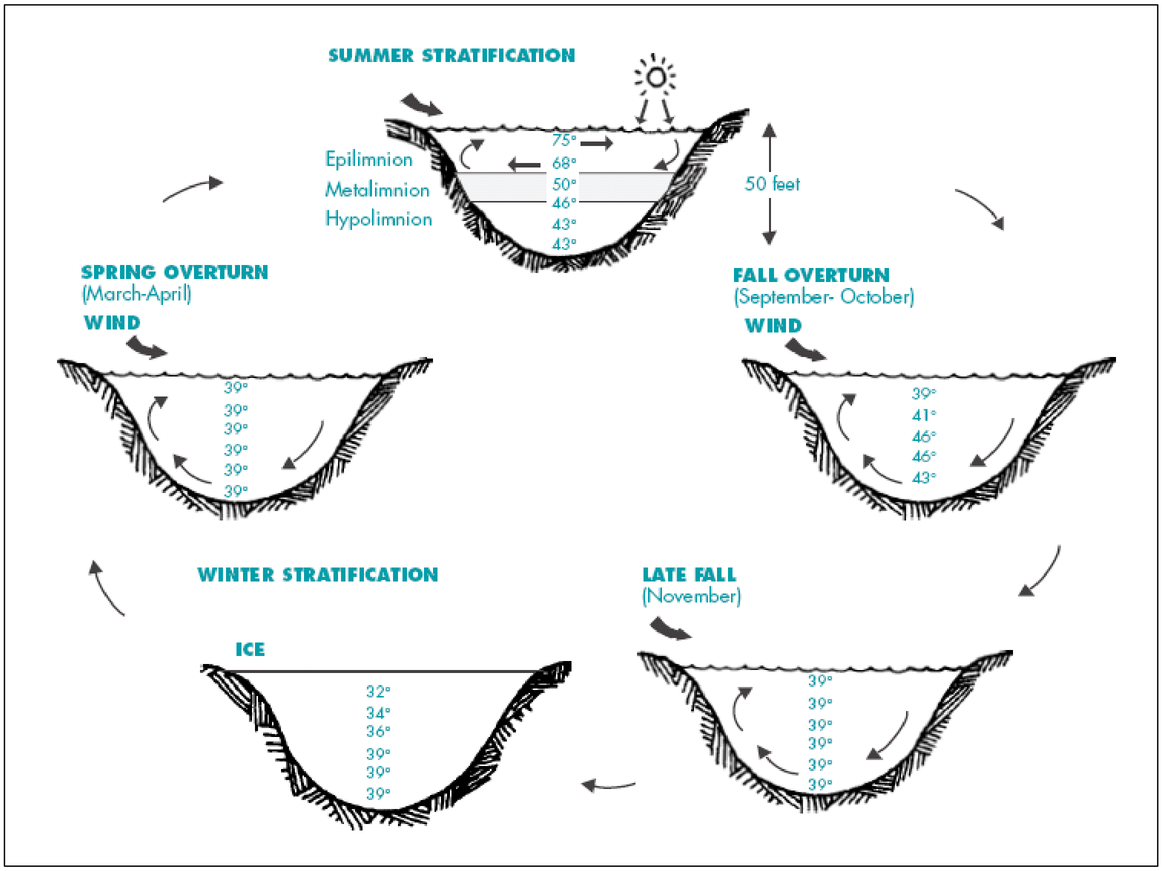

Figure 5-4
Seasonal Thermal Stratification of Lakes
Source: University of WI-Extension and SEWRPC

Stratification is important to the water quality of a lake. During stratification, the bottom waters of a lake are cut off from the atmosphere and new sources of oxygen. Oxygen levels can drop to low levels as discussed in the next section. In addition, chemical processes such as nutrient cycling in a lake are impacted by stratification.

Fox Lake does not stratify and has a relatively uniform temperature from top to bottom (Figure 5-5). This uniform temperature indicates that wind action causes the lake to completely mix during summer months. The lake's aeration system causes mixing during the winter months.

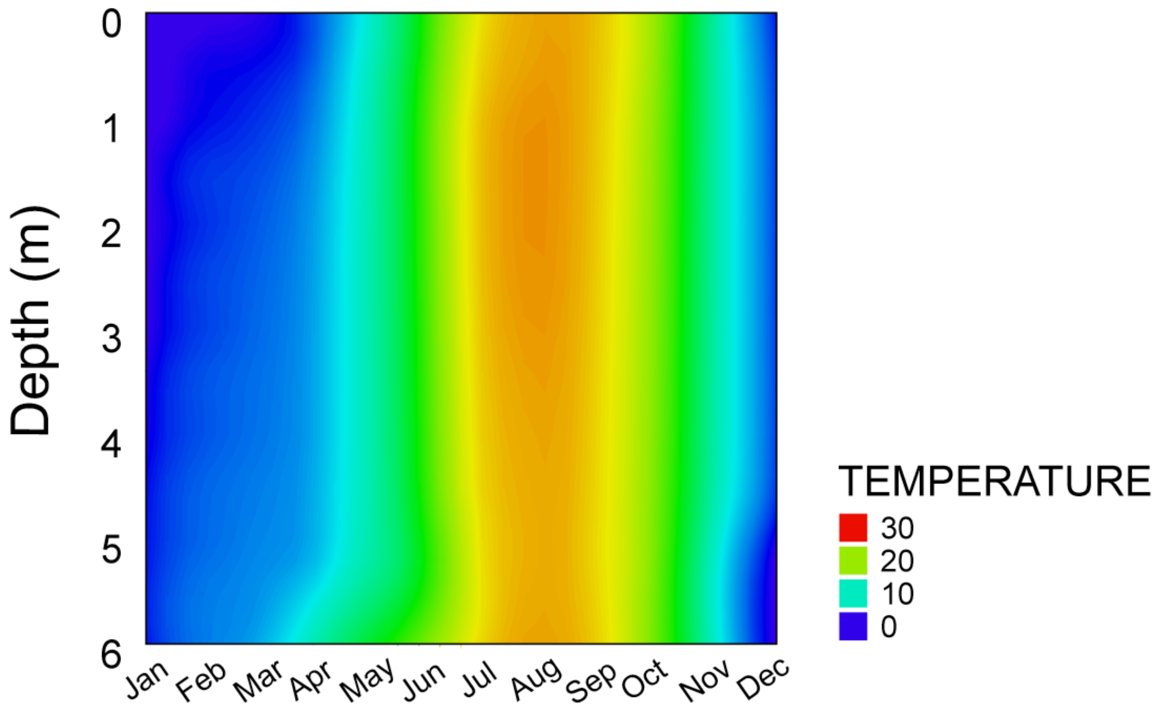

Figure 5-5
Temperature (C) for Fox Lake 2005
Source: University of WI-Milwaukee

Dissolved Oxygen

Dissolved oxygen levels are one of the most important factors affecting water quality. Dissolved oxygen is required for many chemical reactions to occur, which are essential to lake functioning. It is also required by all aquatic animals, which have minimum concentrations for survival. Most warm water fish species require oxygen concentrations above 3.0 milligrams per liter (mg/l) to survive. Cold-water species require higher oxygen levels and require at least 5.0 mg/l of dissolved oxygen for long-term survival. The State of Wisconsin has established 5.0 mg/l as the minimum dissolved oxygen standard for the protection of aquatic life.

Dissolved oxygen concentrations in lakes are affected by a number of physical processes. Primarily, oxygen is produced by rooted aquatic plants and algae during photosynthesis. Thus, there is a decline in dissolved oxygen concentrations during the night when photosynthesis cannot counter-balance the loss of dissolved oxygen through respiration and decomposition. Concentrations of oxygen within the lake are also affected by the amount of oxygen contained in the air and within inflowing streams. More oxygen from the air will dissolve into the water when surface area is increased due to wind and wave action. Additionally, inflowing streams and rivers deliver oxygen to the lake especially if they are turbulent and, therefore, well aerated. The relationship between water temperature and gas saturation also affects the dissolved oxygen concentration in lakes, since cold water can retain more dissolved oxygen than warm water. As a result, dissolved oxygen concentrations are limited by temperature during the summer months.

Dissolved oxygen concentrations may also vary by depth. When any lake becomes stratified, decomposers and chemical processes in the hypolimnion, or deep waters, use up oxygen during the decay process. Stratification isolates the hypolimnion from the atmospheric supply of oxygen, and if stratification lasts long enough, benthic dwelling organisms and organic decay may use up all of the available oxygen. This condition is called anoxia and may be harmful to aquatic life. The border between overlying oxygen rich waters and the deeper oxygen depleted waters is called the oxycline. Chemical processes are also altered in oxygen depleted waters creating a chemical gradient called a chemocline. Conceptually the oxycline and chemocline are similar to the thermocline, related to stratification, related to temperature. In anoxic waters, the sediments more readily release phosphorus, manganese, and iron in the hypolimnion. Of most concern are the effects of phosphorus release from the sediment. Once the lake becomes un-stratified in the spring and fall, the phosphorus rich waters of the hypolimnion are mixed with the overlying surface waters enriching the entire water column. This process of phosphorus release from the sediments is called internal loading. The newly available nutrients may fuel algae and aquatic plant growth in following years (Figure 5-6).

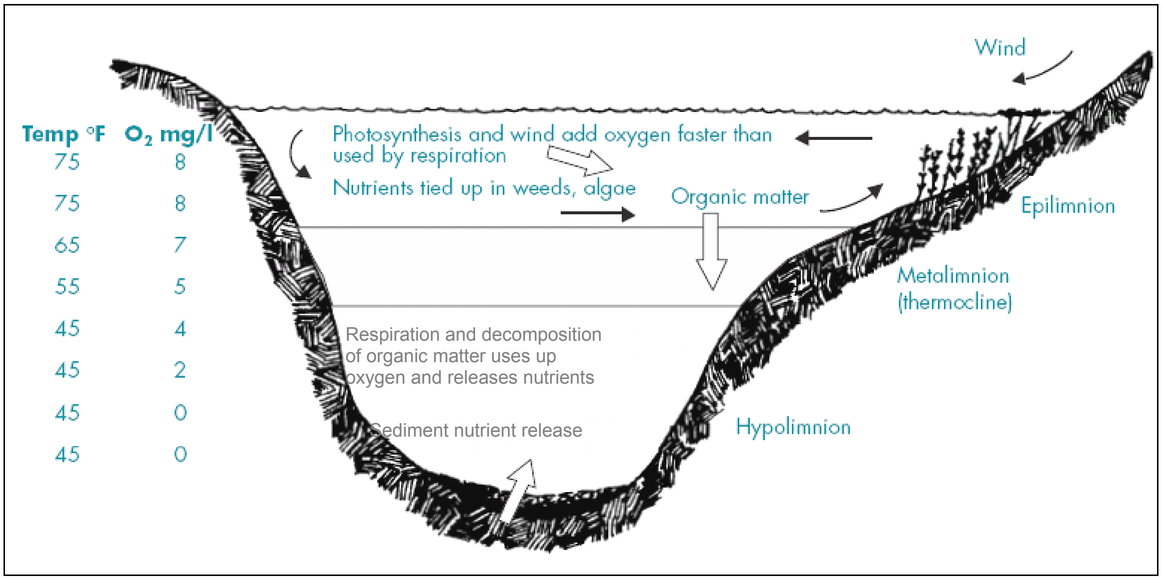

Figure 5-6
Typical Lake Conditions during Summer Stratification
Source: University of WI-Extension and SEWRPC

In Fox Lake the dissolved oxygen is relatively uniformly distributed during the spring and fall. Uniform oxygen distribution is typical for lakes following mixing periods. In the winter months there is a transition from super-saturated conditions near the surface and low levels at the lake bottom, to low levels in most of the water column. This pattern is likely due to the lack of snow cover on the ice early in winter allowing algae to photosynthesize and replenish oxygen near the ice surface coupled with respiration occurring near the sediment-water column interface on the lake bottom. Since light does not reach the lake bottom, respiration locally consumes oxygen. The lake does not mix in winter so there is no source of replenishment other than diffusion. As winter progressed and the lake was covered by snow, the oxygen levels begin to decrease throughout the water column. On January 29th, 2005 the aerator was turned on. After this date, the zone of anoxia does not increase in size. In March the lake mixed completely and the underlying anoxic waters were distributed throughout the water column. Fortunately, the water column is consistently at or above 5 mg/l, limiting the risk of a winterkill event (Figure 5-7).

During the summer months, Fox Lake is anoxic in the deeper (>5 m) portions of the lake. Since Fox Lake is on the cusp of lakes tending to be consistently mixed and those developing stratification, or in this case an oxycline, this is not expected. Calm weather conditions over a period of time may allow shallow lakes to stratify temporarily. Fox Lake is very productive and the depletion in the bottom waters may be due to increased rates of decay due to accumulation of algae cells on the lake bottom. The lake's productivity is further illustrated by super-saturated conditions near the water surface likely caused by prolific algal growth. Overall, the seasonal dissolved oxygen patterns in Fox Lake are not unusual.

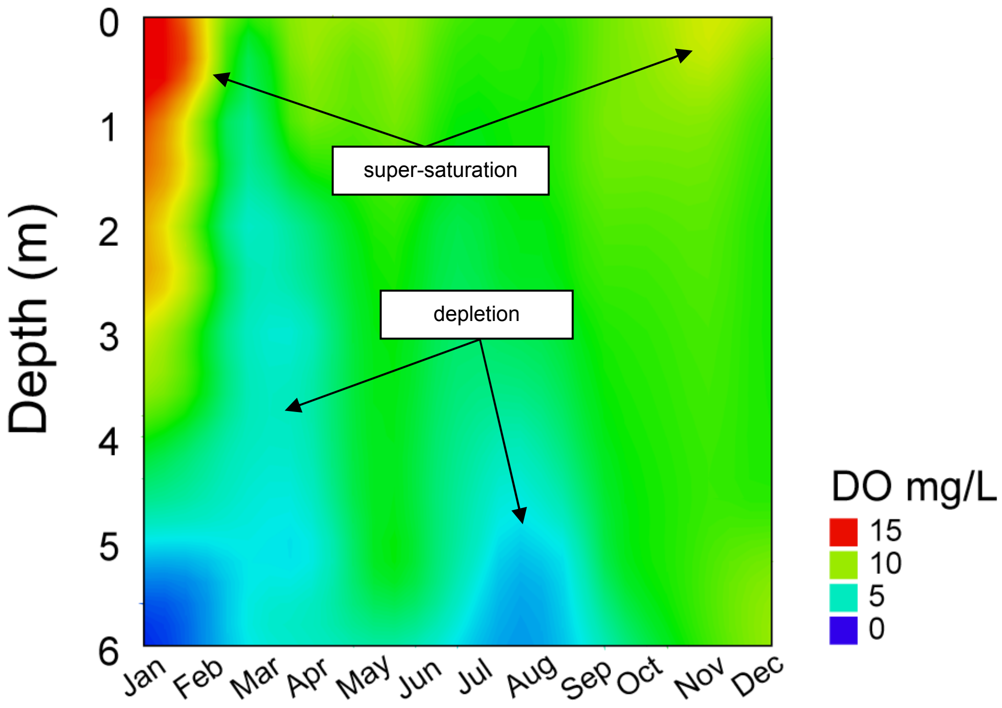

Figure 5-7
Dissolved Oxygen (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

pH

The pH is a measure of the hydrogen ion concentration on a scale from 0 to 14 standard units. A pH of 7 indicates neutral conditions. A pH above 7 indicates basic water; below 7 indicates acidic conditions. The pH of water determines the solubility and biological availability of chemical constituents such as nutrients and heavy metals. Most aquatic life requires a pH range between 6.5 and 9.0 to survive. Below a pH of 6.5 fish begin to become stressed (Table 5-3). Low levels of pH can cause some toxic metals to become more soluble in water. When pH values rise to the range of 8.0 to 9.0, it may be indicative of rapid algae or aquatic plant growth, or the introduction of alkaline materials into the lake either from natural sources or human discharges.

It is important to note that a rise in pH may be the result of rapid algae or plant growth, but it is not the cause. This rise in pH is due to increases in photosynthesis and the consumption of CO_2 and its removal from the water. As the concentration of CO_2 decreases, the pH rises. Another effect of the removal of CO_2 is the precipitation of $Ca(HCO_3)_2$ or marl. As the water becomes more basic, the solubility of $Ca(HCO_3)_2$ lessens and it precipitates out of solution.

Table 5-3
Effects of pH on Aquatic Life
Source: University of WI-Extension and SEWRPC

pH	Effect
6.5	Walleye spawning inhibited
5.8	Lake trount spawning inhibited
5.5	Smallmouth bass disappear
5.2	Walleye and lake trout disappear
5.0	Spawning inhibited in many fish
4.7	Northern pike, white sucker, brown bullhead, pumkinseed, and sunfish disappear
4.5	Perch spawing inhibited
3.5	Perch disappear
3.0	Toxic to all fish

The pH of Fox Lake varies seasonally with the lower or more acidic values measured in the winter. The higher or more alkaline values were recorded during the summer months (Figure 5-8). Since increases in pH coincide with super-saturated oxygen levels, it suggests changes in pH are driven by photosynthetic activity associated with rapid algal growth. The ranges in pH values for Fox Lake are safe for aquatic life.

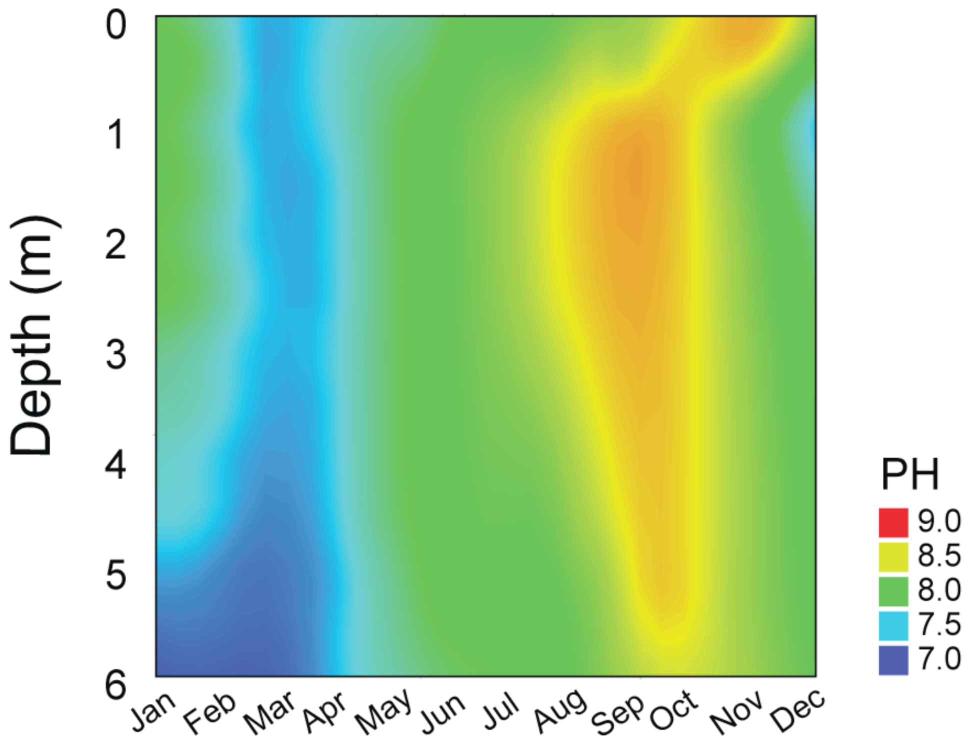

Figure 5-8
pH for Fox Lake 2005
Source: University of WI-Milwaukee

Specific Conductance and Conductivity

Conductivity and specific conductance are indicators of the concentration of dissolved solids in the water column. Conductivity is a raw measurement while specific conductance is corrected for temperature. As the amount of dissolved solids increases, water's ability to conduct an electrical current also increases. Values of specific conductance are approximately two times the water hardness unless the water is receiving high concentrations of human-induced waste. Anoxia can increase the specific conductance near the sediment-water interface as dissolved materials accumulate as they are released from the sediment.

The average specific conductance from 1966 to 2001 is 464 uS/cm for Wisconsin lakes. The values for Fox Lake varied from ~100 - ~600 uS/cm which falls within the expected range. Values were higher in the winter due to the contribution of ice and anoxia in the bottom sediments to the overall ion concentrations. It is likely that the operation of the aerator from January 29th – March 6th, 2005 also added some dissolved materials to the water column by re-suspending bottom material. Snowmelt and resulting runoff were likely contributors to lower measurements near the surface in the spring and fall months. Conductance shows an apparent increase in the summer, but this effect is reduced when the values are corrected for temperature (Figure 5-9).

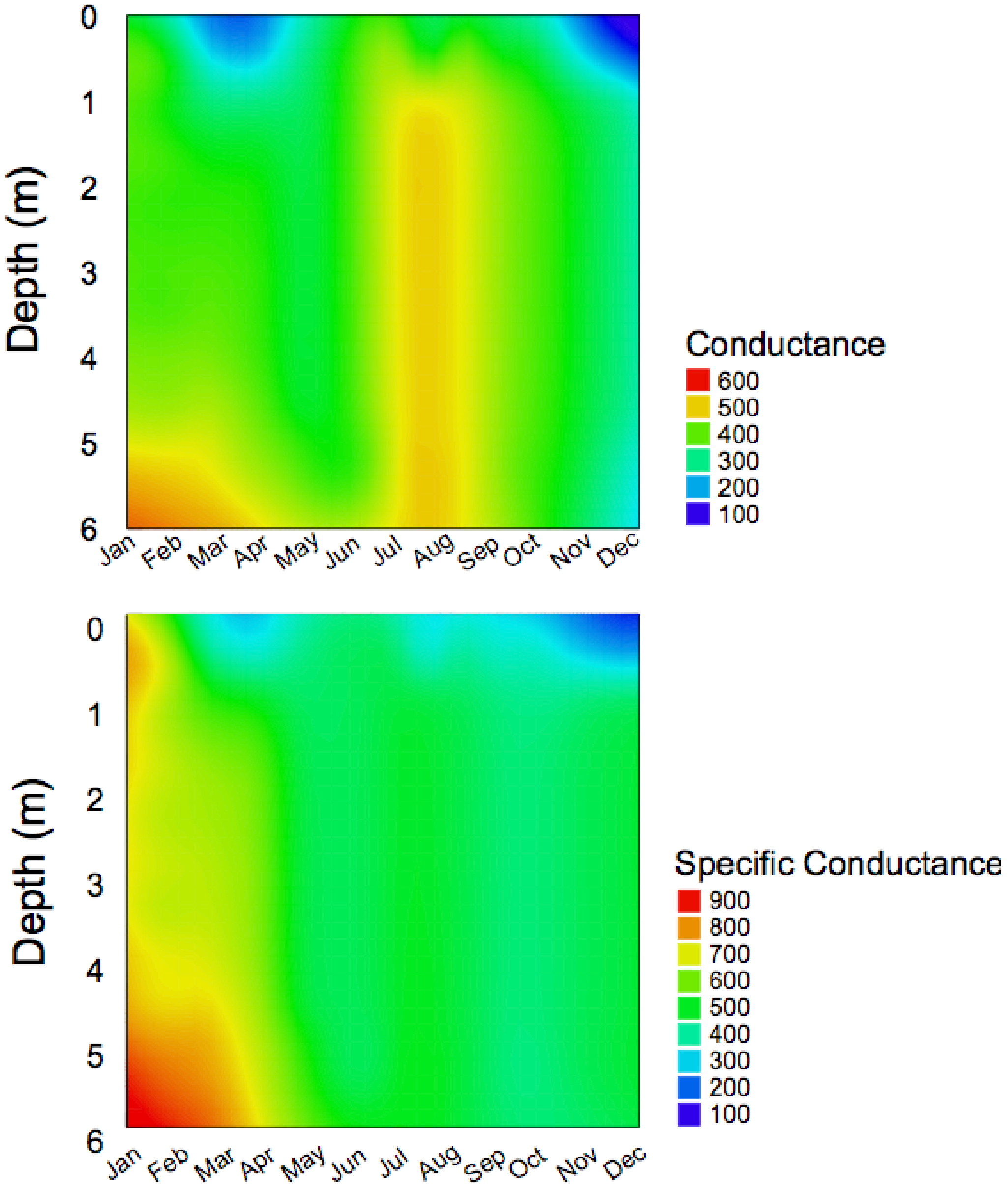

Figure 5-9
Conductivity and Specific Conductance (uS/cm) for Fox Lake 2005
Source: University of WI-Milwaukee

Water Clarity

Water clarity is not a chemical property of lake water. It is an indicator or measure of water quality related to chemical and physical properties. Water clarity is often used as a surrogate measure of a lake's overall water quality. Water clarity has two main components: true color and turbidity. True color is the materials dissolved in the water column while turbidity is composed of materials suspended in the water such as algae and silt. Algae are usually the largest and most variable component of water clarity. The overall clarity (turbidity and color) is measured with a Secchi disk, which is a black and white eight-inch diameter disk that is lowered into the water until a depth is reached at which the disk is no longer visible. The depth is known as the Secchi disk reading while color and turbidity are separate measurements. Water clarity can also be reduced by humic substances in the water as well as by suspended salts and sediments. Salts and sediments in the lake may remain in suspension in the lake as a result of wind and boating activity.

Turbidity

As previously mentioned, turbidity is caused by particles suspended in the water column. Suspended particles dissipate light, which affects the depth at which plants can grow, recreational values, habitat quality, and may cause lakes to fill with sediment at accelerated rates. High turbidity is not aesthetically pleasing to most people and is associated with lakes receiving large amounts of runoff. Turbidity associated with runoff can vary widely and seasonally. Heavy rains or fast moving water can pick up and carry enough dirt and debris to make a clear lake cloudy, at least temporarily. Suspended plants and animals also produce turbidity. Many small organisms have a greater effect than a few large ones. Turbidity can have a negative effect on fishes and other aquatic organisms if levels are sufficiently high and exposure is over an extended duration (Figure 5-10).

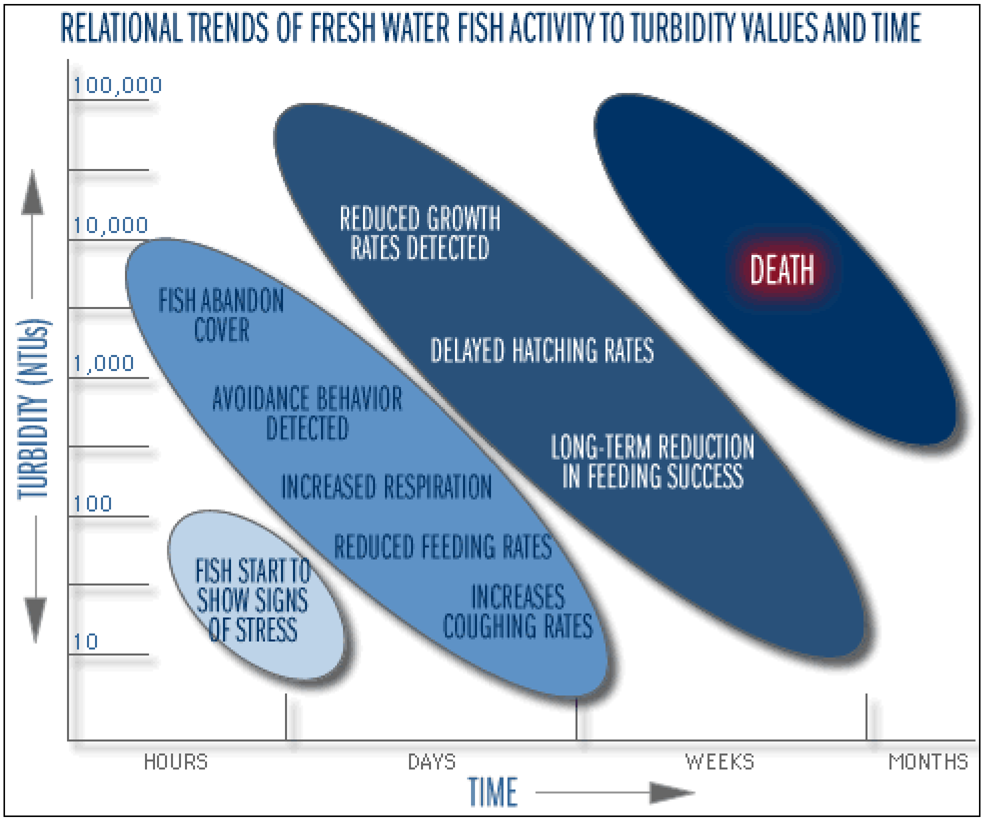

Figure 5-10
Turbidity Impacts to Fish Communities
Source: University of WI-Extension

The turbidity in Fox Lake varied from 0 – 30 NTU, which is relatively low considering the large watershed draining into the lake (Figure 5-11). The relatively high turbidity values measured in the winter months are likely associated with the operation of the aerator installed near the monitoring station. It was in operation from January 29th – March 6th, 2005. The increases in turbidity at the water surface in the spring are likely due to a runoff event because algal density was low at this time. The relatively high turbidity measured in the late summer-early fall are the results of increased algal density. Late summer algal communities are usually dominated by blue-green algae and cause waters to take on a green color.

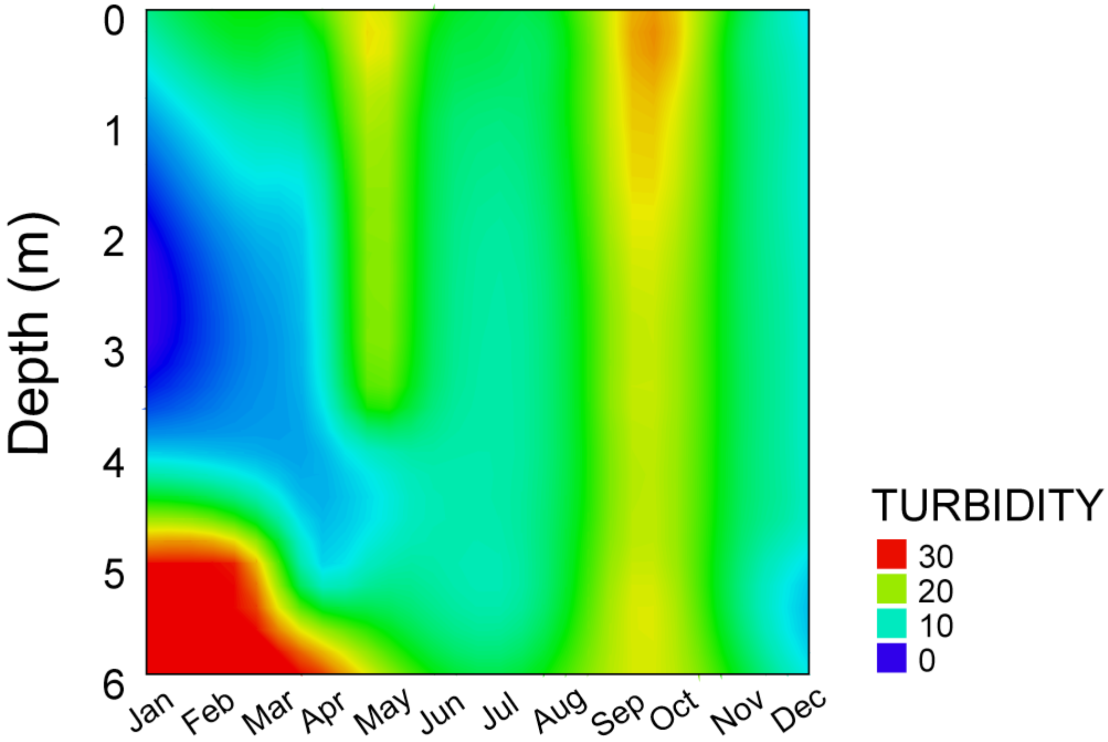

Figure 5-11
Turbidity (NTU) for Fox Lake 2005
Source: University of WI-Milwaukee

Secchi Depth

A Secchi disk is a black and white eight-inch diameter disk that is lowered into the water until a depth is reached at which the disk is no longer visible. This depth is known as the Secchi disk reading or Secchi depth. The Secchi disk was created in 1865 by Pietro Angelo Secchi for the purpose of measuring water clarity in open waters of lakes, bays, and the ocean. Secchi disk readings do not provide an exact measure of transparency due to errors caused by the sun's glare on the water and differences in the user's judgment or eyesight. The Secchi disk is an inexpensive and straightforward method of measuring water clarity. The WDNR Self-Help lake monitoring program has collected Secchi disk data in Wisconsin lakes since the 1980's.

The Secchi depths for Fox Lake were reduced to a summer growing season mean (SGSM) value and compared to other lakes in southeastern Wisconsin. The SGSM value is the average Secchi depth reading of the average monthly values for June, July, and August. Years lacking at least one data point in each of June, July, and August were excluded from the analysis.

Mean water clarity for lakes within southeastern Wisconsin is reported to be 1.6 m (Lillie and Mason, 1983). Secchi disk readings from 1987 - 2005 were generally poor and less than the southeastern Wisconsin average. A general increase in Secchi depth is notable from 2002 – 2005 followed by a decrease in 2006. Secchi depths decrease over the course of the growing season as the water warms, zooplankton populations are reduced, and algal cells are more prevalent (Figure 5-12). The water clarity data suggests that the lake is either 1) cycling back towards a turbid water state or 2) exhibiting annual variation within the clear-water state. This cannot be determined with the current data and will require future monitoring.

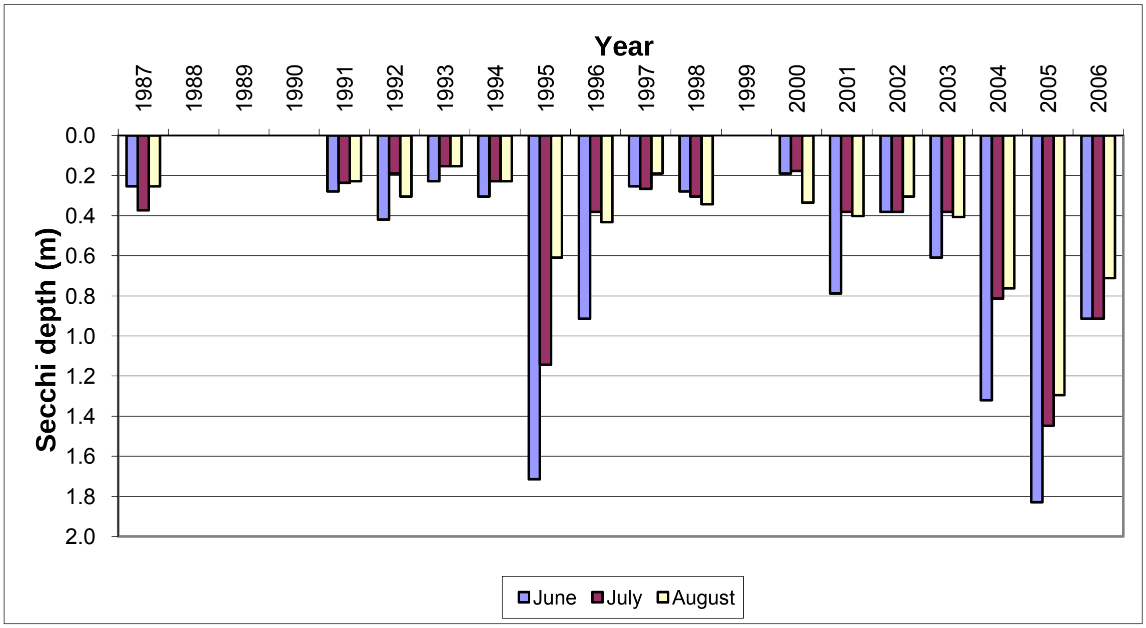

Figure 5-12
Summer Growing Season Monthly Average Secchi Depths for Fox Lake 1987-2006
Source: WDNR Self-Help Lake Monitoring Data

Prior to the unique clear-water year in 1995, the water clarity was consistently poor throughout the growing season. Since 1995, water clarity is both more variable and generally greater in June and decreases over the growing season. This pattern suggests ecological processes have been altered in the lake. Comparing the SGSM Secchi depths pre- and post- drawdown using a Kruskal-Wallis rank-sum test showed a statistically significant difference ($p \leq 0.05$) in water clarity (Figure 5-13) which supports this conclusion. Future monitoring of water clarity should reveal the direction (or lack of) in the lake's condition.

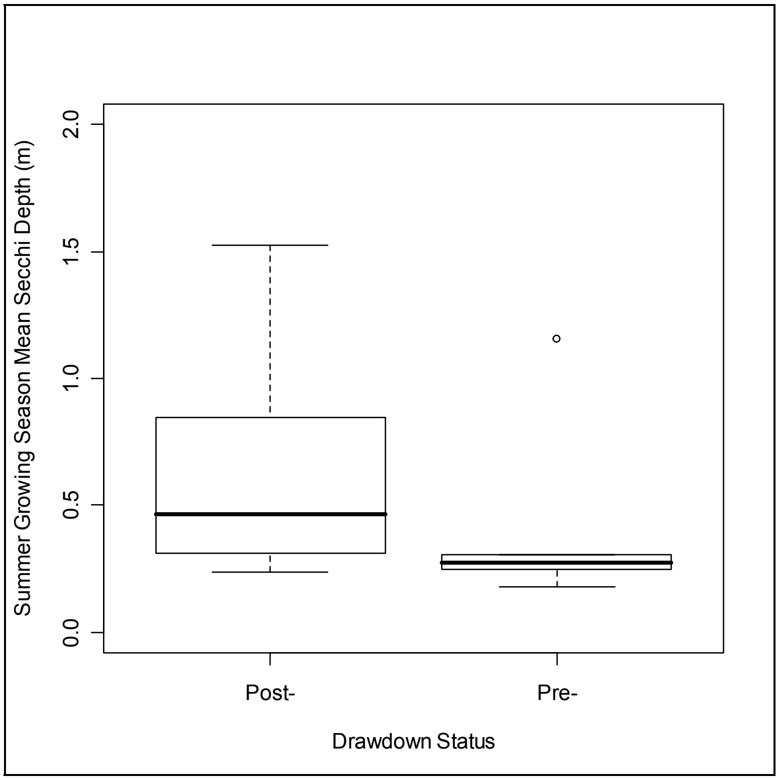

Figure 5-13
Summer Growing Season Mean Secchi Depths for Fox Lake Pre- and Post- Drawdown 1987-2006
(Drawdown Occurred in 1996)
Source: WDNR Self-Help Lake Monitoring Data

Relative Chlorophyll

Chlorophyll-a is the major photosynthetic pigment in algae which are the free floating microscopic plants giving lakes their green hue. The amount of chlorophyll-a is an indicator of the biomass of algae in the water. Relative chlorophyll measures the fluorescence of chlorophyll in the water column, but is not calibrated to the actual chlorophyll-a concentration. As a result, relative chlorophyll provides a meaningful spatial and seasonal comparison of the amount of chlorophyll present in the water column, but cannot be used to estimate trophic status and make comparisons to other lakes. Like chlorophyll-a, relative chlorophyll is usually lowest in the winter and reaches its peak in the summer as algae populations reach their maximum density. The relative chlorophyll measurements for Fox Lake are illustrated in Figure 5-14. The values for relative chlorophyll are scaled from 0-20, but reflect a wider range of actual chlorophyll-a values.

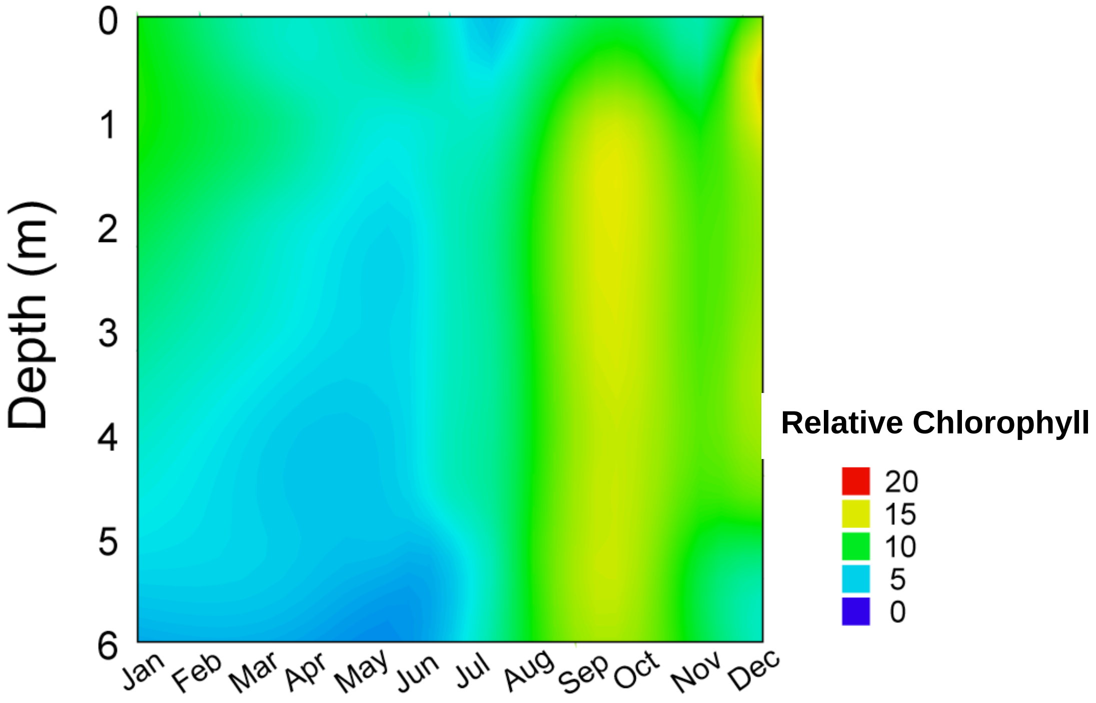

Figure 5-14

Relative Chlorophyll for Fox Lake 2005

Source: University of WI-Milwaukee

In winter, algal productivity is evident just under the ice surface, but was not detected lower in the water column. Spring chlorophyll-a was generally low which is typical during periods of low water temperature. In summer, chlorophyll-a is lower than expected near the water surface which could be a result of active zooplankton grazing or vertical migration of phytoplankton to avoid intense sunlight at the water surface that may cause cellular degradation. In fall, conditions indicate a large algal bloom through much of the water column. Algae blooms in the late summer/early fall are common in many Wisconsin lakes.

Chlorophyll-a

Chlorophyll-a is a major photosynthetic pigment in algae. Algae are free floating microscopic plants. The amount of chlorophyll-a (uncorrected for pheophytin) is an indicator of the biomass of algae in the water. Lakes usually exhibit a noticeable green color when chlorophyll-a concentrations exceed 10 ug/l. Pheophytin is a degradation product which can be used to assess the health of the algal population. A lot of pheophytin would suggest a dying algal population. Chlorophyll-a concentrations are usually lowest in the winter and reach their peak in late summer, when algae populations reach their maximum. The classic pattern of algal community succession for mesotrophic lakes is shown in Figure 5-15, but may not apply to Fox Lake because the Nitrogen to Phosphorus ratios do not conform to those assumed by the general model (discussed in nutrient section in detail).

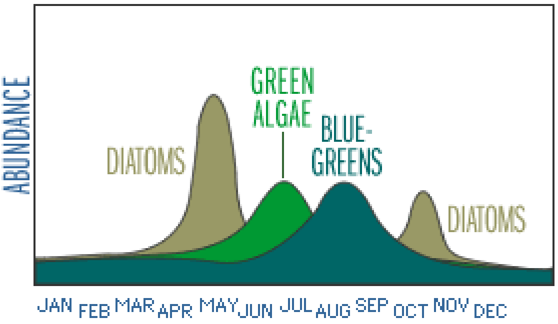

Figure 5-15
Seasonal Algae Community Succession
Source: Water on the Web

Chlorophyll-a appears to follow the classic model on Fox Lake for the Deep Hole site. Values are low in the winter and reach their peak in late summer (Figure 5-16). Chlorophyll-a values ranged from 1- 88 ug/l with the minimum occurring late May and the maximum occurring in late August. Prior investigations on the Fox Lake algae community found that during clear-water conditions in 1995, the algae community was dominated by Green algae and Flagellates in early summer, Diatoms in July, and Blue-green algae in the late summer (Asplund and Johnson 1996). In turbid water years, the algae community was dominated by blue-green algae throughout the summer. It appears that the chlorophyll-a seasonal trend at the Deep Hole site fits the historic pattern for the clear-water year and reflects the expected trends illustrated in Figure 5-14.

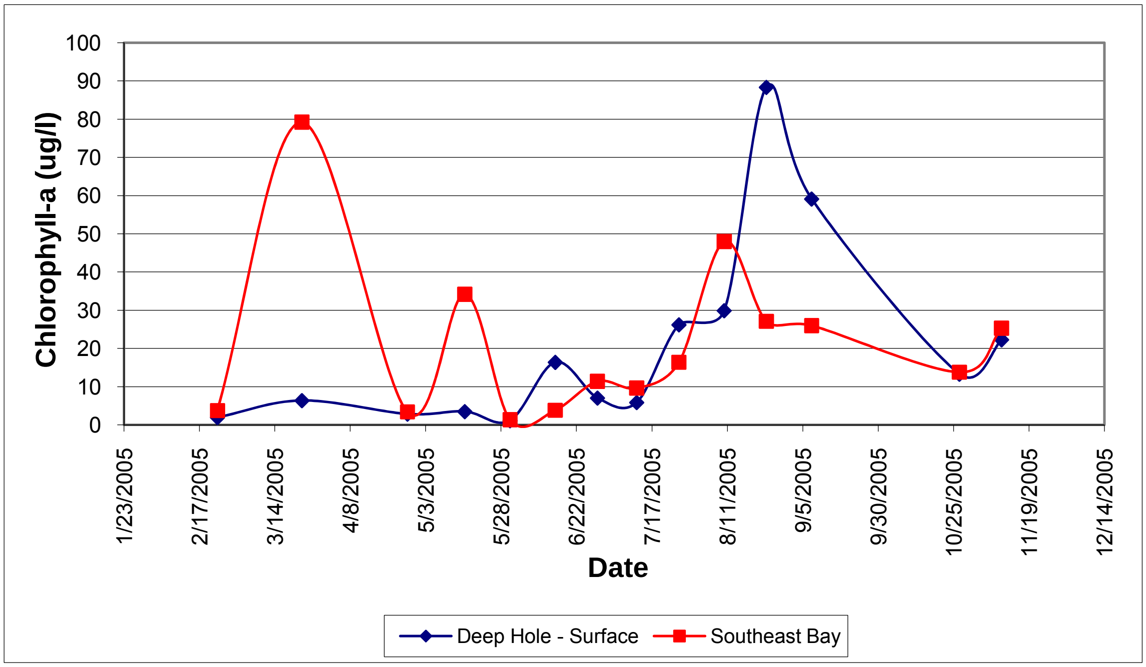

Figure 5-16
Chlorophyll-a (ug/l) for Fox Lake 2005
Source: University of WI-Milwaukee

The patterns in the Southeast Bay are similar to the pattern observed at the Deep Hole site with the exception of increased chlorophyll-a in the early spring and occurring slightly earlier. Because of the shallow depth of the Southeast Bay, it is likely the observed lag time was the result of warmer water in the bay versus mid-lake.

The early spring high chlorophyll-a levels were likely the result of a combination of nutrient re-suspension from bottom sediments due to wind and a rapid increase in temperature once ice-off occurred allowing for rapid reproduction. Since historic measurements were not taken in March, there is no means to assess whether this is a typical annual pattern in the Southeast Bay. It is likely that the initial algal biomass was subsequently reduced by zooplankton grazing. A second increase in algal biomass was likely caused by changing lake conditions and predominance of Green algae. The low values maintained throughout the summer reflect the dense aquatic plant growth in the Southeast Bay and competition for light and nutrients. Plants also act as a refuge for some types of zooplankton so localized consumption of algae may also have occurred. The increase in chlorophyll-a in late summer was coincident with aquatic plants annual senescence and was likely blue-green algae. The relatively fast decline in chlorophyll-a relative to the Deep Hole is likely due to the relatively fast cooling in the bay.

The boxplots depict very similar distribution of chlorophyll-a between the Deep Hole and the Southeast Bay, but do not capture the seasonal variability that occurred (Figure 5-17).

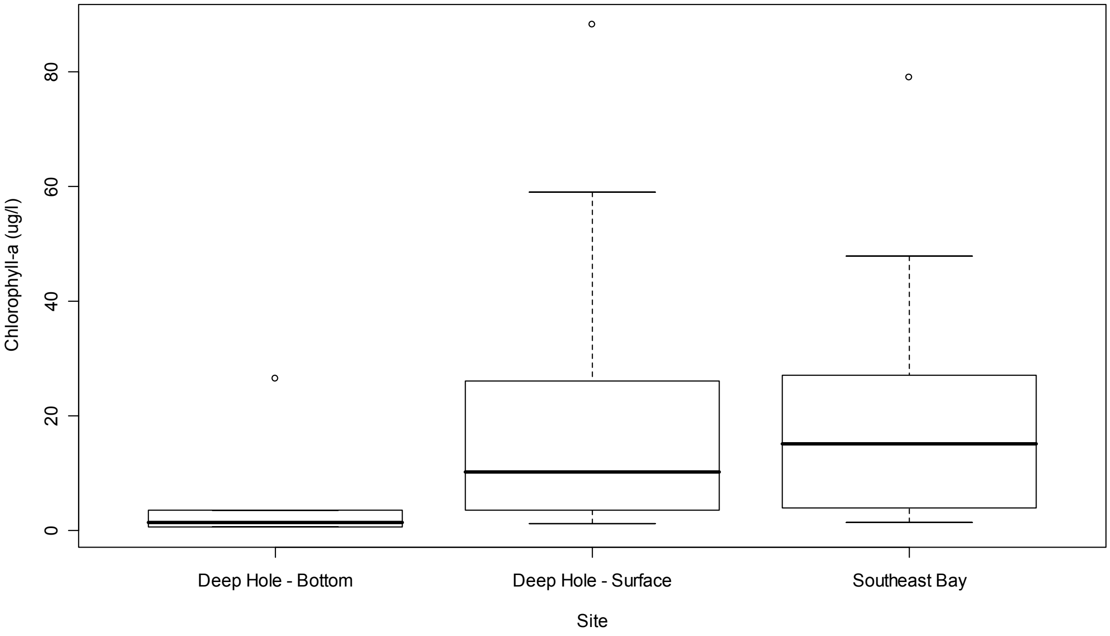

Figure 5-17
Boxplots of Chlorophyll-a (ug/l) for Fox Lake 2005
Source: University of WI-Milwaukee

Total Solids

Total solids are dissolved solids plus suspended and settleable solids in water. Dissolved solids consist of calcium, chlorides, nitrate, phosphorus, iron, sulfur, and other ions that are less than 2-microns in size. Total solids affect water clarity. Higher solids decrease the passage of light through water limiting photosynthesis by aquatic plants. Water will also warm more rapidly and hold more heat when total solids are high. Sources of total solids include industrial discharges, sewage, fertilizers, road runoff, and soil erosion.

Total solids were highest in Fox Lake during the winter months and relatively constant over the rest of the year (Figure 5-18). Since the highest values are near the lake bottom in winter, the increase in total solids is capturing the same phenomenon causing elevated turbidity. This is likely a combination of anoxia and aerator operation. Figure 5-19 shows the data distribution as boxplots and identifies the elevated values in winter as outliers which means they are atypical. The boxplots indicate there is no difference in total solids relative to depth or location.

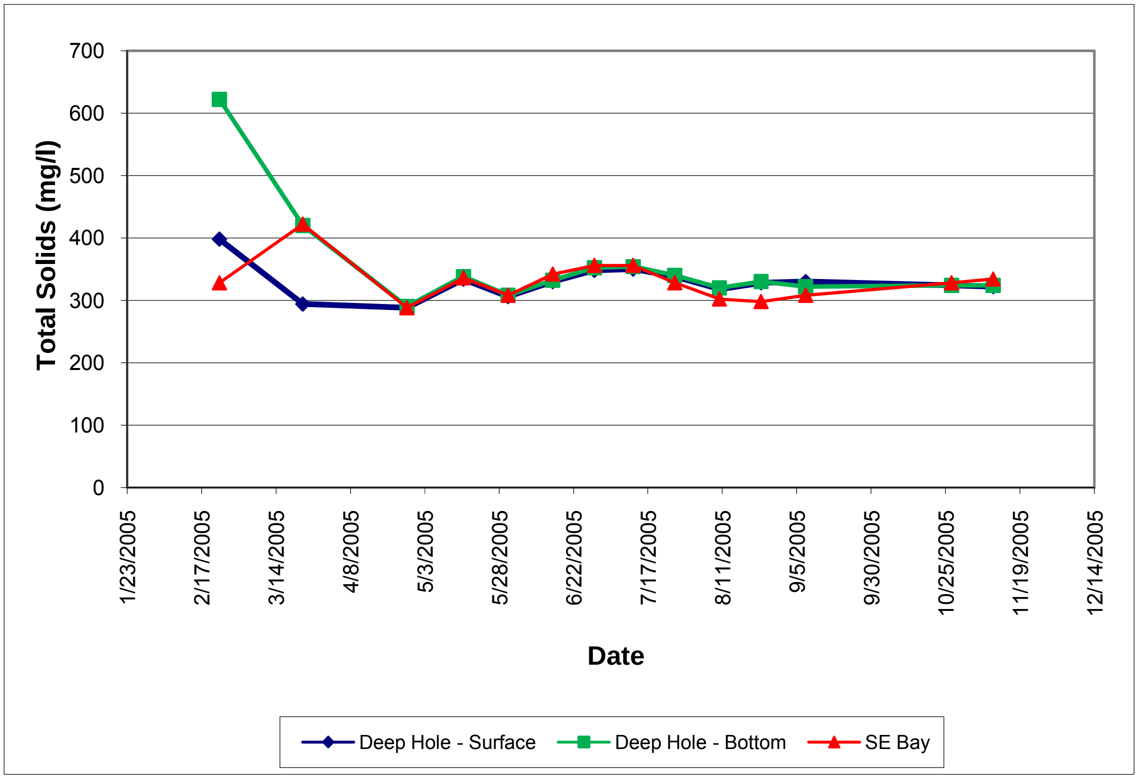

Figure 5-18
Total Solids (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

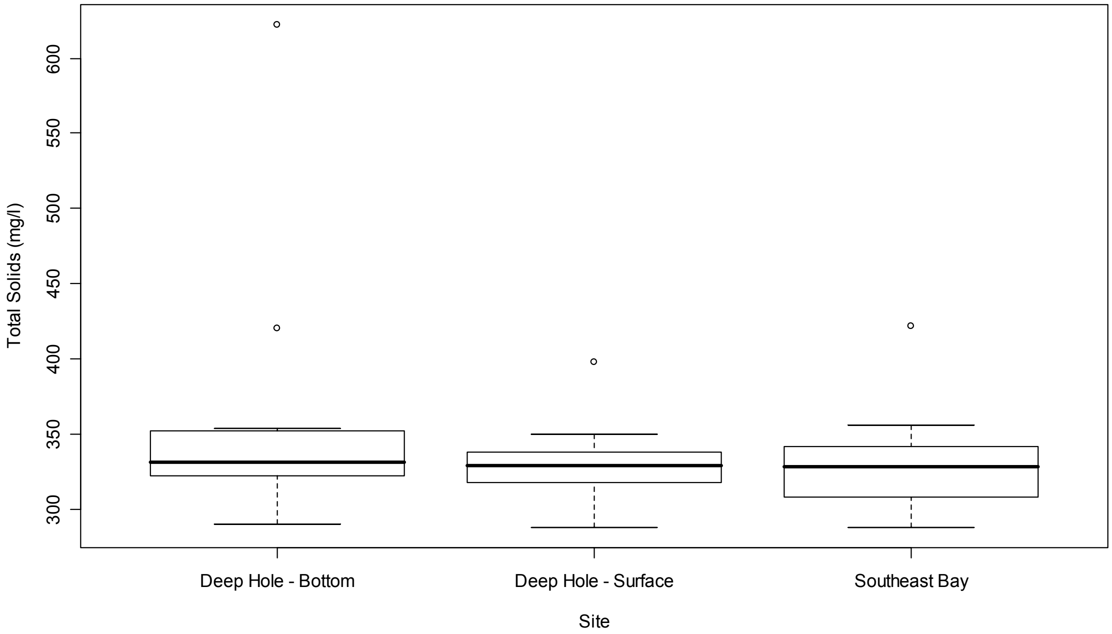

Figure 5-19
Total Solids (mg/l) Boxplot for Fox Lake 2005
Source: University of WI-Milwaukee

Total Suspended Solids

Total suspended solids (TSS) include all particles suspended in water which will not pass through a filter. Suspended solids are associated with nonpoint source pollution, such as soil erosion from agricultural and construction sites. As levels of TSS increase, a water body begins to lose its ability to support a diversity of aquatic life. Suspended solids absorb heat from sunlight, which increases water temperature and subsequently decreases levels of dissolved oxygen. Warmer water holds less oxygen than cooler water. Photosynthesis also decreases, since less light penetrates the water causing less oxygen to be produced by plants and algae. TSS can also destroy fish habitat because suspended solids settle to the bottom and cover coarse bottom materials. Suspended solids can smother the eggs of fish and aquatic insects, and can suffocate newly-hatched insect larvae. Suspended solids can also harm fish by clogging gills, reducing growth rates, and lowering resistance to disease.

The TSS levels in Fox Lake were generally low at all sites, but large spikes were measured in winter near the lake bottom and at all sites in early summer (Figure 5-20). Because both dissolved solids (inferred by specific conductance) and total suspended solids were both elevated in winter, it is likely that the physical disturbance of the lake bottom by the aerator is causing the increase in both values. The boxplots show no differences between sites or depth and the high values are identified as outliers (Figure 5-21). The high values at all sites in early summer may be due to a large runoff event.

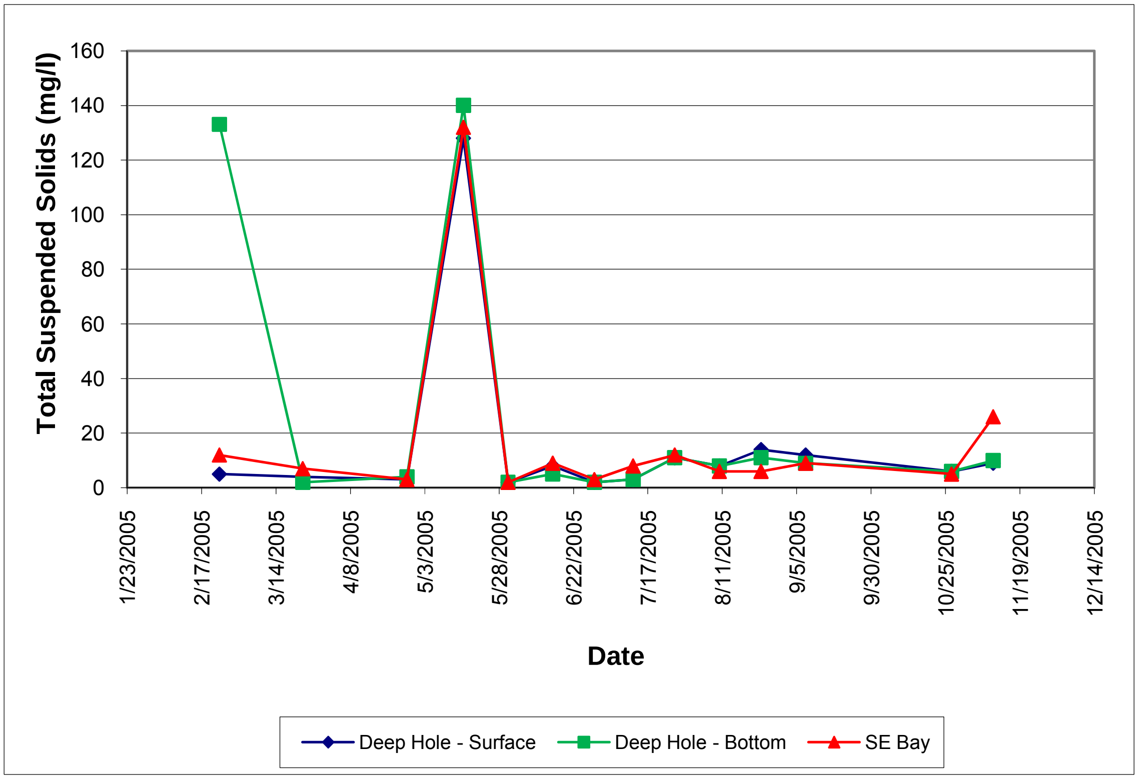

Figure 5-20
Total Suspended Solids (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

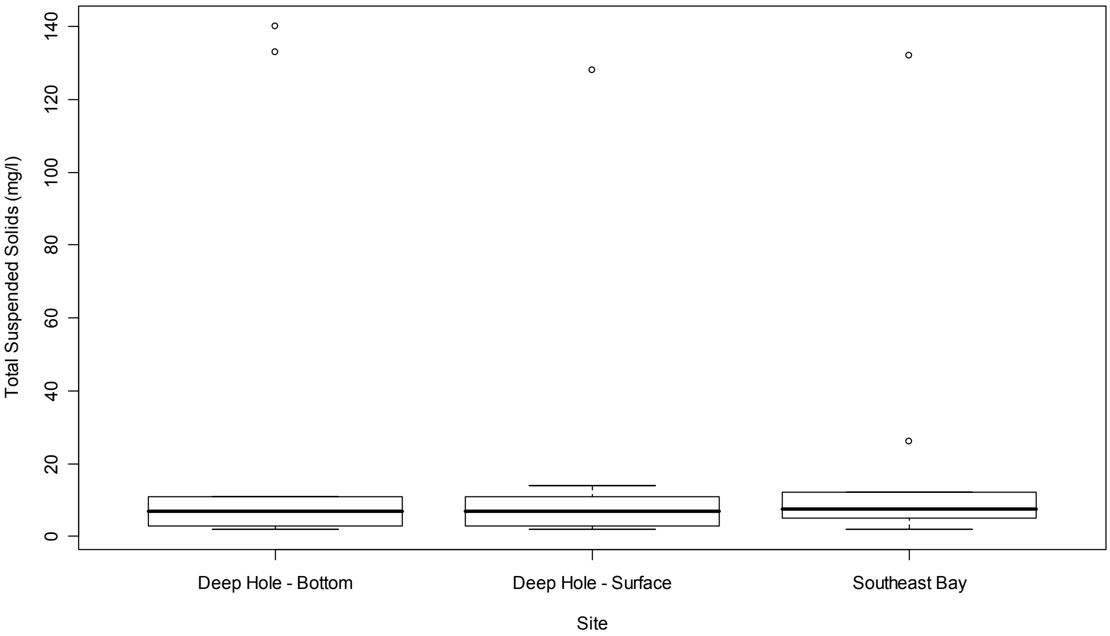

Figure 5-21
Boxplots of Total Suspended Solids (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

Nutrient Characteristics

Aquatic plants and algae require nutrients such as phosphorus, nitrogen, carbon, calcium, chlorides, iron, magnesium, sulfur, and silica for growth. In lakes where the supply of one or more of these nutrients is limited, plant and algae growth may also be limited. The two nutrients that most often limit and control the growth of plants are nitrogen and phosphorus. In nutrient limited lakes, if you add more nitrogen or phosphorus, you will get more plant or algae growth.

Nitrogen to Phosphorus Ratio

The ratio of total nitrogen to total phosphorus (N:P Ratio) in the lake can indicate which nutrient is likely to be limiting algal growth. When the total nitrogen to total phosphorus ratio is greater than 15:1, the lake is likely phosphorus limited, while a ratio of less than 10:1 indicates nitrogen is probably the limiting nutrient. Intermediate values indicate co-limitation. Lakes within the State of Wisconsin have a mean total nitrogen concentration of 0.86 mg/L and a mean total phosphorus concentration of 0.031 mg/L and are generally phosphorus limited (Lillie and Mason 1983). Fox Lake is nitrogen limited or co-limited in spring and summer and phosphorus limited in the fall (Figure 5-22); however, because Fox Lake's nutrient concentrations are very large relative to other Wisconsin lakes, the lake is likely limited by light attenuation.

Phosphorus

Fox Lake's annual average total phosphorus is 0.144 mg/l, or more than 4 times the state average (Figure 5-23); and total nitrogen is 1.477 mg/l, or nearly double the state average at the Deep Hole–Surface station. Lakes become eutrophic at ~0.050 mg/l of total phosphorus. As a result, adding more nutrients will not likely change the algal or plant density because the lake is saturated with nutrients.

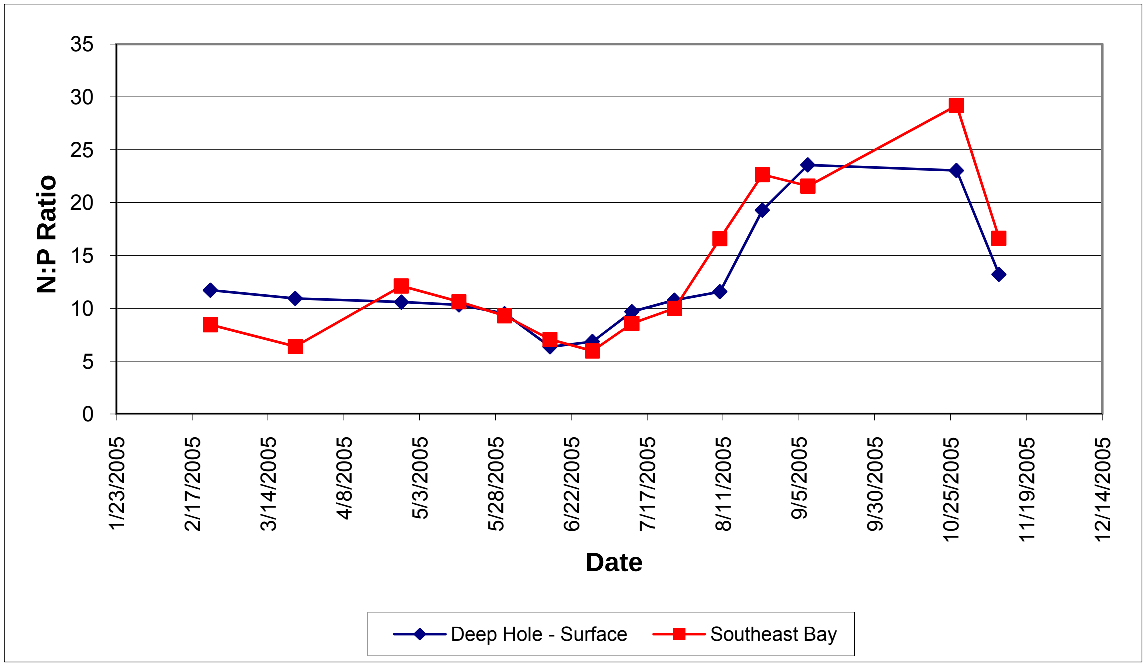

Figure 5-22
Nitrogen to Phosphorus Ratios for Fox Lake 2005
Source: University of WI-Milwaukee

The total phosphorus for Fox Lake was highest in the winter and spring for all sites and generally decreased over the year (Figure 5-23). The total phosphorus concentration at the monitoring stations is uniform (Figure 5-24) which is typical of a shallow, well mixed lake.

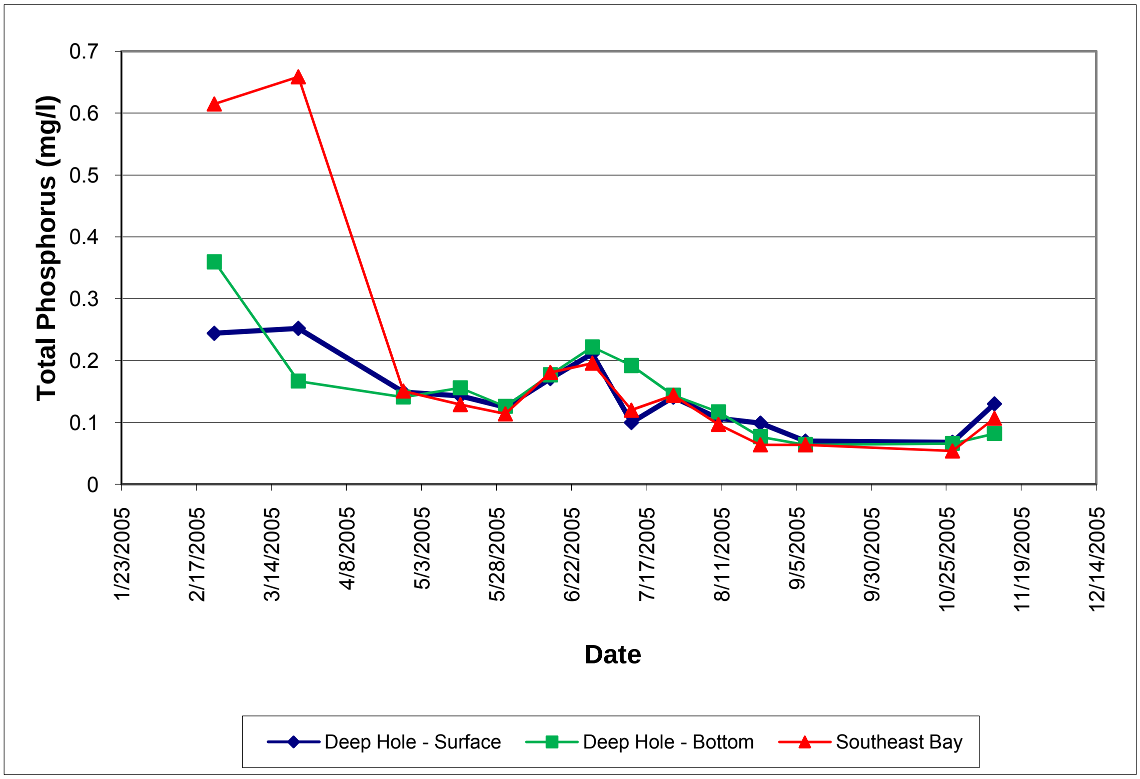

Figure 5-23
Total Phosphorus (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

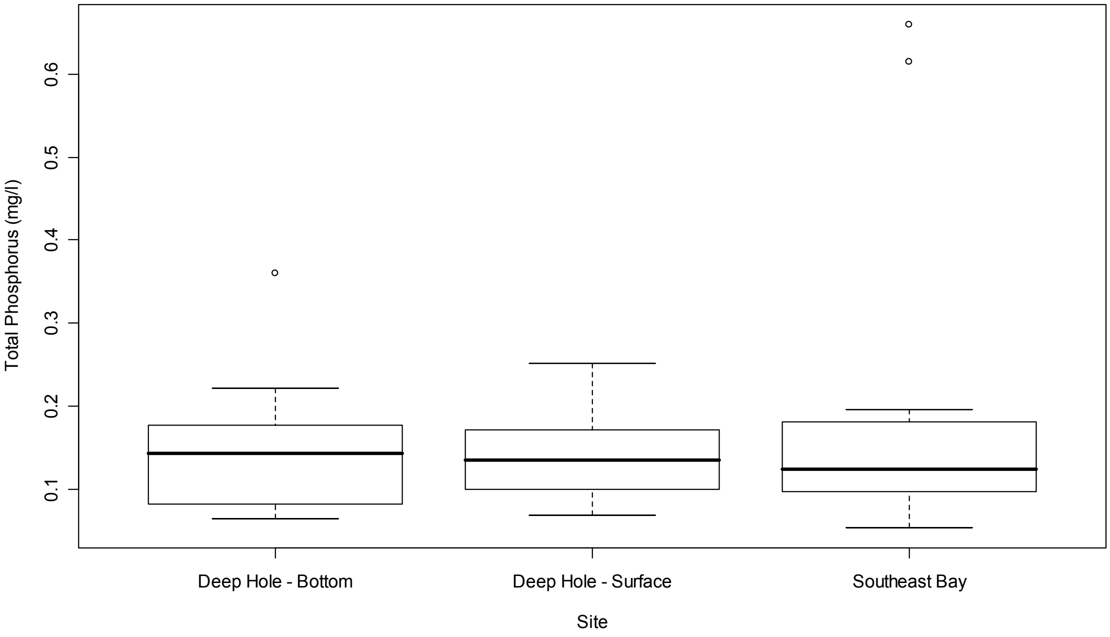

Figure 5-24
Total Phosphorus (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

Dissolved ortho-phosphate (DOP) is an important parameter for algal growth in lakes. In stratified lakes, the phosphorus that has accumulated in the lake sediments over time can be resolubilized and, as the lakes mix during spring and fall turnover, the dissolved phosphorus from the bottom of the lake can become available as a food source for algal cells higher in the water column, and a rapid growth of algae may occur. In well-mixed lakes, dissolved phosphorus concentrations generally tend to be low, but this is not the case in Fox Lake.

Figure 5-25 shows the DOP concentration over the duration of the monitoring period. There is relatively abundant DOP early in the year that generally declines over time. The relative availability of DOP suggests that temperature is limiting productivity early in spring. The influxes of DOP following the initial decline are likely the result of seasonal algae die-offs and changing algae community composition. Algae are very productive as conditions allow, but also die back quickly. As one group of algae die off, their cells breakdown and release DOP which is, in turn, taken up by other algae. The relatively high levels of DOP in summer may also indicate the un-utilized DOP is the result of light intensity insufficient to support algae at its maximum potential density.

Most lakes exhibit algae blooms when the spring turnover DOP is in excess of 0.01 mg/l and nuisance (more severe) algae blooms can be expected when spring turnover DOP exceeds 0.02 mg/l. Fox Lake's spring turnover DOP was 0.36 mg/l or tenfold higher than the value associated with nuisance algae blooms. The boxplots for DOP indicate there is no difference between sites (Figure 5-26).

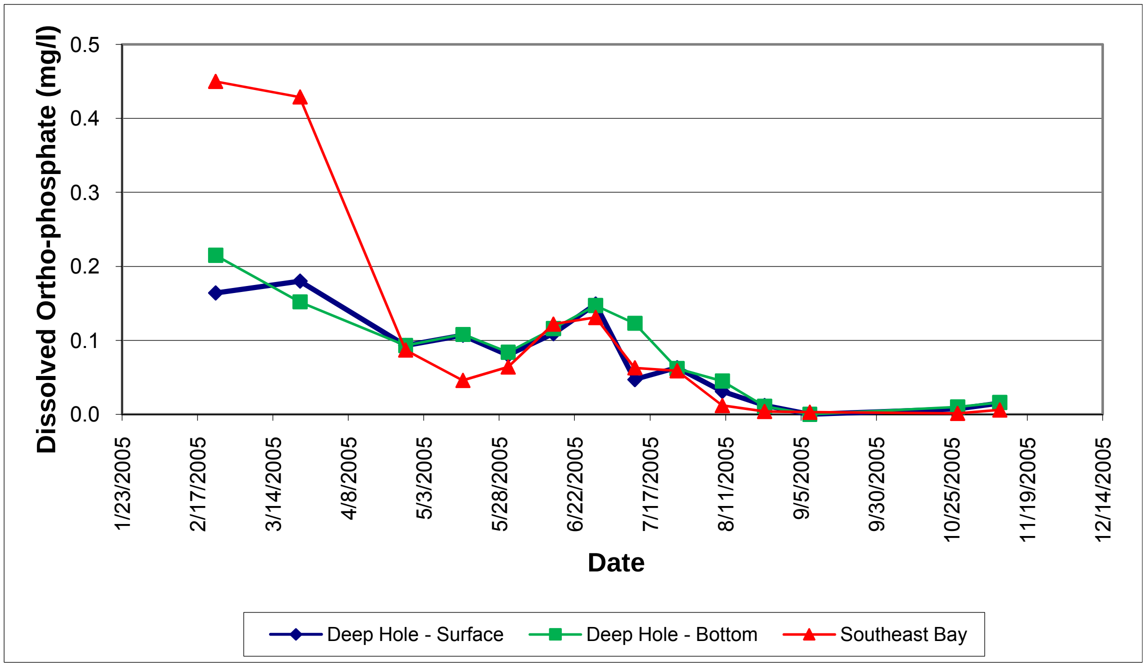

Figure 5-25
Dissolved Ortho-phosphate (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

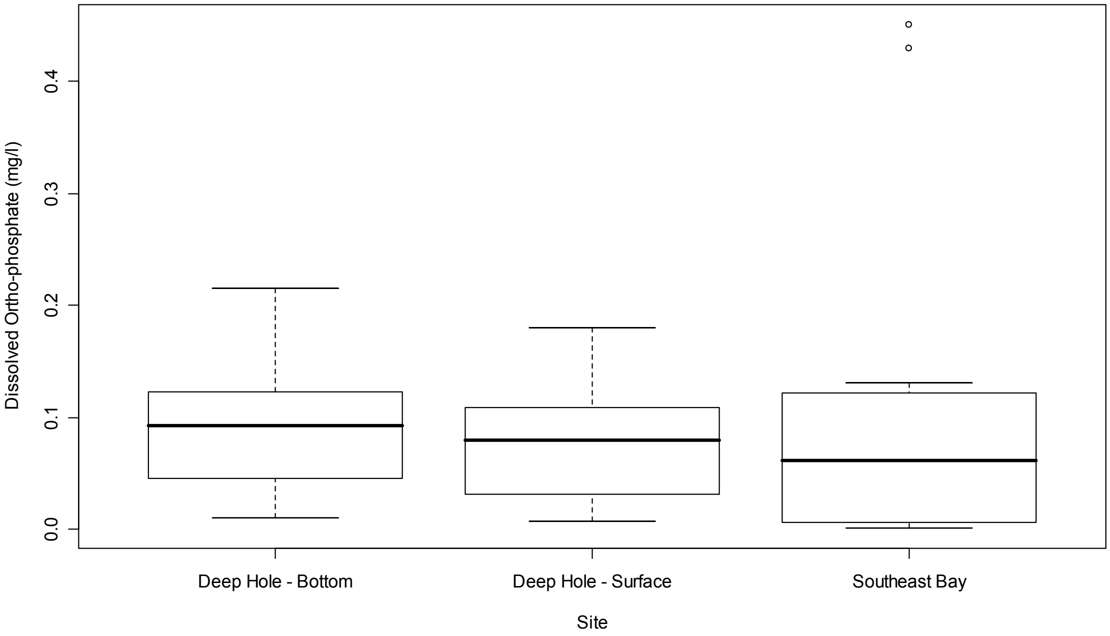

Figure 5-26
Boxplots of Dissolved Ortho-phosphate (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

Nitrogen

The amount of nitrogen in lake water usually corresponds to local land uses. Nitrogen may come from fertilizer and animal wastes on agricultural lands, human waste from sewage treatment plants or septic systems, and lawn fertilizers used on lakeshore property. Nitrogen may enter a lake from surface runoff or groundwater sources. Nitrogen exists in lakes in several forms (Figure 5-27). Total nitrogen is calculated by adding nitrate and nitrite (NO3+NO2) to Kjeldahl nitrogen. Organic nitrogen, or Kjeldahl nitrogen, is often referred to as biomass nitrogen. Nitrogen does not occur naturally in soil minerals, but is a major component of all organic matter. Decomposing organic matter releases ammonia, which is converted to nitrate if oxygen is present. This conversion occurs more rapidly at higher water temperatures. All inorganic forms of nitrogen (NO_{3-}, NO_{2-} and NH_{4+}) can be used by aquatic plants and algae. If these inorganic forms of nitrogen exceed 0.3 mg/l in spring, there is sufficient nitrogen to support summer algae blooms.

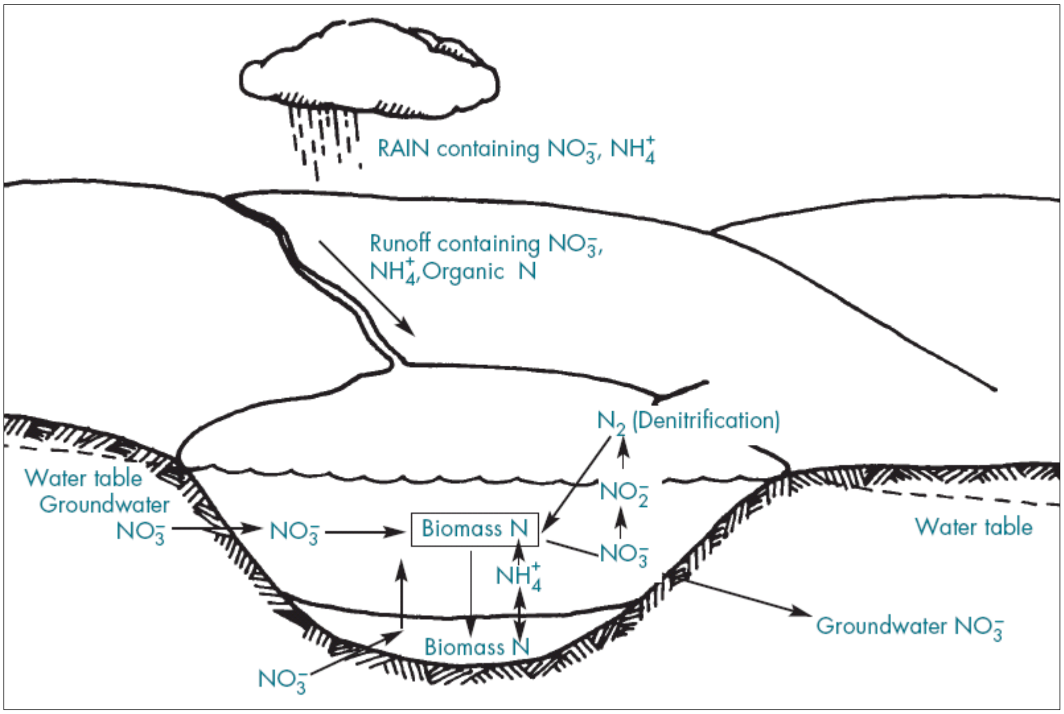

Figure 5-27
Typical Nitrogen Cycle
Source: UW-Extension and SEWRPC

Low nitrogen levels do not guarantee limited algae growth in the same way low phosphorus levels do. Nuisance blue-green algae blooms are often associated with lakes that have low nitrogen to phosphorus (N:P) ratios. These algae use atmospheric nitrogen gas (N_2) dissolved in lake waters as a nitrogen source in contrast to other types of algae and plants which utilize inorganic nitrate and ammonium forms of nitrogen.

Nitrogen concentrations measured during the monitoring periods are higher than the statewide mean total nitrogen concentration of 0.86 mg/l for lakes, but are close to the mean for southeastern Wisconsin of 1.43 mg/l (Figure 5-28). Boxplots show similar data distribution for total nitrogen at all three sites (Figure 5-29).

Recent studies in Wisconsin lakes have shown that, while phosphorus is usually the limiting nutrient for algae, nitrogen in the lake sediments is typically the limiting nutrient for rooted aquatic plants especially Eurasian water-milfoil. Both nitrogen and phosphorus should be of concern when developing a lake protection plan.

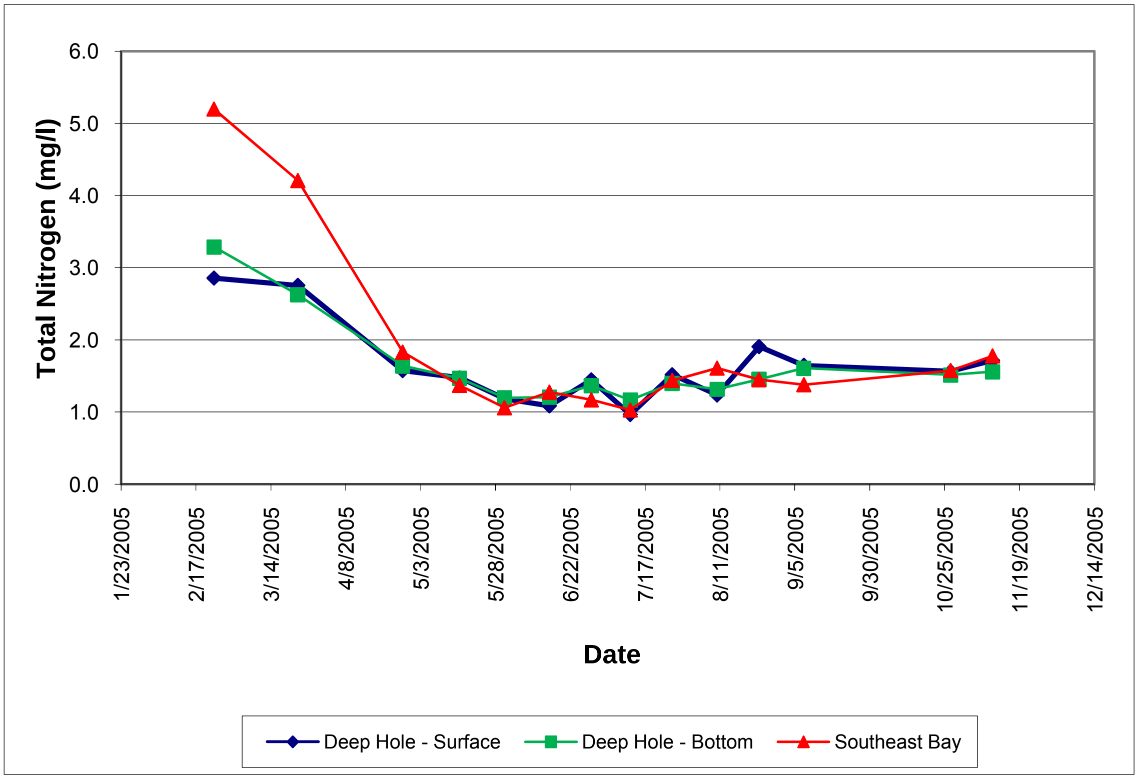

Figure 5-28
Total Nitrogen (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

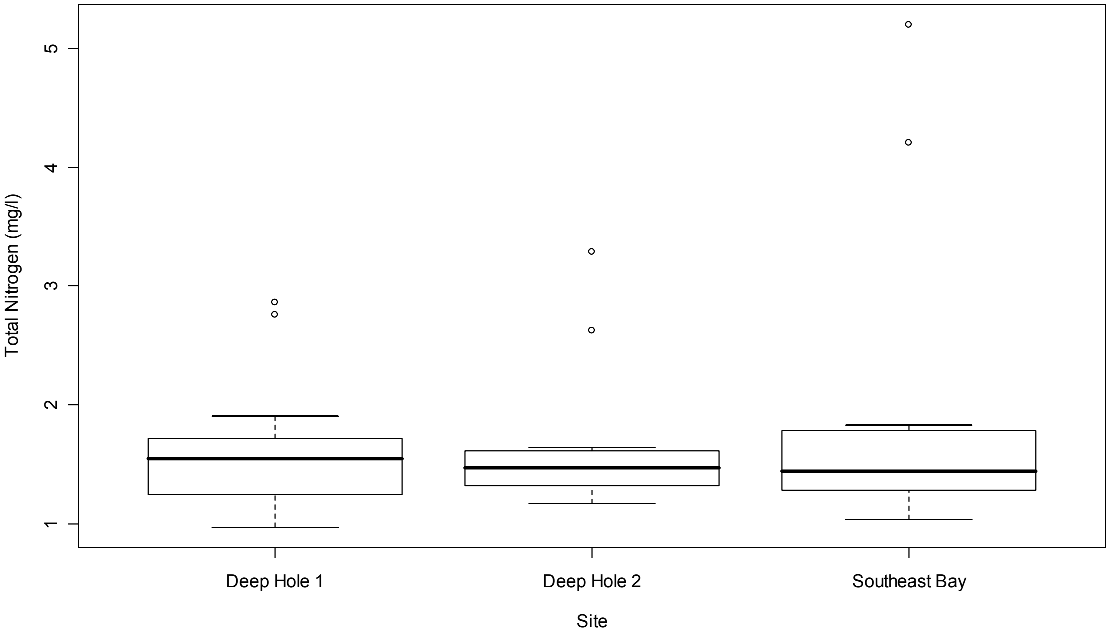

Figure 5-29
Boxplots for Total Nitrogen (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

The total Kjeldahl nitrogen (TKN) is an indicator of the amount of biomass and other organic materials in the water column. High levels of organic nitrogen in water may indicate excessive production or organic pollution from the watershed. This type of pollution includes animal and human waste. TKN levels in excess of 0.50 mg/l may indicate some form of pollution. These levels are exceeded in Fox Lake (Figures 5-30 and 5-31), but likely reflect high levels of biomass or a combination of biomass and watershed sources.

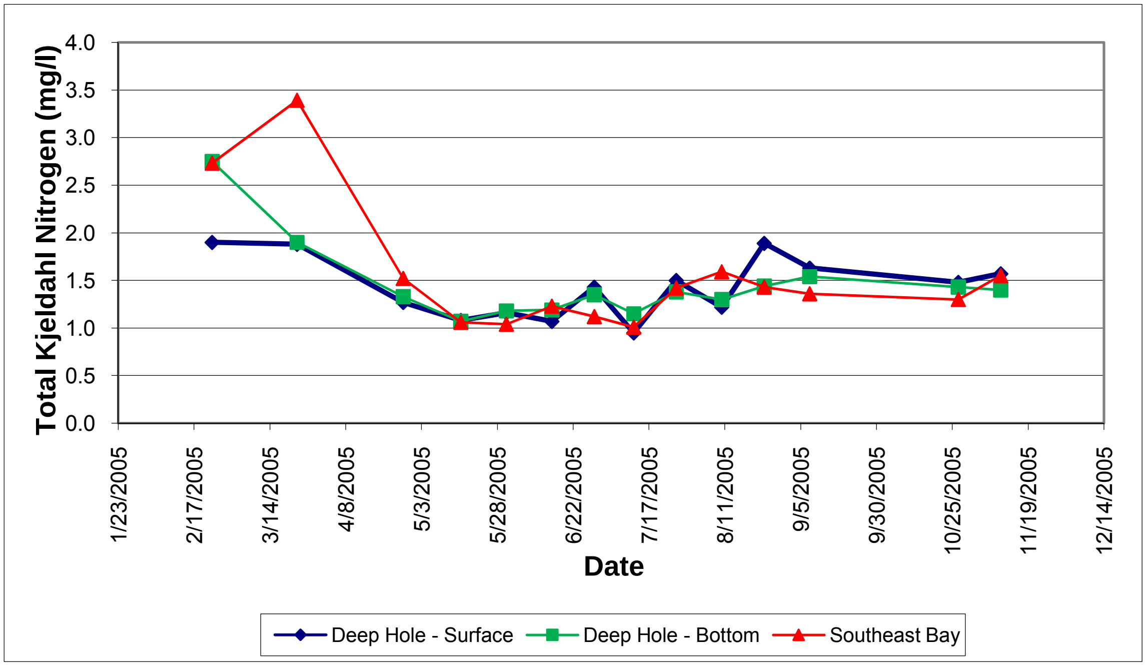

Figure 5-30
Total Kjeldahl Nitrogen (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

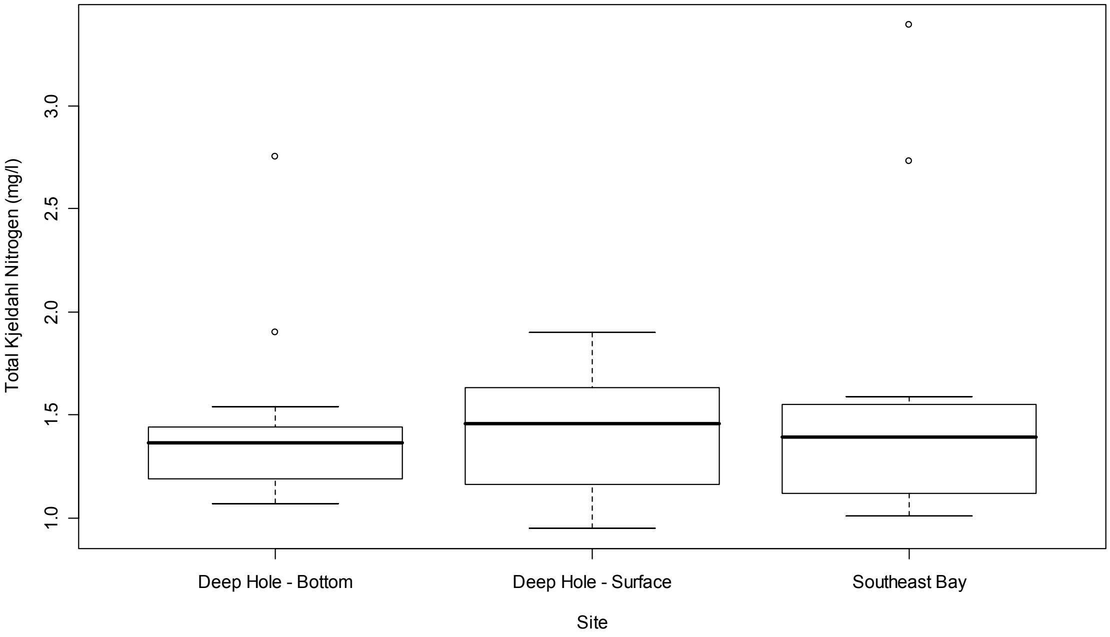

Figure 5-31
Boxplots of Total Kjeldahl Nitrogen (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

The nitrate-nitrite measurements in the early spring exceed 0.3 mg/l, indicating that algae blooms should be common in Fox Lake (Figures 5-32 and 5-33). There is also strong evidence that nitrate-nitrite is limiting beginning in May and continuing throughout the rest of the year. In many systems with abundant phosphorus and limited nitrogen, blue-green algae become the dominant algae group. Nitrogen limitation may also induce a crash in the zooplankton community because many blue-green algae are not desirable as a food source.

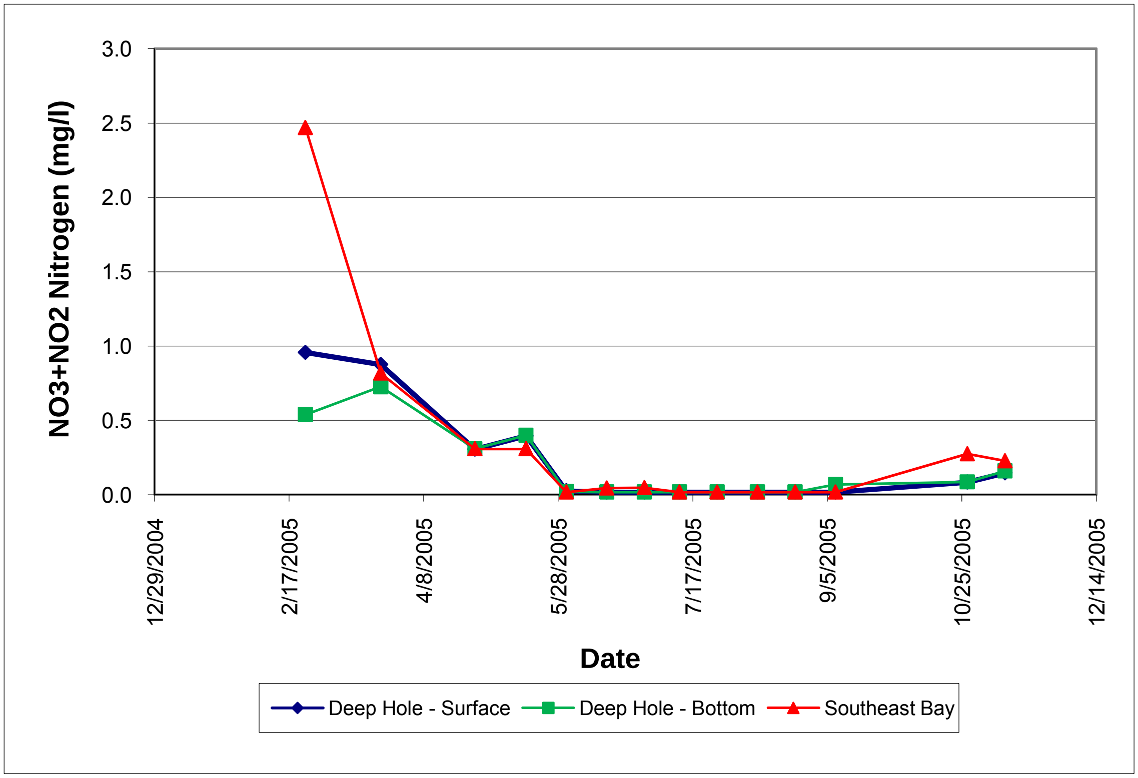

Figure 5-32
Nitrate + Nitrite (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

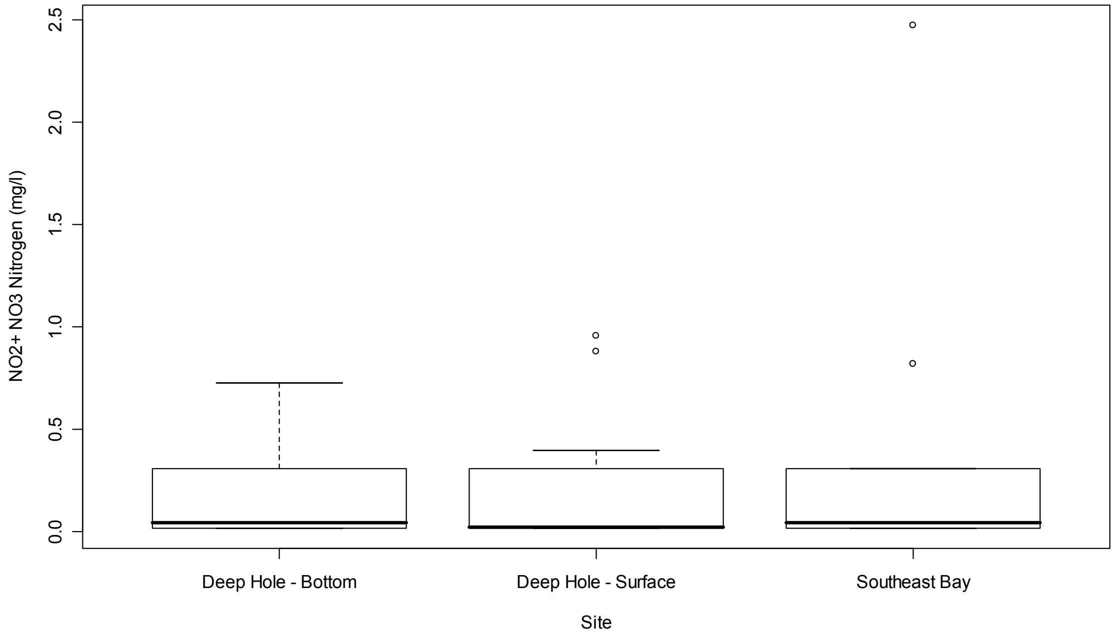

Figure 5-33
Boxplots of Nitrate + Nitrite (mg/l) for Fox Lake 2005
Source: University of WI-Milwaukee

Total Phosphorus and Chlorophyll-a Historic Data Analysis

A nested analysis of variance (ANOVA) was conducted to explore the yearly and seasonal variation in Total Phosphorus and Chlorophyll-a for data collected at the Deep Hole in Fox Lake between 1990 and 2005. Data were categorized by meteorological season, based upon the month the sample was collected. Not all seasons were sampled in all years, resulting in unequal replication.

The ANOVA tables summarize the results of fitting a general linear statistical model relating Total P and Chl A to the 2 predictive factors. The ANOVA table for Total P tests the statistical significance of each of the factors as it was entered into the model (Table 5-4). Notice that the highest P-value is 0.0305, belonging to Season (Year). Since the P-value is less than 0.05, that term is statistically significant at the 95% confidence level. Since the P-value is less than 0.05, there is an indication of possible serial correlation.

Serial correlation occurs as successive values in time series are correlated with one another. Serial correlation needs to be taken into account when testing significance of the correlation between two time series. Serial correlation can severely reduce the effective number of degrees of freedom in a time series when evaluating trends.

The R-Squared statistic indicates that the model as fitted explains 51.8903% of the variability in Total P. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 37.5418%. The standard error of the estimate shows the standard deviation of the residuals to be 59.7336.

Table 5-4
Analysis of Variance for Total Phosphorus

```
Type III Sums of Squares
------------------------------------------------------------------------------------
Source                     Sum of Squares     Df   Mean Square    F-Ratio    P-Value
------------------------------------------------------------------------------------
Year                             171671.0     14       12262.2       3.44     0.0005
Season (Year)                     34086.0      3       11362.0       3.18     0.0305
Residual                         203382.0     57        3568.1
------------------------------------------------------------------------------------
Total (corrected)                422746.0     74
```

The second ANOVA table for Chl A tests the statistical significance of year and seasonal factors (Table 5-5). Since the P-value for Year and Season (Year) are less than 0.01, they are statistically significant at the 99%confidence level. The R-Squared statistic indicates that the model as fitted explains 82.6213% of the variability in Chl A. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 69.816%. The standard error of the estimate shows the standard deviation of the residuals to be 26.9152.

Table 5-5
Analysis of Variance for Chlorophyll A

```
Type III Sums of Squares
------------------------------------------------------------------------------------
Source                     Sum of Squares     Df   Mean Square    F-Ratio    P-Value
------------------------------------------------------------------------------------
Year                              77083.8     13       5929.52       8.19     0.0000
Season (Year)                     32690.2      3       2179.34       3.01     0.0030
Residual                          27528.3     38       724.428
------------------------------------------------------------------------------------
Total (corrected)                158403.0     66
```

Figures 5-34 and 5-35 show the yearly least-square means in Total P and Chl A together with the 95% confidence intervals calculated with error-estimates from the nested analysis of variance. In other words, these are the “seasonally-adjusted” means and the error bars indicate how different another value must be in order to be confident that the difference is not by chance. If the confidence bars do not overlap, then you can be 95% confident that the values are not equal. For Phosphorus, this shows that the two years with extreme lower and higher values were 1992 and 1997 respectively, and significant declines through 1999. Chl A was highest in 1997 and lowest in 2005.

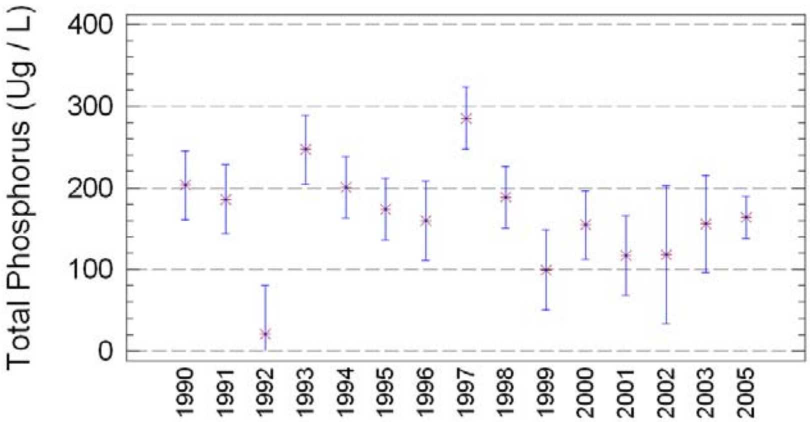

Figure 5-34
Deep Hole Total Phosphorus 1991-2005

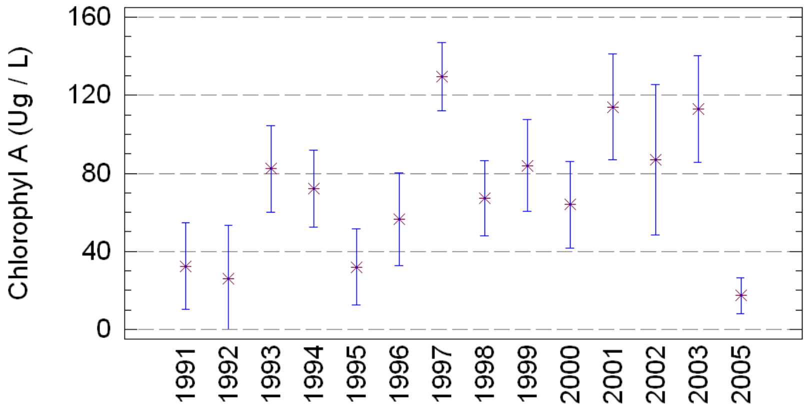

Figure 5-35
Deep Hole Chlorophyll-a 1991-2005

Trophic State Index

The trophic state index (TSI) assigns a trophic condition rating based on Secchi disk transparency and total phosphorus and chlorophyll-a concentrations and can be used to summarize the quality of a lake. The trophic state index was developed by Carlson in 1977 to compare the three water quality values on a scale from 0 to 100. A version of the original TSI has been calibrated for Wisconsin lakes by the Wisconsin Department of Natural Resources in 1993 with values ranging from 0-110 (Lillie et al. 1993). Values from 0 to 39 describe lakes defined as oligotrophic—lakes that are generally clear, deep, and free of rooted aquatic plants and algae blooms. Values above 50 define eutrophic lakes—lakes that are high in nutrients and tend to support a large biomass of rooted aquatic plants and algae. Mesotrophic lakes with values from 35 to 50 lie between oligotrophic and eutrophic lakes, and are typical of undisturbed lakes in southeastern Wisconsin. Expectations for each TSI score range are summarized in Table 5-6. The summer growing season mean, or SGSM, value is used to calculate TSI scores.

Table 5-6

Expected Lake Conditions Relative to Trophic Status Index Scores

Source: Carlson 1996

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

The WI-TSI scores for Fox Lake are summarized in Table 5-7. They each indicate that Fox Lake is hyper-eutrophic, but relatively large variations occurred based on the parameter used to calculate the WI-TSI.

Table 5-7

Wisconsin Trophic Status Index Scores for Fox Lake 2005

Source: UW-Milwaukee

WI-Trophic State Index Score		
Total Phosphorus	Chlorophyll-a	Secchi Depth
66.3	60.2	53.9

Comparing the individual TSI scores (total phosphorus to Secchi depth to chlorophyll-a) can provide valuable insight into potential environmental conditions driving trophic state. Table 5-8 summarizes the probable environmental conditions indicated by specific relationships between TSI scores.

Table 5-8

Relationships Among Trophic Status Index Scores

Source: Carlson 1996

Relationship Between TSI Variables	Conditions
TSI(Chl) = TSI(TP) = TSI(SD)	Algae dominate light attenuation
TSI(Chl) > TSI(SD)	Large algal particulates dominate
TSI(TP) = TSI(SD) > TSI(CHL)	Non-algal particulates or color dominate light attenuation
TSI(SD) = TSI(CHL) > TSI(TP)	Phosphorus limits algal biomass (TN/TP >15:1)
TSI(TP) >TSI(CHL) = TSI(SD)	Algae dominate light attenuation but some factor such as nitrogen limitation; zooplankton grazing or toxics limit algal biomass.

Fox Lake does not follow any of the general patterns, but conclusions can still be drawn from the relationships among TSI scores. The first is that Fox Lake is hyper-eutrophic and should be expected to support dense algal growth, dense aquatic plant growth, or some combination of the two. The second conclusion drawn from the relationship between TSI (TP) > TSI (CHL) scores is that algae dominate light attenuation but nitrogen limitation and zooplankton grazing are also important in limiting overall algae densities. A third conclusion is that relatively large algal particles may be dominant in the water column indicated by the TSI (CHL) > TSI (SD) relationship.

SUMMARY

Fox Lake is a shallow, well mixed hyper-eutrophic lake characterized by high nutrient levels, prolific algal growth, poor water clarity, and complex ecological interactions. In general, Fox Lake exhibits many of the characteristics expected of shallow lakes such as periods of limited anoxia and uniform distribution of most water quality measurements for most of the year including nutrients. Data suggests the lake is alternately nitrogen and phosphorus limited, but the role of zooplankton is likely just as important in limiting chlorophyll-a-related turbidity as nutrient levels.

There is some oxygen depletion in the winter and summer months in the deeper (>5 m) 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; however, the aeration system appears to be causing physical re-suspension of bottom sediment. The suspended bottom sediment is causing increases in suspended solids, dissolved solids, and turbidity. 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 is currently either: 1) exhibiting a directional shifting back to the turbid water that was dominant for many years prior to 1995 or 2) exhibiting patterns related to cyclical annual variations in water clarity while maintaining the clear-water state. Prior to the clear-water year in 1995, the water clarity was consistently poor throughout the growing season. Since 1995, water clarity was both more variable and generally greater in June and decreases over the growing season. This pattern suggests some ecological cycle has been altered in the lake. The future monitoring of water clarity should reveal the direction (or lack of) in the lake’s condition.

Total phosphorus trends show a peak in 1997, following the lake drawdown, and alternating years of relatively high and low values. Chlorophyll-a also peaked in 1997 and were lowest in 2005.

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CHAPTER 6: LAKE BIOLOGICAL CONDITIONS

INTRODUCTION

Fox Lake has a long history of management and monitoring of biological conditions in the lake including fish monitoring, fish stocking, rough fish removal, aquatic plant management and monitoring, and zooplankton and phytoplankton sampling. Based upon an analysis of the ecological and trophic status of Fox Lake and a comprehensive survey conducted in 1995 (Asplund and Johnson, 1996), management recommendations for the fishery of Fox Lake were established. These goals were designed to promote a “clear-water phase” by using a top-down food-web approach to increase the abundance of large algae-eating zooplankton by reducing the numbers of plankton eating fish through the promotion of piscivorous fish species.

Figure 6-1 illustrates the general model used to understand the interactions of biological and non-biological components related to shallow lakes shifting from clear to turbid states.

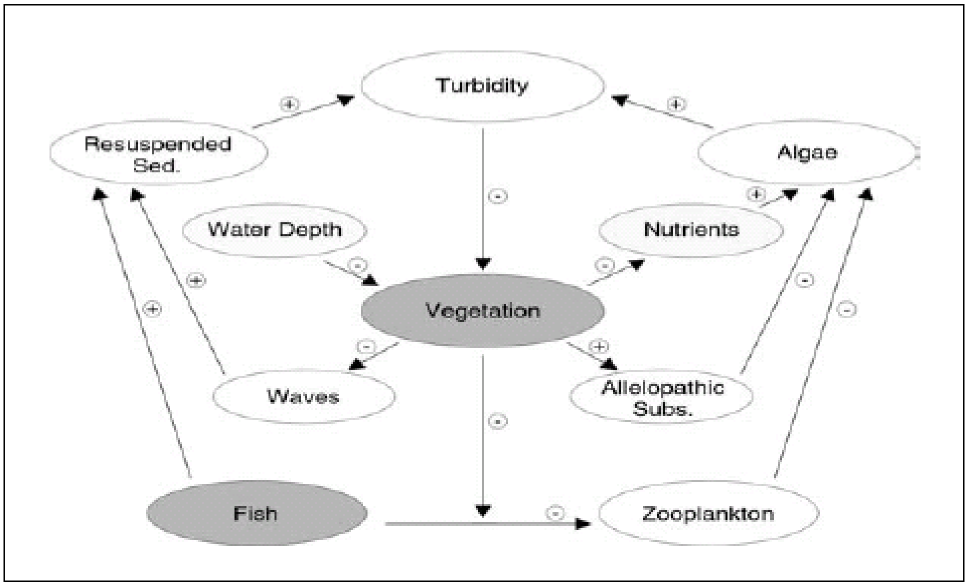

Figure 6-1
Ecological Model for Shallow Lakes
Source: Scheffer 2001

The goals resulting from the 1995 study included:

(1) Increase the recruitment of northern pike and walleye:

Actions that were proposed included:

- Improvement of northern pike habitat by promoting sediment compaction and improvement in the abundance of suitable vegetation by conducting a summer drawdown.
- Manage lake water levels to encourage increases in submergent plant growth and maintain emergent plants in marsh areas.
- Control carp populations and reduce their access to pike spawning areas.
- Increase the recruitment of northern pike and walleye by stocking.
- Increase the abundance of large predator species by reducing harvest on bass, northern pike and walleye.

(2) Promote the development of a yellow perch / bluegill dominated planktivore community:

Actions proposed included:

- Establish aquatic vegetation in littoral zones
- Increase predator abundance to control crappie reproduction
- Encourage increased angler harvest of crappie.

(3) Reduce the carp population:

Actions proposed included:

- Commercial carp fishing
- Chemical spot treatment
- Increase predatory fish species to reduce young-of-year carp.

To assess whether the lake management goals were being met, the initial lake-wide assessment in 1995 has been followed by a series of additional studies. Another comprehensive fishery survey of Fox Lake was conducted in 2000-2001 (WDNR, Stremick-Thompson 2001), which made use of numerous sampling methodologies including seining, gill-netting, fyke and mini-fyke netting, and electrofishing and included sampling in different seasons of the year. Yearly fall electrofishing surveys have been conducted annually from 2002-2006. Zooplankton monitoring was conducted in 2005. Aquatic plant surveys have occurred from 2003-2005. The following sub-sections summarize the results of these surveys and their relationship to the overall trophic status of Fox Lake.

Fishery Conditions

The 2001 comprehensive survey was followed with yearly fall electrofishing surveys that have been conducted from 2002-2006 (Stremick-Thompson 2006). Fall electrofishing was conducted on Fox Lake on October 11 and 18, 2006 using a large boomshocker. Numbers were standardized by total effort in the form of time spent shocking and/or miles of shoreline shocked. 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.

The yearly trends in the total weighted abundances of major fish species are presented in Figure 6-2. With respect to predator species, walleye have increased consistently in abundance from about 20 per hour to over 100 per hour. This 5-fold increase in walleye, due largely to stocking efforts, was paralleled by increased largemouth bass due to natural reproduction. Largemouth abundance increased from around 2 fish per hour in 2002 to over 60 per hour in 2006. Northern pike abundance on the other hand has not increased to nearly the same extent during the same period (from about 1 fish per hour in 2002 to 4 fish per hour in 2006). It will be interesting to see if the northern pike recruitment improves as a result of the increase in high-quality vegetation habitat for spawning. Musky remain at a consistently low abundance, maintained by stocking.

The trend for increased abundance in both walleye and largemouth bass is curious, to say the least, and may not be stable for the future. Recent research in Wisconsin (Fayram 2005) suggests that management efforts to support walleye populations with stocking and to simultaneously maximize largemouth bass may be unrealistic due to the shared resource requirements and predatory relationship between the species. The tapering off of the trend in abundance in 2005 and 2006 suggest that they may be close to the maximum levels that Fox Lake can support.

The jump in largemouth bass abundance correlated with the increase in aquatic vegetation in 2005 and 2006 is consistent with the observation that bass are littoral-vegetation specialists with respect to their foraging behaviors and do significantly better ecologically in lakes with healthy littoral vegetation zones (Werner et al, 1990). The increase in bluegill abundance of the same period may also be related to the establishment of littoral vegetation, which allows for niche partitioning among bluegill size classes (Mittlebach 1984) between vegetation and open water habitats.

Because perch grow through a series of ontogenetic niche shifts, from planktivore, to benthivore, and finally to piscivore, it is difficult to interpret the rise and subsequent fall in yellow perch abundance during the 2002-2006 period. It is possible that this could reflect either predatory relationships with increasing piscivore populations (e.g. walleye), or potential competitive relationship with the increasing bluegill population. However, perch reproductive success can be highly variable due to weather and other abiotic conditions. The size distributions shown in Figure 6-3 suggest that yellow perch may have exhibited some weak year classes (e.g. 4-7 inch size class) which could be responsible for the decline in numbers of the past 2 years.

Both white crappie and black crappie exhibit consistent declines in abundance across the 2002-2006 time period. White crappie declined nearly 10-fold and black crappie abundance was cut in half. Generally speaking, high abundance of crappie is often associated with turbid-water conditions in agricultural area lakes. Hergenrader (1983) showed that zooplankton in ponds containing YOY crappie shifted in size and composition to a smaller species assemblage (less efficient as grazers). Corresponding to this size shift was an increase in phytoplankton biomass and a decrease in water quality. Ponds with northern pike shifted to a moderate- to large-sized zooplankton community. Egerston and Downing (2004), in a study of agriculturally eutrophic lakes, showed that black crappie CPUE increased with specific conductivity while that of white crappie increased with total suspended solids. As carp abundance increased, there was a corresponding significant increase in white crappie, and a significant decrease in bluegill. The positive correlation between white crappie CPUE and carp CPUE may result from crappie’s good adaptation to turbid, shallow waters. Since white crappie can spawn in deeper water (1-3m), their nests may escape disturbance by carp feeding.

Data on in-lake carp populations is limited to the comprehensive surveys in 1995 and 2001. Carp data from the fall annual electro-shocking surveys provides limited information on current carp populations due to the limitations of the technique to capture carp but has nonetheless remained relatively stable with lower CPUE’s in 2002 and 2006 (pers. com. Laura Stremick-Thompson). A plot of carp harvest versus total carp biomass based estimated at 478,183 lbs. (Sesing 1993) indicates the current level of harvest is not significant although it was in prior years (Figure 6-4). Figure 6-5 shows that Carp harvest is weakly negatively correlated to summer water clarity. If Carp removal was an important component to manage water clarity, we would expect a positive relationship. A negative relationship suggests that Fox Lake’s water clarity is not greatly affected by Carp populations. It is possible that the initial large-scale removal of Carp was a mechanism to allow for the establishment of large bluegill year classes by creating undisturbed conditions in the preferred shallow bluegill spawning areas and was subsequently followed by predation on Carp YOY by an increasing bluegill population, but a lack of data leaves this conclusion as a hypothesis only.

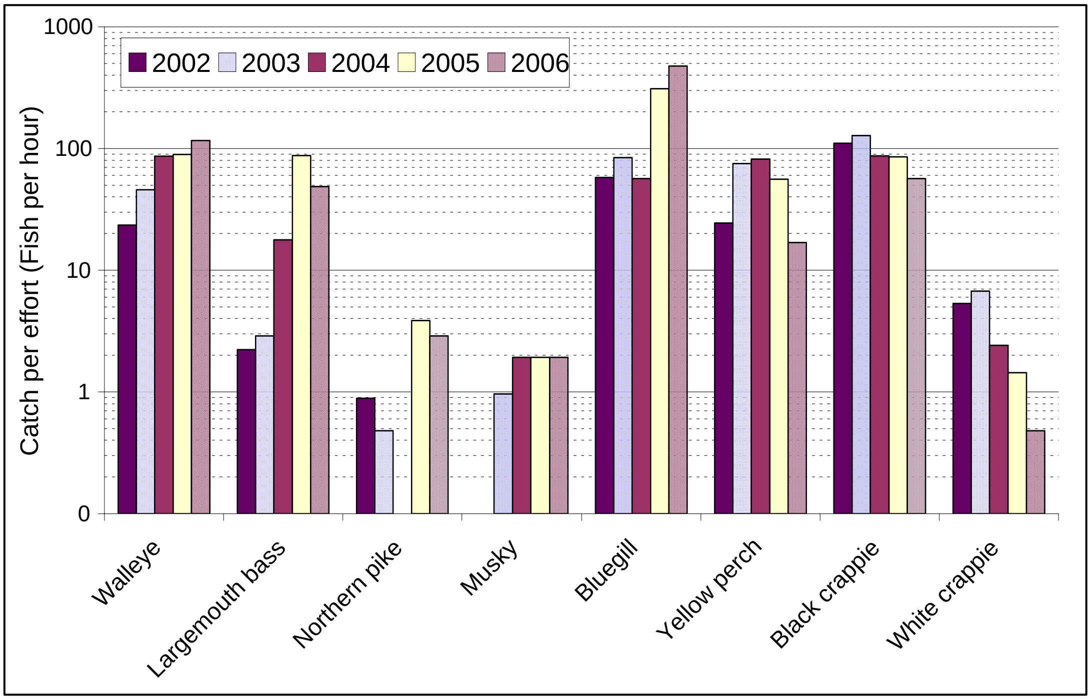

Figure 6-2
Yearly trends in game fish species between 2002 and 2006 from Fox Lake, Wisconsin as estimated from fall electrofishing surveys. Data from WDNR, c/o Laura Stremick-Thompson.

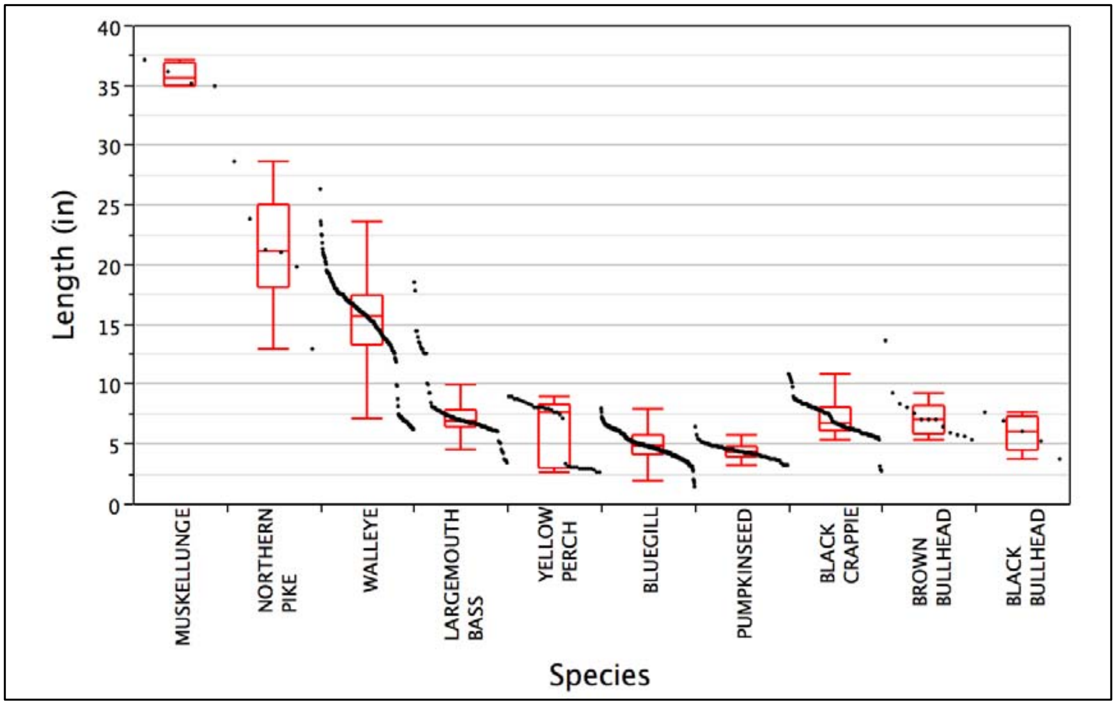

Figure 6-3
Length distribution of major game fish species collected during the 2006 fall electrofishing survey in Fox Lake, Wisconsin. Box plots show the 10th, 25th, 50th, 75th, and 90th percentiles of total lengths measured for each species. Dot distributions show actual lengths for fish measured.

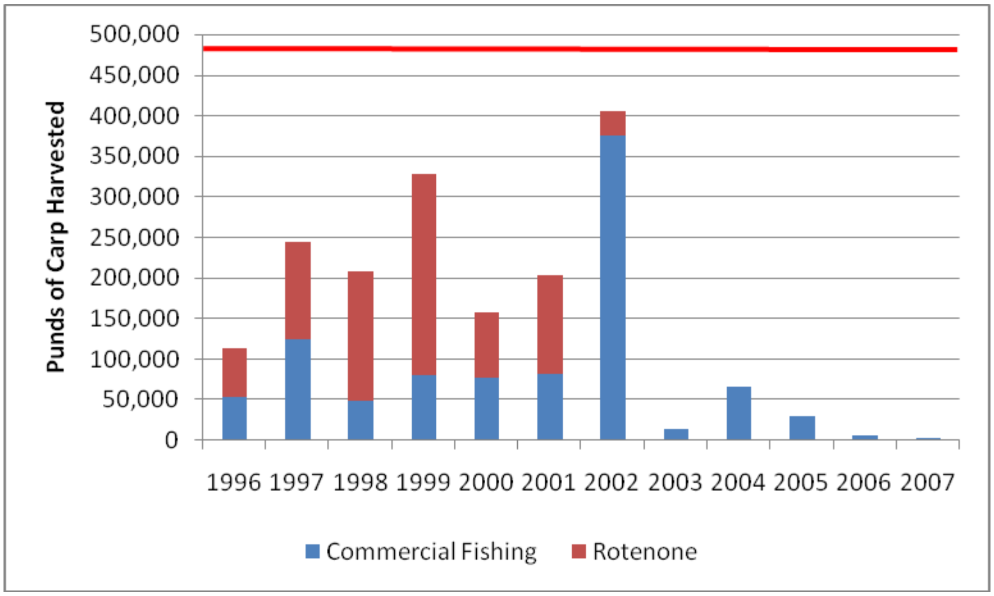

Figure 6-4
Carp Harvest by Year Relative to Total Estimated Biomass (red line)

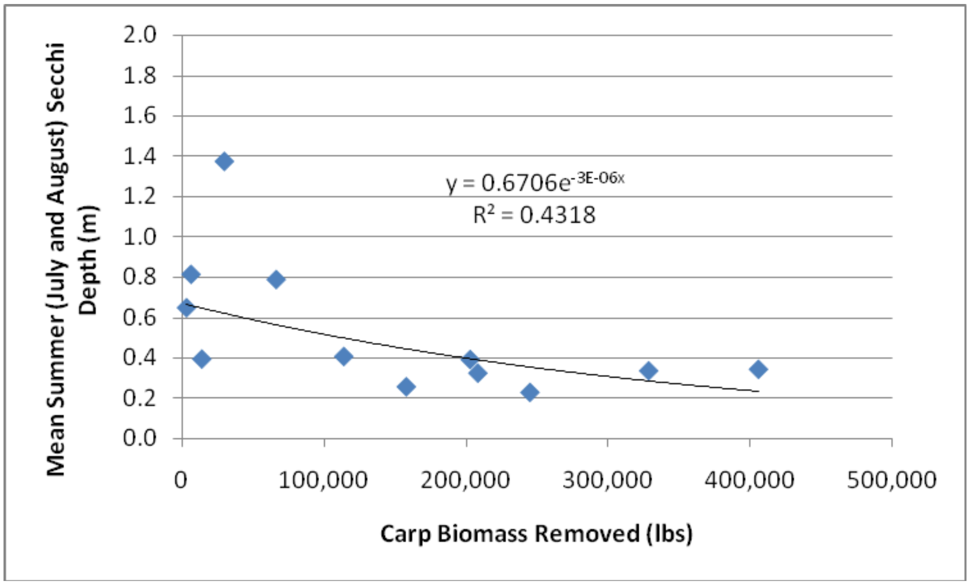

Figure 6-5
Carp Harvest (lbs.) versus Summer Secchi Depth (m)

Zooplankton

Vertical zooplankton tows were conducted monthly in Fox Lake (Dodge County, WI) from January through April 2005, and bimonthly from May through November (see table 1). Tows were conducted using a 12 centimeter diameter, 80 µm mesh, Wisconsin plankton net. Zooplankton study sites included the Deep Hole where 4.0 m tows were conducted and the South-East Bay where 1.0 m tows were performed. On each sample date, two replicate tows were collected from both sample sites. All samples were preserved in 70% Ethanol.

Prior to analysis, individual samples were standardized to a common volume of 200 ml. For each sample, two 5 ml aliquots were removed for analysis from the agitated sample without replacement. Zooplankton were identified using a dissecting microscope and a zooplankton counting wheel. All *Daphnia* were identified down to species while copepods were categorized as either calanoid or cyclopoid copepods according to Balcer et al. 1984. Based on these categories, we determined numbers of individuals per liter, species composition (relative abundance and relative frequency), and total *Daphnia* biomass as described in Asplund and Johnson (1996). Results from 2005 were compared to similar studies in Fox Lake conducted from 1994-1999 (Asplund and Garrison 2002, Asplund and Johnson 1996).

Seasonal trends in *Daphnia* abundance are shown in Figure 6-6. 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. However, in 2005 the vegetation-dwelling cladoceran, *Diaphanosoma*, became abundant during late August and September (Figures 6-7 and 6-8). It is likely 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.

It is important to note that small crappie are effective at feeding both on copepods as well as on large cladocerans because of their finely-spaced gill rakers and feeding behavior (Ellison 1984). Even though the presence of large-bodied zooplankton is most often cited as the key to maintaining clear-water states in eutrophic lakes (Asplund and Johnson 1996, Mittlebach et al 2006), crappie are capable of driving down total zooplankton abundance of daphids and copepods to a far greater degree than planktivores like bluegill sunfish. This is an important difference between crappie and bluegill sunfish and may serve to re-emphasize the importance of keeping the crappie abundances in check as part of the fish management strategy for Fox Lake.

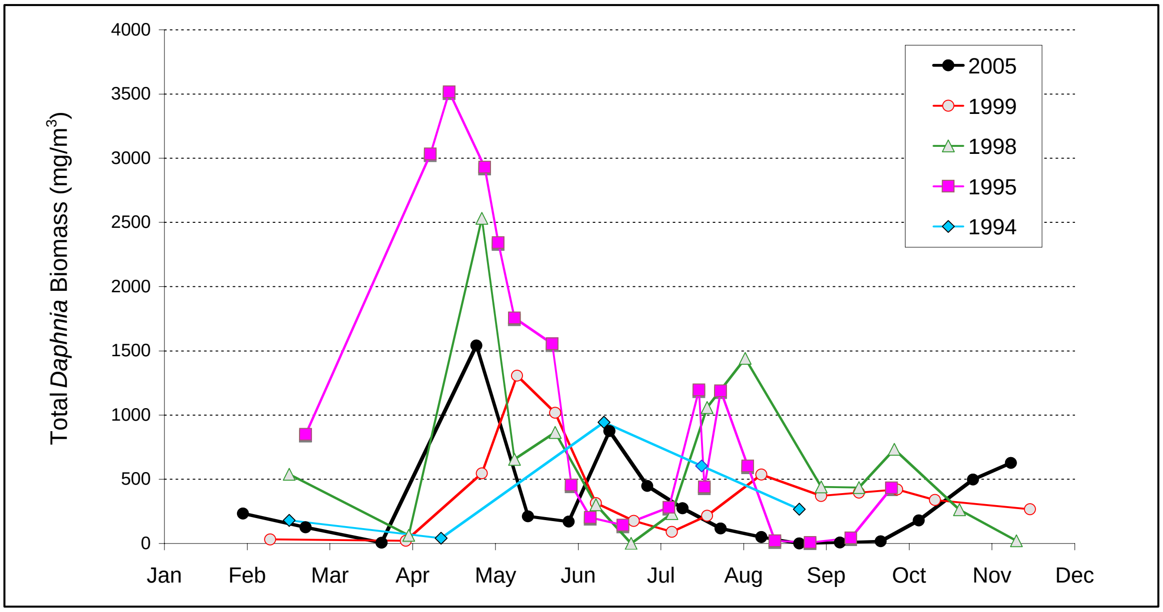

Figure 6-6

Seasonal trends in the biomass density of large-bodied Daphnia in Fox Lake Wisconsin between 1994 and 2005. Data from the 1990s was taken from Asplund and Garrison 2002.

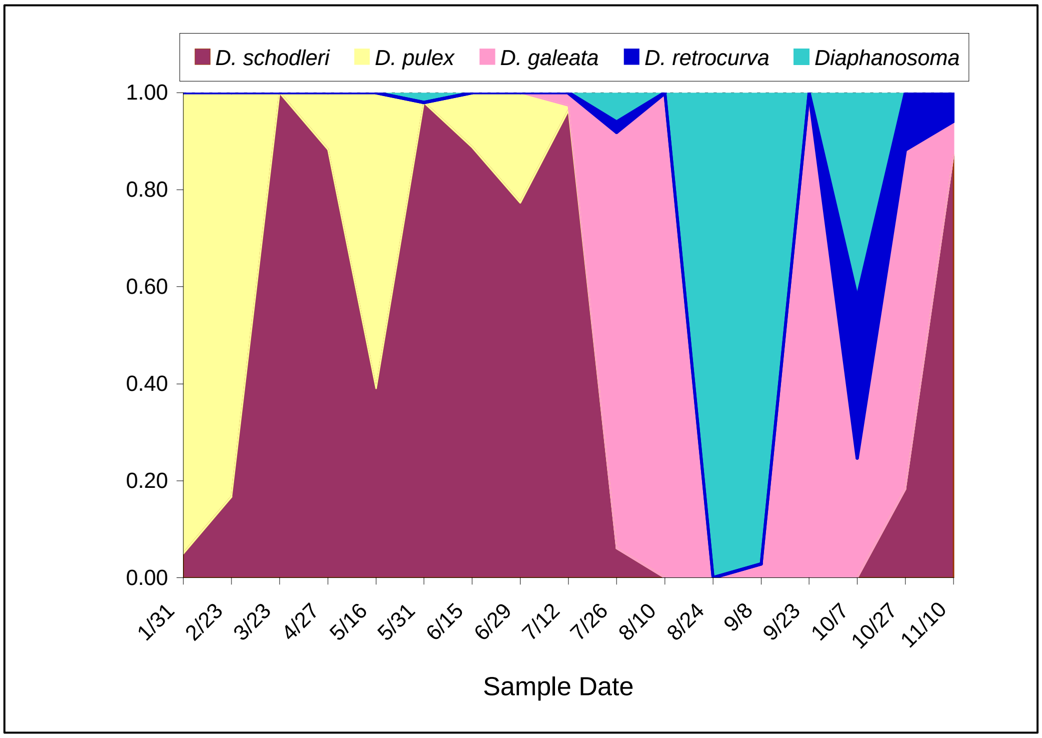

Figure 6-7

Seasonal trends in the proportional numerical abundance of cladoceran species, including the genus *Daphnia* and *Diaphanosoma* in Fox Lake, Wisconsin in 2005.

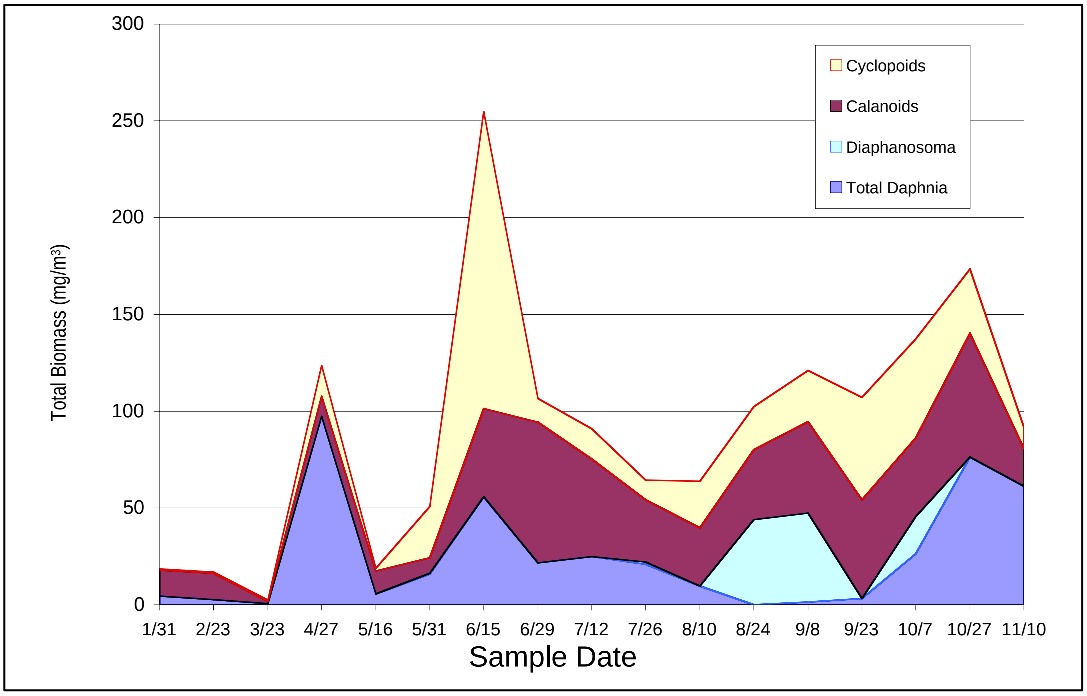

Figure 6-8

Seasonal trend in zooplankton numerical abundance in Fox Lake, Wisconsin for 2005. Data are shown for cyclopoid and calanoid copepods and for daphnid and Diaphanosoma cladocerans

Aquatic Plant Community

Historically, the plant community on Fox Lake was surveyed using a transect-based technique. In 2006, a comprehensive point-intercept survey was conducted on the lake to provide a better overall picture of the aquatic plant community. Point-intercept surveys contain many more survey points than transect-based surveys (~900 versus 135) but less sampling intensity per site (one replicate versus four). The historic transects were recreated from the 2006 data from sampling locations from the point-intercept survey that roughly correspond to historic sampling locations; however, methodological differences do exist between the survey types as noted. As a result, comparisons between 2006 and prior years are likely not as precise as comparisons between years where the transect method was solely applied. In applicable cases, the 2006 data for the estimated historic transects and the comprehensive survey is included. The comprehensive data (point-intercept) is labeled as “total” where it is included while the transects extracted from the comprehensive survey are noted as a date only. Figures 6-8 and 6-9 contain both types of data as noted in their labels. Data presented in the text without comparisons to prior years is for the 2006 comprehensive survey (point-intercept) unless otherwise noted.

Aquatic plant data was available for Fox Lake from 1950 to the present. A brief explanation of each calculation follows:

1) Frequency of Occurrence: the number of sites a plant species was collected divided by the total number of sites. The abundance of plants is not taken into account with this calculation. Only the presence/absence is noted. This value is also used to calculate the total percentage of littoral zone supporting aquatic plant growth.

2) Maximum Rooting Depth: the deepest sampling point that contained rooted aquatic plants. This measure is an important estimate of water clarity. Aquatic plants usually grow at 2-3 times the Secchi depth.

3) Floristic Quality Index (FQI, Nichols 1999): a biological index value based on the presence/absence of species and the ability of plants to tolerate disturbed conditions. FQI is calculated by multiplying the average C value for all native plant species by the square root of the number of native plant species collected. "C" is the coefficient of conservatism which is a value assigned to native aquatic plants estimating a plant's likelihood to occur in an undisturbed lake. The values range from 0-10, with 10 representing an undisturbed condition and 0 representing severely degraded conditions.

4) Simpson's Diversity Index (SDI, Simpson 1949): the index represents the probability that two individuals randomly selected from a sample will belong to different species. There are two components important to diversity – richness and evenness. Richness is the number of species per sample. Evenness is a measure of how species are distributed across samples. High evenness means that most species have a moderately high relative abundance while low evenness means that one or two species dominate and the rest are rare.

Fox Lake supports a plant community typical of a shallow lake in southern Wisconsin. This is evident by the frequency of occurrence of aquatic plants (Figure 6-9), the Floristic Quality Index scores, Simpson's Diversity Index Scores, and the presence of exotic invasive species. The recent trends indicate Fox Lake's aquatic plant community expanded in the littoral zone and maintained an adequate level of diversity. This is in contrast to initial reports in 1998 that the lake drawdown and Carp removal program was a failure in terms of restoring the aquatic plant community. Since 1998, the percentage of plant cover has more than doubled in the littoral zone and plants are growing at greater depths.

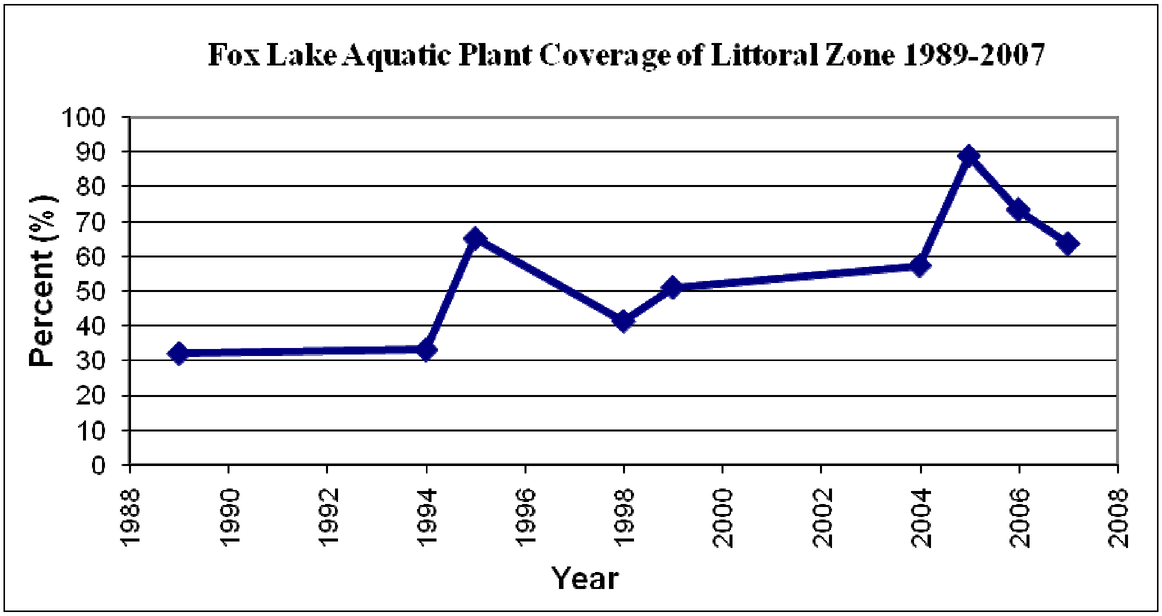

Figure 6-9
Percent Plant Cover in Littoral Zone
Source: WDNR and Hey and Associates, Inc.

The native plant community is competing well with the non-native invasive species present in the lake. Typically, exotic invasive species will occupy most, if not the entire, littoral zone and push out native aquatic plants. A monotypic or low diversity aquatic plant community is the result. The frequency of occurrence and relative frequency statistics indicate EWM may be starting to gain more dominance in the aquatic plant community relative to previous years (Figures 6-10 and 6-11). Other significant trends in the aquatic plant community are summarized in Figure 6-12.

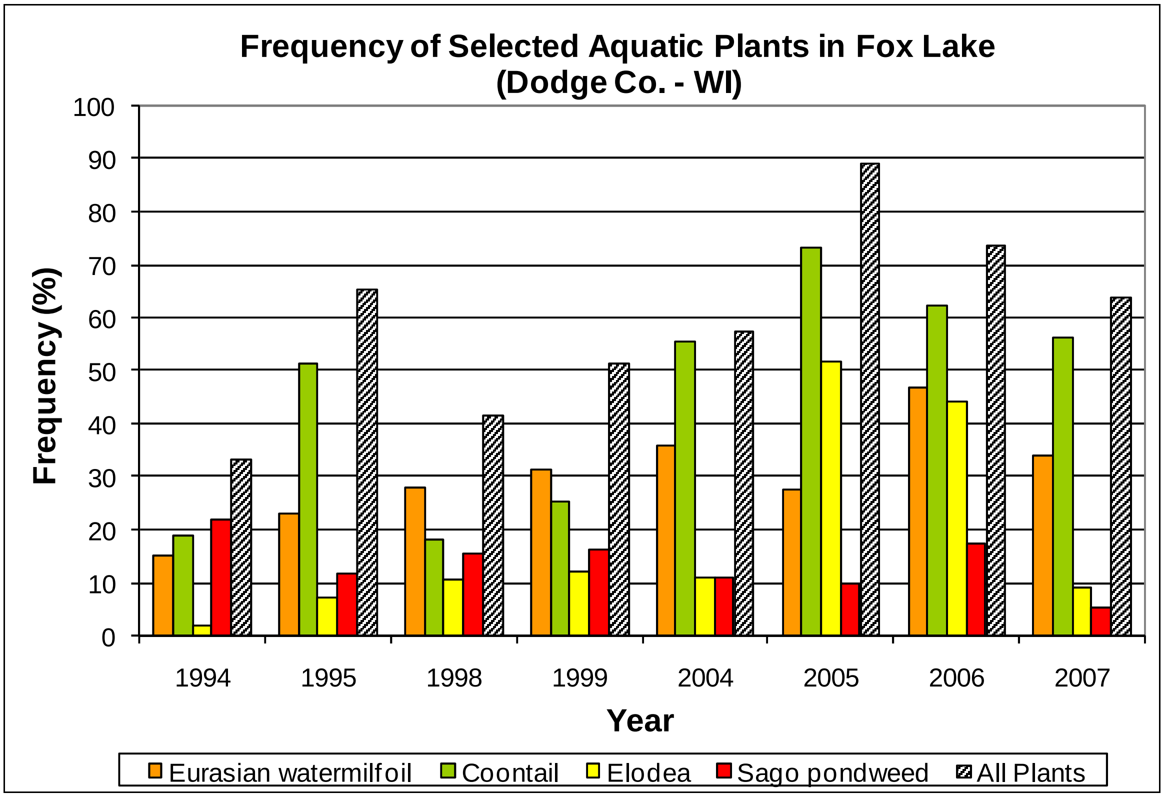

Figure 6-10
Frequency of Occurrence of Dominant Aquatic Plants
Source: WDNR and Hey and Associates, Inc.

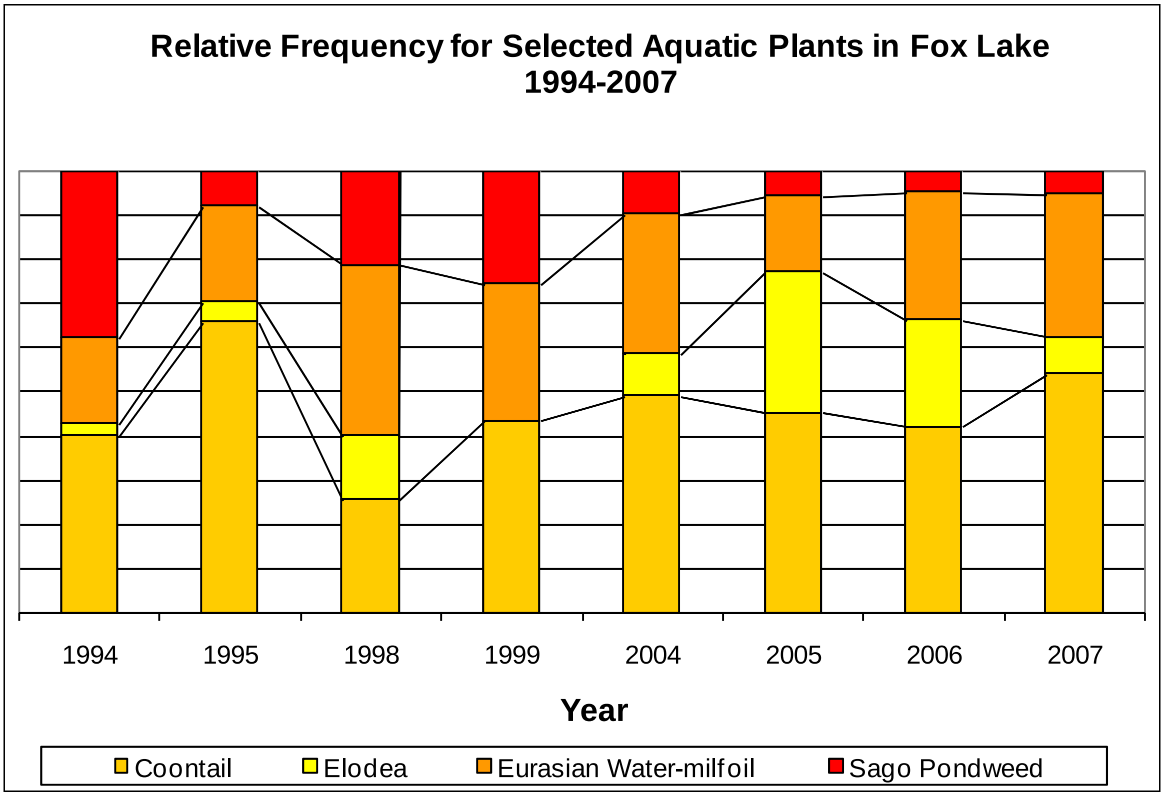

Figure 6-11
Relative Frequency of Dominant Aquatic Plants
Source: WDNR and Hey and Associates, Inc.

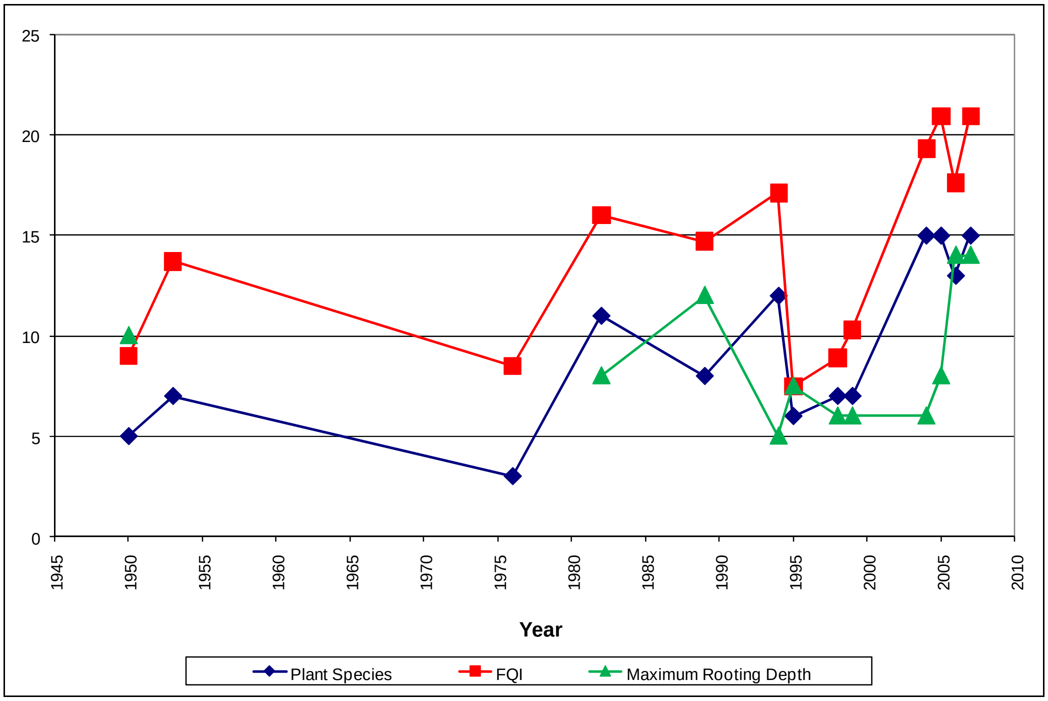

Figure 6-12
Plant Community Trends
Source: WDNR and Hey and Associates, Inc.

Aquatic Plant Management

There are a total of four aquatic plant species in Fox Lake that may be managed. They are Coontail, Elodea, Curly-leaf pondweed, and Eurasian water-milfoil. Filamentous algae were also found at a large number of sites in Fox Lake.

1) Eurasian water-milfoil (*Myriophyllum spicatum*), a non-native invasive species. Eurasian water-milfoil forms dense mats at the water surface that shade out native plants, deposits large amounts of dead plant material as it dies back in the fall that may cause local shifts in water chemistry and dissolved oxygen, and supports fewer invertebrates than native plants (Cheruvelli et al. 2001). Eurasian water-milfoil was found at a relatively high number of sites in 2006 (~50%) relative to 2005 (27.4%) and 2004 (35.9%). Increased frequency of EWM may become a negative trend especially if it is expanding at the expense of native plants.

2) Curly-leaf pondweed (*Potamogeton crispus*, CLP) is another non-native invasive species found in Fox Lake. It may become dominant in lakes due to its unique life history namely its ability to grow during the winter months when most plants are dormant (Nichols and Shaw 1986). Curly-leaf pondweed is actually intolerant of warm water temperatures and dies back in early July. Mid to late summer surveys are inconsistent at detecting the actual extent of CLP in lakes because their life cycle is atypical. As a result, surveys to detect CLP should occur in late May or early June to provide more accurate information. CLP does not appear to be a problem in Fox Lake during mid to late summer, but may be a key to preventing large amounts of sediment resuspension in the early spring.

3) Coontail (*Ceratophyllum demersum*) is a native plant that may form dense beds and may impede recreation. Coontail is the primary nuisance plant in Fox Lake and occupied 62.3% of the sampling sites lake-wide. The transect-based survey indicated the frequency was comparable to 2005 and generally higher than historic measurements. A careful balance must be reached to allow for navigation in areas with dense coontail because it plays an important role in maintaining the clear water state.

4) Elodea (*Elodea canadensis*) was the third most dominant aquatic plant in 2005 and 2006 but appears to have decreased slightly in 2006. Elodea provides habitat for invertebrates that are a food source for fish and waterfowl and produces more oxygen than most aquatic plants. It appears that Elodea is competing well with Eurasian water-milfoil.

5) Filamentous algae were found at 65.0% of sites in 2005 and 23.9% of sites in 2004. No data was available from previous surveys regarding its presence in Fox Lake. Excessive algae growth usually indicates excessive nutrients are present and causes recreational use and navigation problems. Filamentous algae were a problem in Fox Lake in 2005, but did not appear to be as severe a problem in 2006 at the time of the aquatic plant survey (13.2%). Research has also shown filamentous algae may have a negative effect on aquatic plant in shallow lakes (Jones and Sayers 2003).

Aquatic plant management on Fox Lake must balance the ecological benefits of maintaining a clear-water state versus facilitating recreational uses by lake residents. “Alternate Stable States” refers to a model used to explain the often rapid shift that occurs in shallow eutrophic lakes--such as Fox Lake--from the clear-water, macrophyte-dominant state to a turbid-water, algal-dominant state (Figure 6-13).

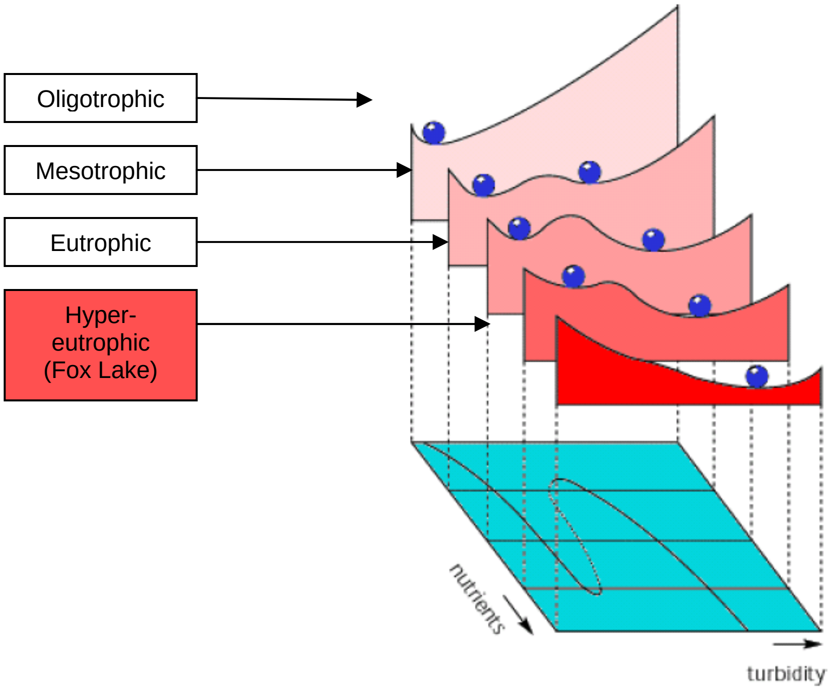

Figure 6-13
Alternate Stable States Model
Source: Modified from Sheffer et al. 2001

Currently, Fox Lake is in a clear-water, macrophyte-dominant state. Previous survey data suggests that as recently as 1998, Fox Lake was in a turbid-water state. Since no data was available from 1998 to 2004, the shift to the clear-water state was not entirely documented. Significant increases in the abundance and frequency of aquatic plants was documented from 2004 to 2005. Relatively high levels of aquatic plants were also found in 2006. The areas of the lake supporting dense plant growth are shallow littoral areas with a silty bottom. Since much of the littoral zone in Fox Lake is shallow (<6 feet deep) and silty, it should be expected that abundant aquatic plants will develop in those areas.

Conclusions and Recommendations

As a hyper-eutrophic lake, the ecological balance of Fox Lake is delicately linked with the maintenance of the abundance of top predators with planktivores. The lake responds very quickly to biological manipulations.

Another comprehensive fish survey should be conducted in 2007-2008.

Efforts to keep white and black crappie abundance low should be continued both by maintaining an aggressive bag limit and by promoting predator fish species.

Carp do not appear to be a major contributor to trophic problems in Fox Lake, and continued commercial harvest subsidies do not seem necessary. Efforts to capture and eradicate carp moving upstream into tributaries may be possible, but logistic issues may not make this feasible.

The relative changes in walleye and largemouth bass abundance should be monitored and walleye stocking should be reduced if bass populations decline.

In addition, efforts to introduce musky should be put on hold until it can be determined if the increases in submerged vegetation in the lake will promote increased northern pike reproduction.

Yellow perch year-class strength should be monitored and potential relationships to management actions should be examined.

Plant management activities should be minimized to promote the clear-water state while facilitating lake access and recreational uses. Beneficial plant management in the lake would include strategies that reduce the impact of Eurasian water-milfoil and promote native plants. Potential management strategies include herbicide applications, manual and mechanical harvesting, and lake level management.

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CHAPTER 7: RESULTS OF WATERSHED MONITORING AND WATER, SEDIMENT AND NUTRIENT BUDGET FOR FOX LAKE

INTRODUCTION

Fox Lake is fed by three main tributary streams: Alto Creek, Drew Creek, and Cambra Creek (Figure 7-1). The lake outlets to Mill Creek, which drains into Beaver Dam Lake. As part of the evaluation project, the three tributaries and outlet were monitored to develop a water, sediment, and nutrient budget for the study year from August 2004 through July 2005. The purpose of these budgets is to develop a better understanding of the major sources of nutrients that are driving the water quality of Fox Lake. As part of the evaluation, additional monitoring was conducted in the spring of 2006 at multiple sites in each tributary to identify likely sources of the inputs of sediment and nutrients to the lake.

METHODS

At each of the main tributary sites and outlet monitoring site YSI 6500 recording sondes were installed to measure continuous water levels, temperature, dissolved oxygen and turbidity. Each main tributary site was sampled on 20 dates for stream flow, total suspended solids, total phosphorus, dissolved phosphorus, total kjedahl nitrogen, and nitrate/nitrite nitrogen. All laboratory analysis was conducted by the Wisconsin State Lab of Hygiene. Flows measured with “Flo-Mate Model 2000” portable flowmeter (Marsh-McBirney, Inc.) were used with stream stage readings to develop rating curves for each site to convert the continuous stage readings into discharges. A detailed discussion of the analysis methods is included in the following sections of this chapter.

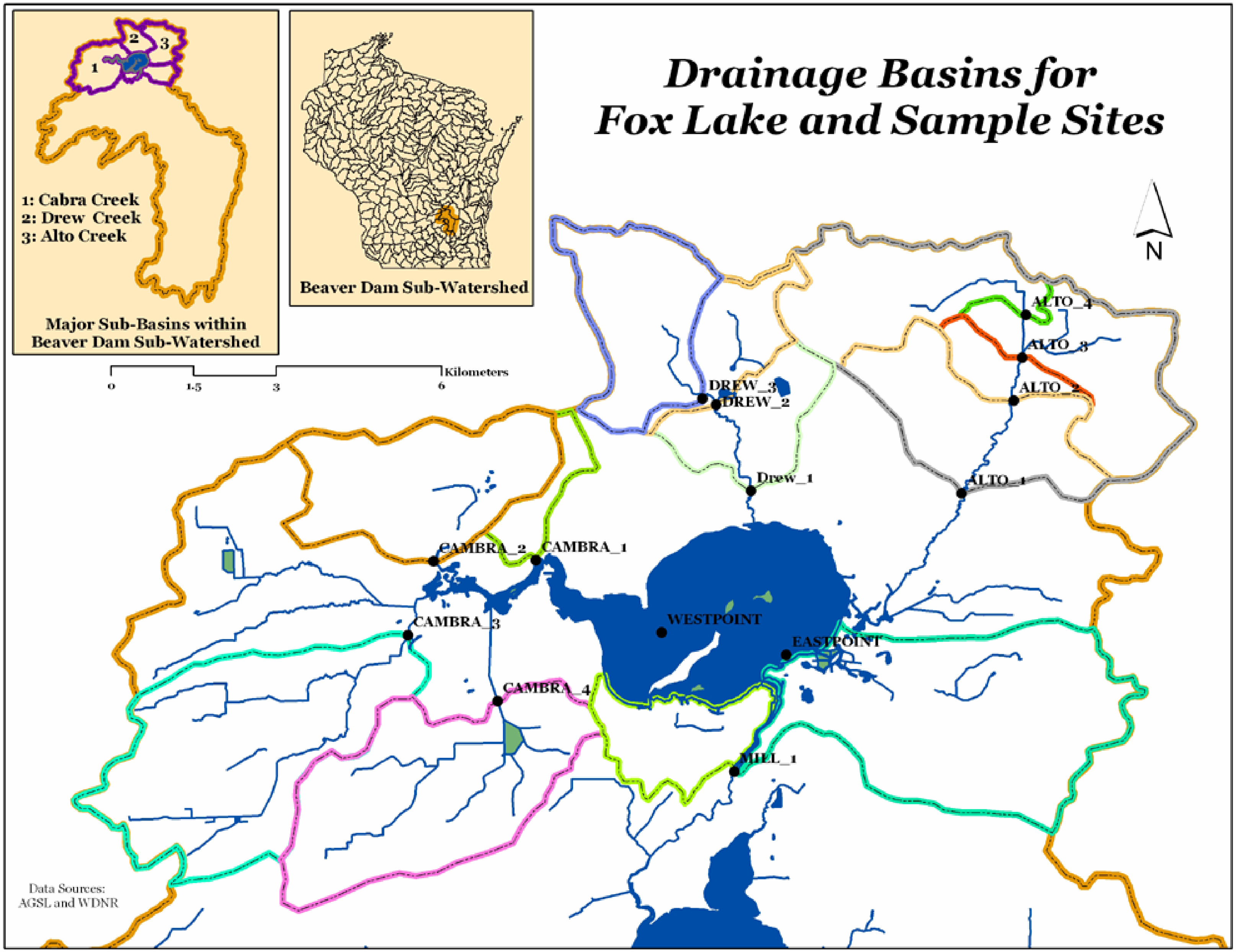

Figure 7-1

Fox Lake Tributary Watersheds and Monitoring Locations

WATER AND NUTRIENT BUDGETS

Water Budget

Method

A water budget is a quantification of the hydrologic cycle, the process by which water moves from rainfall to outflow from the lake (Figure 7-2). For any one lake, the sum of the volumes of water coming into the system, and leaving the system, and the change in volume of water retained in the system, must equal zero over the long term. This summation of volumes is expressed in the following mass balance equation:

$$P + Q_{in} - Q_{out} + G_{in} - G_{out} - E - T = \text{Change in Storage}$$

Where P is precipitation, Q_{in} and Q_{out} are surface water inflows and outflows, G_{in} and G_{out} are groundwater inflows and outflows, E is evaporation, T is plant transpiration, and Change in Storage is the volume of water retained in the system, such as in the lake and riparian wetlands.

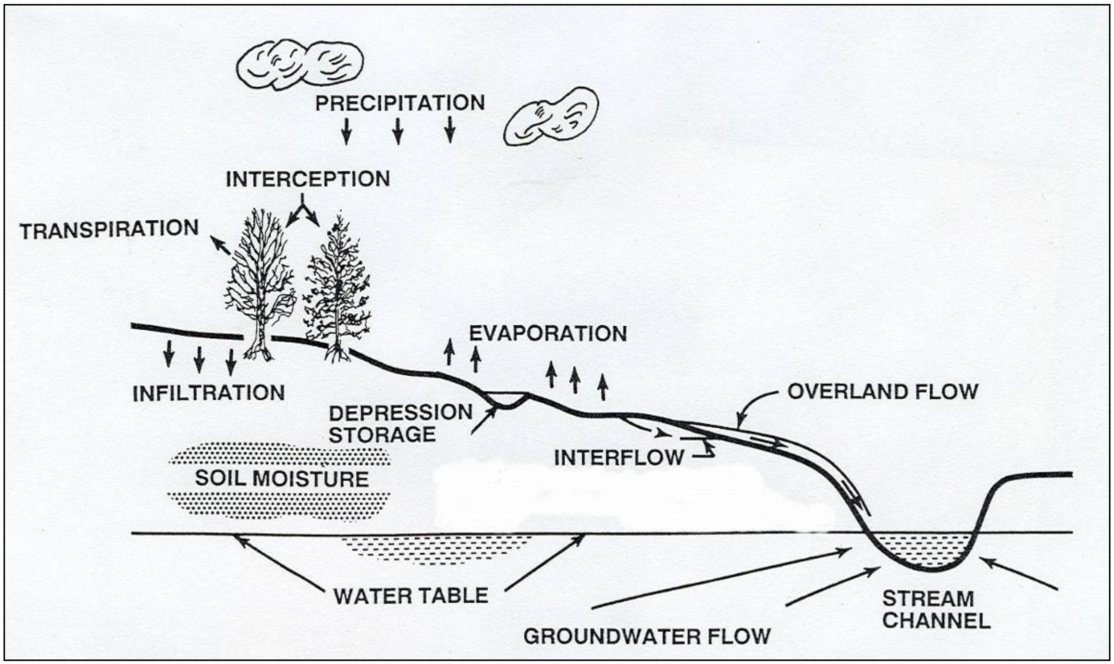

Figure 7-2

Hydrologic Cycle

An annual water budget for Fox Lake was constructed based on available hydrologic data from nearby weather stations and stream gauges installed on Alto, Drew, Cambra and Mill Creeks (Figure 7-1). Groundwater inflow and outflow were not monitored as part of the lake study, but net groundwater flow was estimated from a mass balance of the known inflows and outflows.

The study period for the water budget is based on a calendar (12 month) period from August 2004 through July 2005.

Hydrologic Parameters

Direct Precipitation

Precipitation is the volume of water in the form of rain or snow, which falls upon the lake area (rain depth x lake area). The precipitation data used in this analysis was collected at three locations:

- National Oceanic and Atmospheric Administration (NOAA) weather station in Fond du Lac, Wisconsin.
- Rain gauge installed by the University of Wisconsin-Milwaukee at the CTH F stream gauge at Alto Creek.
- Rain gauge at the Fox Lake Regional Wastewater Treatment Facility.

The average yearly precipitation for the 121-year record at Fond du Lac, from 1884 to 2005, was as 76.61-cm (30.16 inches) of rainfall. For the study period of August 2004 through July 2005 at Fond du Lac, only 58.95-cm (23.21 inches) of rainfall was measured, 17.65-cm (6.95 inches) below normal. Figure 7-3 illustrates the departure below normal on a monthly basis for the study period at Fond du Lac, illustrating that the summer months of August and September in 2004 and March through July 2005 had below normal rainfall. Figure 7-4 illustrates the rainfall and snow fall depths measured at the Fox Lake Treatment Plant located in the western portion of the Fox Lake watershed. Based on a lake surface area of 10.2 kilometers (2,525 acres), it is estimated that 5,637,403 cubic meters (4,570 acre-feet) of water fell directly on the lake surface during the study period.

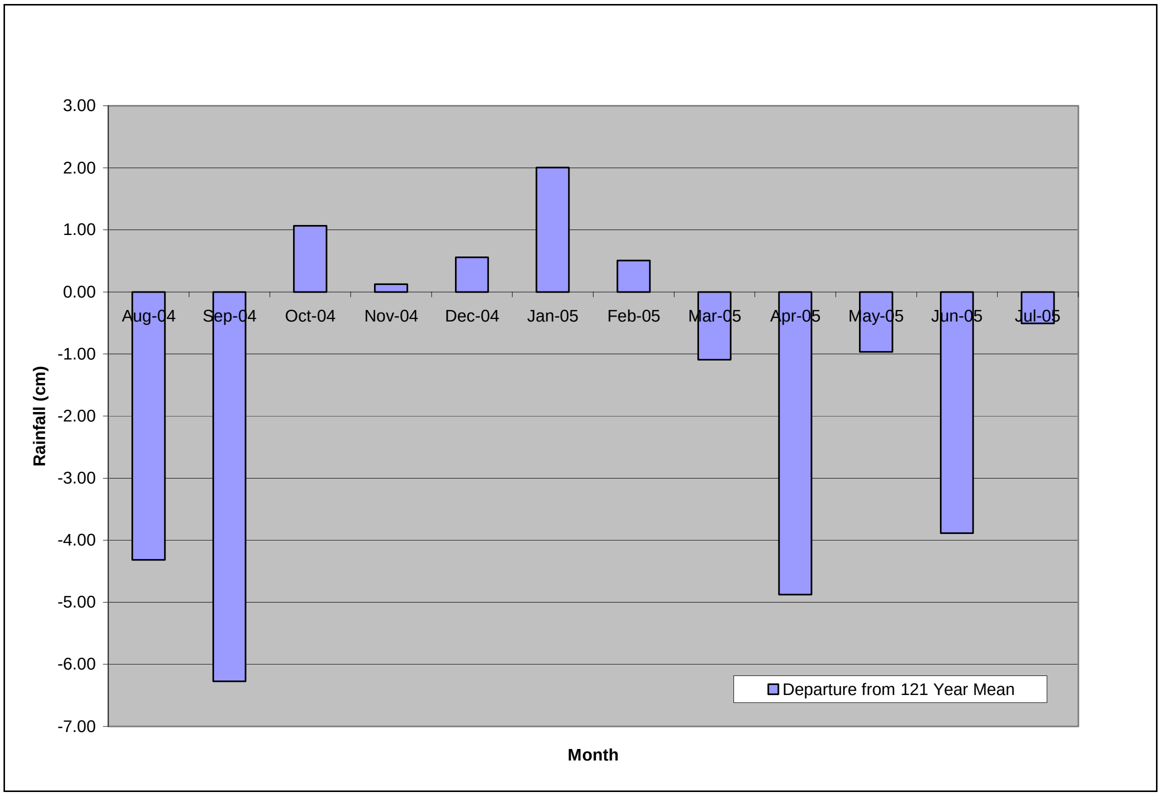

Figure 7-3
Rainfall Departure from Normal at Fond du Lac, Wisconsin
(Source: NOAA)

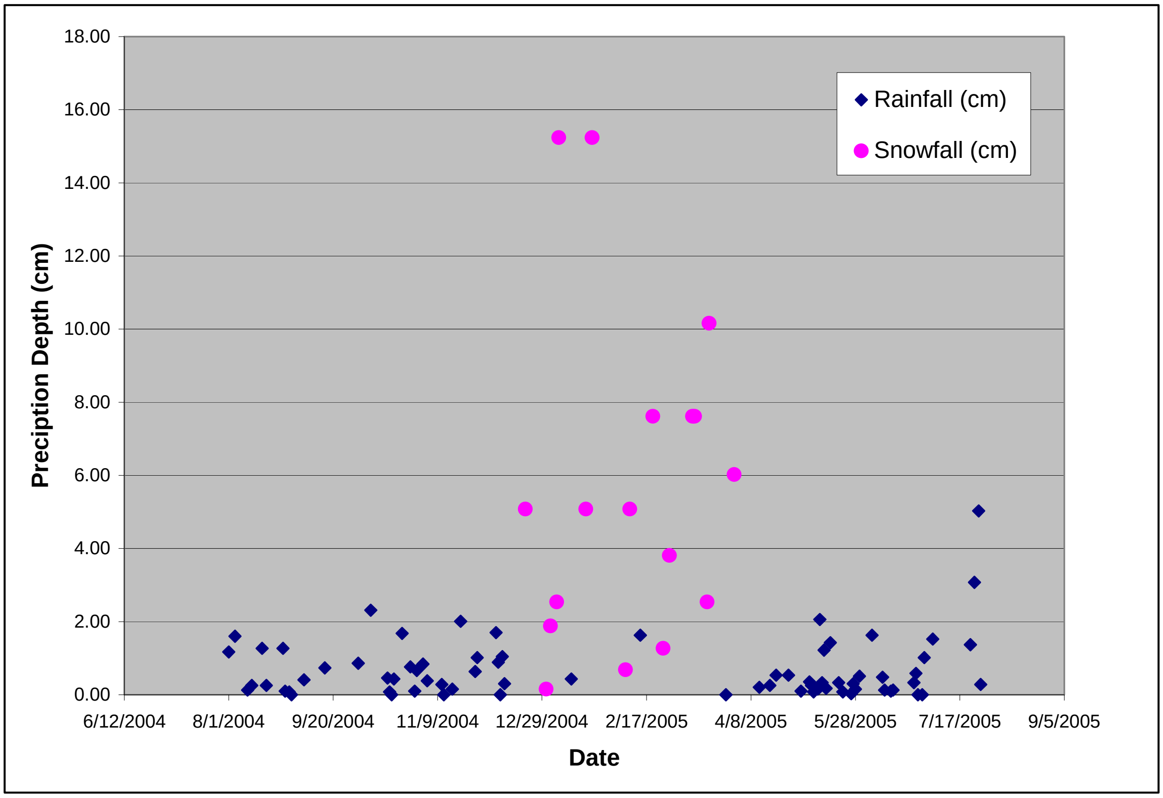

Figure 7-4
Rainfall and Snowfall Depth August 2004 through July 2005 at Fox Lake Treatment Plant
Source: Fox Lake Regional Treatment Works

Surface Water Inflow and Outflow

Surface water inflow and outflow were estimated at Fox Lake at the following locations shown on Figure 7-1:

- Alto Creek at CTH F
- Drew Creek at CTH F
- Cambra Creek at CTH A
- Mill Creek at lake outlet

Stream flow was measured continuously at Alto and Drew Creeks using recording YSI 6500 Sonde® depth recorders. Measurements were taken every twenty minutes during the study period (Figure 7-5). A rating curve for these two sites was developed from a series of instantaneous flow readings taken on 10 dates using a Marsh McBerny Flowmate® stream flow meter. Missing flow readings at Drew Creek were estimated from the Alto Creek flow record using regression analysis between instantaneous flow reading taken at all sites on the same dates. Flows at Mill Creek were estimated based on a regression analysis of instantaneous flow readings versus daily flow values recorded downstream at the USGS gauging station on the outlet of Beaver Dam Lake. The Regression formulas and R^2 values showing the degree of fit for the formula to actual values for Drew and Mill Creeks is shown in Table 7-1. Flows at Cambra Creek, where velocities could not be measures due to backwater conditions from the lake, and the un-monitored direct drainage area to the lake, were estimated from the Alto Creek flow record using a ratio of watershed areas.

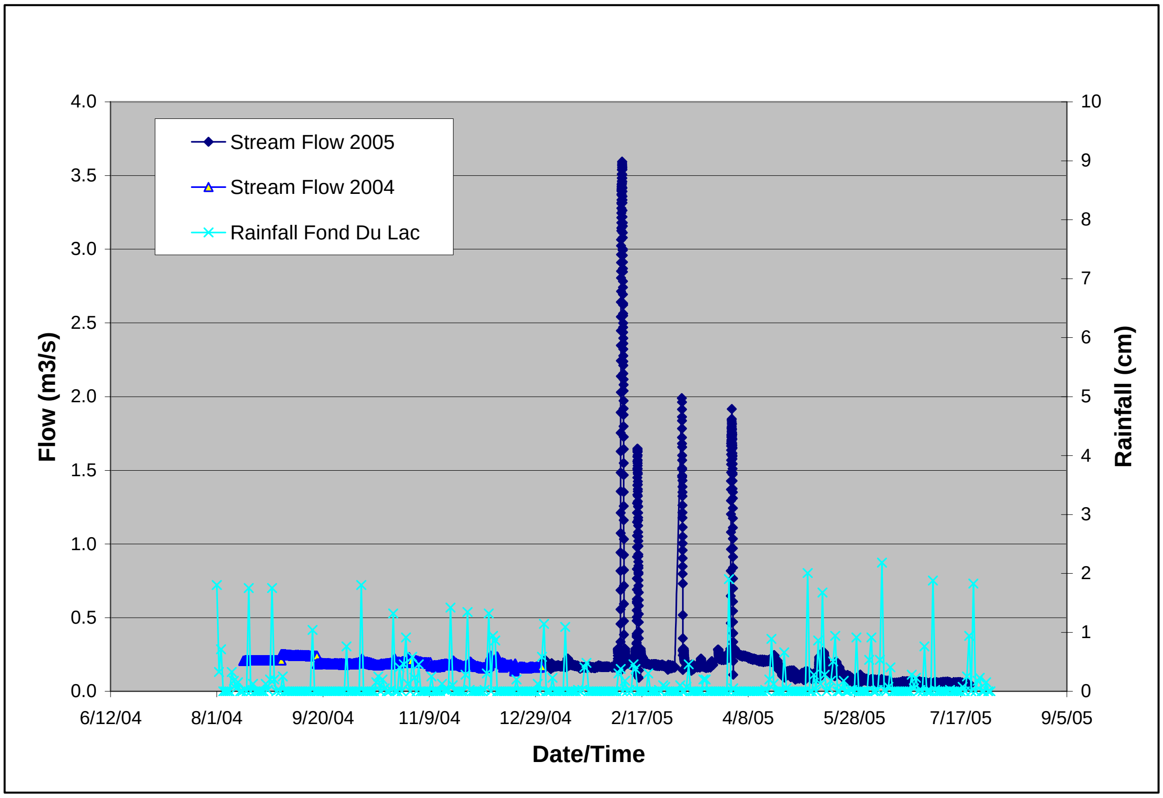

Figure 7-5

Flow Record at Alto Creek During Study Period
(Source: University of Wisconsin-Milwaukee)

Table 7-1
Regression Formulas to Estimate Missing Flow Values at
Ungaged Locations or Dates Using Alto Creek Data

Stream	Regression Formula	R^2
Drew Creek	y = 0.0436Ln(x) + 0.1517	0.9254
Mill Creek	y = 3.4126x - 0.1452	0.728

Estimated Annual flow volumes from the three inlet streams and outlet stream are summarized in Table 7-2.

Evaporation/Transpiration

Fox Lake experiences water losses both through evaporation from open water areas and evapotranspiration from areas of emergent vegetation such as cattails. Evapotranspiration is the combination of evaporation and transpiration or the loss of moisture to the atmosphere due to evaporation from the vegetation. Evaporation losses from Fox Lake were estimated using estimated evaporation data from the National Weather Service for Marshfield, WI. An additional conversion ratio is needed to translate the estimated evaporation to free water surface evaporation. In the technical report Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States, NOAA Technical Report NWS 34, US Department of

Commerce (Farnsworth and Thompson 1982) it is stated that pan evaporation data overestimates potential evaporation. NOAA recommends that to use pan evaporation data for large bodies of water the numbers should be adjusted by applying a factor between 0.6 and 0.8. The annual evaporation at Marshfield for the study period was estimated at 116.4 cm (45.83 inches). Adjusting for lake surface evaporation, using an adjustment multiplier factor of 0.7 or the middle of the accepted range indicated above, the estimated evaporation from the 291-acre lake surface is estimated at 8,326,590 cubic meters (6,750.38 acre-feet).

Storage

Change in lake storage is the difference of the volume of water within the lake at the beginning of the study period as compared to the volume at the end. Change in storage was estimated based on daily lake level readings read at a staff gage located on the Chief Kono Trail causeway (Figure 7-6). During the study period, the lake levels ranged from a low of 89.10 feet to a high of 90.0 feet, with a total annual loss in storage of 2,024,790 cubic meters (1,640 ac-ft).

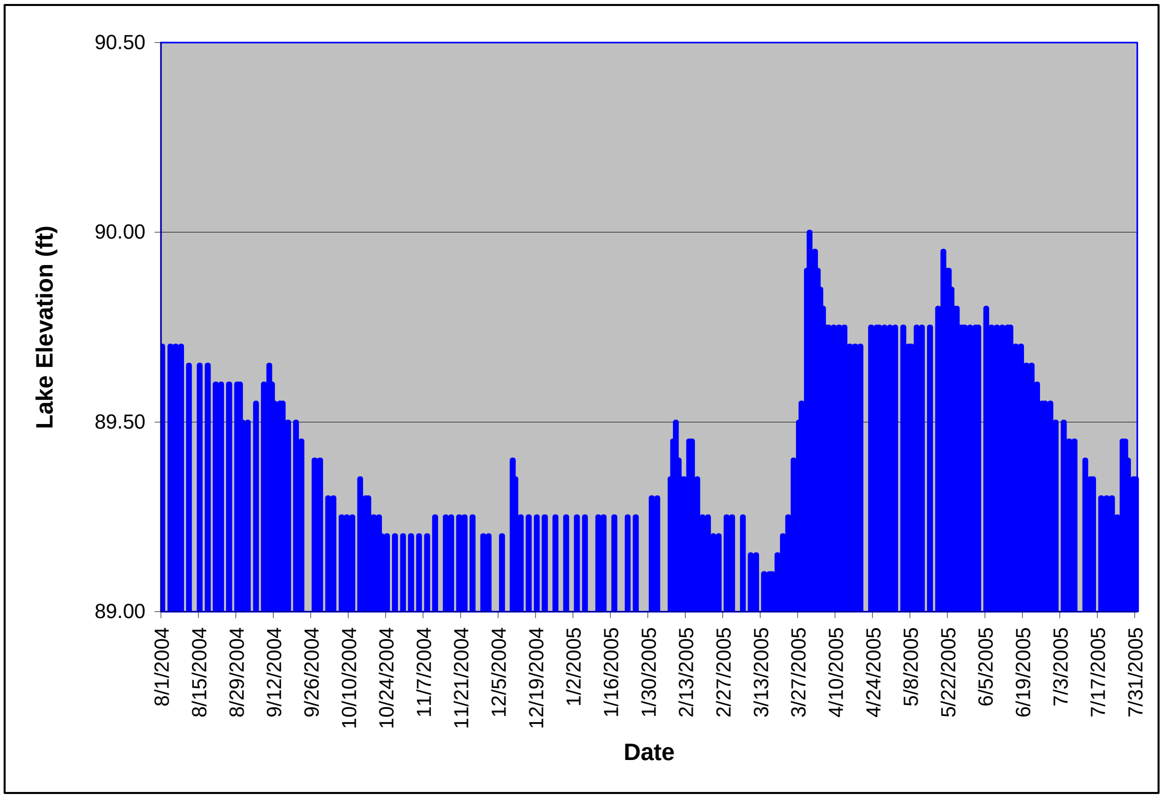

Figure 7-6
Lake Level as Measured at Chief Kono Trail Staff Gauge
(Source: City and Town of Fox Lake)

Groundwater

Groundwater inflow and outflow was not measured as part of the University of Wisconsin-Milwaukee monitoring project. Net groundwater inflow was estimated based on a mass balance of measured inflows and outflows. During the study period, total outflow and change in lake storage exceeded known surface inflows by 2,977,713 cubic meters. For this study it is assumed that this net difference was due to excess groundwater inflow. Total groundwater inflow and outflow during the study period is unknown.

Water Budget Summary

Table 7-2 summarizes the estimated water budget for the study year of August 1, 2004 through July 31, 2005.

Table 7-2
Annual Water Budget for Fox Lake for 2004-2005 Study Year

Parameter	Volume (cubic meters)	Percent
	Inflow	
Alto Creek	5,200,309	18.95
Cambra Creek	9,848,744	35.89
Drew Creek	2,605,415	9.49
Direct Drainage	1,172,377	4.27
Atmospheric Deposition on Lake Surface	5,637,403	20.55
Net Groundwater inflow	2,977,713	10.85
Total Inflow	27,441,961	100
	Outflow	
Mill Creek	21,140,160	71.74
Evaporation	8,326,590	28.26
Total Outflow	29,466,750	100
Change in Storage	-2,024,790	NA

Source: University of Wisconsin-Milwaukee and Hey and Associates, Inc.

As seen in Table 7-2, during the study period, outflow exceeded inflow by approximately 2,000,000 cubic meters (1,620 ac-ft). The largest source of inflow water was surface water runoff from Cambra, Alto, and Drew Creeks--in order of significance. The largest source of outflow was over the outlet dam into Mill Creek.

Based on inflows and outflows, it is estimated that the retention time of water in Fox Lake during the study period was approximately 1.39 years. The retention time is a measure of how often the entire volume of the lake is replaced by new incoming water. The water residence time is calculated as the lake volume divided by the annual inflow. Due to the drier than normal weather conditions during the study period, the measured retention time is likely longer than normal. As part of a 1998 study titled *Evaluation of Detention and Stream Buffers to Protect Fox Lake from Uncontrolled Upland Erosion* (R. A. Smith and Associates, 1998), the hydraulic residence time for Fox Lake, under normal rainfall, was estimated at 0.28 years.

Nutrient and Sediment Budgets

Annual budgets for total phosphorus, dissolved phosphorus, total nitrogen, and total suspended solids were developed for Fox Lake for the 12-month study period of August 2004 through July 2005. The budgets represent a mass balance of inflows, outflows, and retention in the lake. The budget is based predominantly on monitored data collected by the University of Wisconsin-Milwaukee. The following discussion outlined the methods used to develop the mass balance budgets.

Surface Water Inflow and Outflow

As discussed in the water budget section above, surface water inflow and outflow was measured or estimated at the following locations shown on Figure 7-1:

- Alto Creek at CTH F
- Drew Creek at CTH F
- Cambra Creek at CTH A
- Mill Creek at lake outlet

At each of the monitoring locations, grab samples for total phosphorus, dissolved phosphorus, nitrite/nitrate, organic nitrogen (TKN) and total suspended solids were collected from August 2004 through May 2006. Samples were collected at a water depth of 0.6 percent of the total water depth following the methods outlined in described in Edwards and Glysson (1999). The results of the sampling are summarized in Table 7-3, including the minimum, maximum, average (mean), and number of samples collected at each site.

Table 7-3
Summary of Concentration Data for Tributary Monitoring at Fox Lake

Stream	Statistic	Total Suspended Solids (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Dissolved Phosphorus (mg/l)
Alto Creek	Minimum	7	7.730	0.039	0.006
	Maximum	60	18.960	0.224	0.104
	Average	16.747	12.457	0.093	0.037
	Count	19	20	20	20
Drew Creek	Minimum	3	2.750	0.051	0.017
	Maximum	150	22.060	0.375	0.327
	Average	23.389	12.167	0.180	0.116
	Count	18	19	19	19
Cambra Creek	Minimum	2	1.319	0.086	0.003
	Maximum	37	4	0.447	0.327
	Average	10.111	1.991	0.182	0.085
	Count	18	17	20	19
Mill Creek	Minimum	2	0.919	0.034	0.005
	Maximum	37	2.479	0.257	0.087
	Average	10.263	1.356	0.120	0.037
	Count	19	16	20	19

Using the above concentration data and instantaneous flow reading, loading for each sampling incident was calculated. A series of regression equations were developed to calculate loadings-based flow values for the entire period of flow record. The regression equations were based on the mathematical relationship between nutrient and solids concentrations and instantaneous flows. The resulting equations were used to calculate loadings for each 20-minute flow measurement collected with the YSI Sondes. The form of the regression equations was:

$$\log10(\text{Loading in mg}) = \text{Coefficient} + \text{Slope} * \log10(\text{Flow in m}^3/\text{s})$$

Table 7-4 summarizes the equation coefficients, slope values and fit statistics.

Table 7-4
Summary of Regression Equations Used to Calculate Instantaneous Loading Values for Tributary Streams

Dependent Variable	Stream	Coefficient	Slope	r	p
Total Suspended Solids	Alto	3.82	0.68	0.652	0.002
	Cambra	4.19	1.43	0.522	0.022
	Drew	3.95	0.90	0.815	0.000
	Mill	4.29	1.64	0.836	0.000
Total Nitrogen (TKN+NO2/3)	Alto	4.17	1.09	0.970	0.000
	Cambra	3.40	1.13	0.897	0.000
	Drew	4.46	1.23	0.977	0.000
	Mill	3.51	1.56	0.917	0.000
Total Phosphorus	Alto	1.78	0.86	0.797	0.000
	Cambra	2.32	1.11	0.728	0.000
	Drew	1.66	0.72	0.895	0.000
	Mill	2.31	1.37	0.860	0.000
Dissolved Ortho Phosphate	Alto	1.48	0.99	0.755	0.000
	Cambra	1.67	0.98	0.319	0.170
	Drew	1.41	0.71	0.813	0.000
	Mill	1.55	1.13	0.716	0.000

For direct drainage area to Fox Lake, that area adjacent to the lake shoreline that enters through predominately sheet flow, the nutrient and sediment inputs were estimated using unit area loading values measures in the Alto Creek watershed. Unit area loading, which is mass per unit area per unit of time, was multiplied by the drainage area to calculate annual loadings.

Atmospheric Loadings

Atmospheric loading, which is direct precipitation of material on the lake surface deposited with rain water, was calculated based on monthly mean concentrations of total nitrogen and total phosphorus levels measured by the Illinois State Water Survey at Bondville, IL, for the study period of 2004 through 2005. Concentration data was not available for total solids or dissolved phosphorus.

Groundwater

Groundwater was not studied as part of the University of Wisconsin-Milwaukee project. Therefore, groundwater inflow and outflow were not measured. Based on tributary stream monitoring, it has been seen that base-flow samples of Alto and Drew Creeks show high concentrations of total nitrogen and total phosphorus, indicating that the groundwater is likely a significant source of nutrients to the lake. If we analyze the base flow concentrations of the tributary stream sampling (flows less than 0.75 m^3/s) we find the statistical relationships outlined in Table 7-5.

Table 7-5
Summary of Base-Flow Nutrient Concentrations for Fox Lake Tributary Streams

Statistic	Flow (m^3/s)	Total Suspended Solids (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Dissolved Phosphorus (mg/l)
Mean	0.0355	19.780	11.912	0.149	0.069
Min	0.00541	2.000	0.967	0.042	0.025
Max	0.07233	198.000	25.100	0.626	0.198
Std Dev	0.0239	54.607	7.999	0.159	0.054

If we multiply the mean nutrient concentration times the net groundwater inflow we identify the annual loadings summarized in Table 7-7. It should be noted that the groundwater inputs of nutrients are based on net groundwater inflow which may not represent total groundwater inflow and the groundwater nutrient input calculations likely underestimate groundwater loadings to the lake.

Internal Loading

Internal loading is the amount of phosphorus that is recycled into the water column of the lake from the bottom sediments through physical re-suspension and biological activity of plants and benthic organisms. Internal loading is difficult to measure in shallow lakes such as Fox Lake; therefore, the loading was estimated based on a mass balance approach by calculating the total load needed to generate the measured in-lake concentrations of total phosphorus in the water column and subtracting the known external loading sources. Methods to estimate total loadings of total phosphorus to lakes have been developed by several authors. Table 7-6 summarizes the results of total load calculations based on several widely used trophic models. Included in the table is a summary of the model's calibration data set and calibration range. For the modeling of Fox Lake for the 2004-05 study period, a hydraulic residence time of 1.387 years, mean in-lake total phosphorus concentration of 145 mg/m^3 (ug/l), and mean depth of 1.524 meters (5 feet) were used.

Table 7-6
Results of Total Phosphorus Loading Estimates based on Several Trophic State Models

Trophic Model	Data Set for Model	Model Range	Estimated Loading (mg/yr)
Vollenweider (1975)			3,541,792,800
Vollenweider Combined OECD (1982)	87 lakes worldwide	0.016<Tw<700yr, 3.0<P<750mg/m3, 0.0047<Pin<1425mg/l	18,225,479,850
Vollenweider Shallow Lake/Reservoir (1982)	24 shallow lakes	3.0<P<750mg/l, 0.16<Tw<700yr, 0.047<Pin<1425mg/l	20,107,730,970
Walker General Model (1977)	105 north temperate lakes	P<900mg/m3, Pin<1.0mg/l	9,369,173,779
Walker Reservoir Model (1985)	41 USACOE reservoirs throughout US	1.5<z<58m, 0.014<Pin<1.047mg/l, 0.13<Tw<1.19yr	Not Applicable to Fox Lake based on Retention time
Dillon-Rigler (1975)	18 Canadian Shield Lakes	P<15mg/m3, 1.5<qs<223m/yr, 107<L<2210mg/m2-yr, 0.21<p<63yr	3,541,381,871

Source: WDNR, 2003 and Hey and Associates, Inc.

Based on the mean depth, hydraulic residence time, and in-lake phosphorus concentration in Fox Lake, the Vollenweider Shallow Lake/Reservoir Model (1982) was used for this analysis. The Vollenweider Model estimated to produce an in-lake total phosphorus concentration of 145 mg/m^3 (ug/l), a annual total input loading of 20,107,730,970 mg/yr would be required. Using a mass balance with measured inputs, the unmeasured source of total phosphorus to the lake from internal recycling and groundwater was estimated at 14,513,357,304 mg/yr. This amount is the result of internal recycling and un-estimated groundwater inputs.

If we do not account for internal recycling, the estimated external loadings of total phosphorus for the 2004-05 study period would result in an in-lake total phosphorus concentration of only 2.11mg/l, less than 2% of the observed in-lake concentration, illustrating how important internal recycling is to the in-lake total phosphorus concentrations.

Internal loading models for suspended solids, total nitrogen, and dissolved phosphorus are generally not available.

Conclusions

Table 7-7 summarizes the inflow loading estimates for total suspended solids, total nitrogen, total phosphorus and dissolved phosphorus for the study period of August 2004 through July 2005. Table 7-8 summarizes the outflow loading amounts.

Inflows for total nitrogen, total phosphorus and dissolved phosphorus exceed outflows. It is estimated that 68% of the total nitrogen, 80% of the total phosphorus, and 65% of the dissolved phosphorus was retained in the lake. This nutrient retention is mostly in the form of deposited sediment and organic matter from decomposing plants and algae. Total suspended solid outputs exceeded inputs, likely due to solids in the form of suspended algae leaving the lake over the outlet dam.

Even without the ability to accurately estimate groundwater inputs, internal loading from physical and chemical sediment release and biological activity such as plant growth and algal growth and decay are major components of the annual phosphorus budget. This is true for many macrophyte rich lakes and has been documented by numerous researchers (McRoy et al 1972, Wetzel and Manny 1972, Twilley et al 1977, Nichols and Keeney 1973, Otsuki and Wetzel 1974, Godshank and Wetzel 1978, Carpenter 1980, Brunberg and Boström 2004, Carpenter 1983, and others). It is our opinion that management of external sources alone will not reduce the high phosphorus levels in Fox Lake to target levels in the short term. Other reports by the Department and Hey and Associates and R. A. Smith (1998) have referenced that internal loading of phosphorus is likely high in Fox Lake. The prior DNR studies indicated internal loading composed from 59 – 80% of the total phosphorus load to Fox Lake (Sessing, 1993 and Winkleman and Garrison 1994) which is consistent with the internal load estimate provided in this report. Any management plan for Fox Lake must recognize that bottom sediments that are the result of decades of agricultural runoff are high in nutrients as documented by the USACOE in 1996.

With regards to tributary inflows, Cambra and Alto Creeks were major sources of suspended sediment in the form of total suspended solids, Alto and Drew Creeks were major sources of total nitrogen, Cambra and Drew Creeks were major sources of total phosphorus. Dissolved phosphorus made up 53.7% of the total phosphorus entering the lake from external sources. Drew Creek was the largest source of dissolved phosphorus.

Table 7-7
Inflow Sediment and Nutrient Loadings to Fox Lake for the Study Period of August 2004 through July 2005

Watershed	Estimated Total Susp. Solids Loading (mg)	Percent Total Susp. Solids	Estimated Total Nitrogen Loading (mg)	Percent Total Nitrogen	Estimated Total P Loading (mg)	Percent Total-P	Estimated Dis-P Loading (mg)	Percent Dis-P
Alto Creek	80,251,348,070	35.46	95,514,270,790	48.82	548,997,886	2.73	225,656,788	9.66
Cambra	97,932,970,374	43.27	21,298,321,004	10.89	1,811,459,013	9.01	471,841,127	20.20
Drew Creek	30,065,760,299	13.28	41,991,784,457	21.46	1,481,423,724	7.37	1,382,988,364	59.21
Direct Drainage Area	18,092,157,416	7.99	21,533,086,535	11.01	123,768,091	0.62	50,872,892	2.18
Atmospheric Deposition on Lake Surface	NA	0.00	15,299,911,742	7.82	1,183,854,630	5.89	NA	0.00
Net Groundwater Inflow	0	0.00	35,471,410,570	0.00	444,870,322	2.21	204,479,552	8.75
Internal Load and Groundwater	NA	0.00	NA	0.00	14,513,357,304	72.18	NA	0.00
Grand Total	226,342,236,159	100.00	231,108,785,098	100.00	20,107,730,970	100.00	2,335,838,723	100.00

Table 7-8
Outflow Sediment and Nutrient Loadings to Fox Lake for the Study Period of August 2004 through July 2005

Source	Estimated Total Susp. Solids Loading (mg)	Estimated Total Nitrogen Loading (mg)	Estimated Total P Loading (mg)	Estimated Dis-P Loading (mg)
Mill Creek	370,629,326,611	62,071,299,871	4,021,288,964	730,500,373
Evaporation	0	0	0	0
Grand Total	370,629,326,611	62,071,299,871	4,021,288,964	730,500,373

Tributary Monitoring

To understand the sources of nutrients and sediment entering Fox Lake, additional tributary monitoring was conducted in the spring of 2006. Samples were collected at several points in the watershed as identified in Figure 7-1. The results of the sampling are summarized in Table 7-9. Included in the table for comparisons are statewide means and ranges for nitrogen and phosphorus based on data for 240 streams as part of the study, *Nutrient Concentrations and Their Relations to the Biotic Integrity of Wadeable Streams in Wisconsin* (USGS, 2006). Values in bold text indicate mean concentrations above the state, ecoregion or environmental phosphorus zone averages as reported by USGS.

Table 7-9

Results of Additional Tributary Monitoring for Source Identification
Mean Values from Five Sampling Dates

Watershed and Station No.	Total Suspended Solids (mg/l)	Organic Nitrogen (TKN) (mg/l)	Nitrate/Nitrite (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Dissolved Phosphorus (mg/l)
Alto No. 1	9.878	*0.654*	*12.893*	*13.547*	*0.070*	0.043
Alto No. 2	31.600	*1.040*	*8.830*	*9.87*	*0.117*	*0.067*
Alto No. 3	18.520	*1.216*	*7.770*	*8.986*	*0.129*	*0.074*
Alto No. 4	25.720	*1.472*	*8.536*	*10.008*	*0.129*	*0.065*
Cambra No. 1	5.750	*1.766*	*1.315*	*3.081*	*0.127*	*0.057*
Cambra No. 2	7.667	*0.972*	0.027	*0.999*	*0.221*	*0.156*
Cambra No. 3	27.750	*1.342*	*4.304*	*5.646*	*0.138*	*0.069*
Cambra No. 4	26.200	*1.598*	*4.218*	*5.816*	*0.169*	*0.060*
Drew No. 1	8.600	0.456	*18.800*	*19.256*	*0.094*	*0.062*
Drew No. 2	10.100	*0.694*	*21.040*	*21.734*	*0.101*	0.040
Drew No. 3	71.333	*1.074*	*20.740*	*21.814*	*0.200*	*0.055*
Mill Creek	4.200	*1.108*	0.085	*1.193*	*0.073*	0.040
	Statewide Means (USGS, 2006)					
Mean	-	0.675	2.086	2.807	0.116	0.079
Median		0.563	1.048	1.695	0.085	0.050
Minimum	-	0.070	0.005	0.131	0.012	0.004
Maximum	-	2,350	20.550	21.260	1.641	1.495
Standard deviation	-	0.414	2.865	2.860	0.144	0.122
	Eco-region Means (USGS, 2006)					
Median	-	-	-	0.811	0.025	-
0% percentile	-	-	-	0.777	0.023	-
100 percentile	-	-	-	21.260	1.641	-
	Environmental Phosphorus Zone Means (USGS, 2006)					
Median	-	-	-	0.632	0.042	-
0% percentile	-	-	-	0.298	0.016	-
100 percentile	-	-	-	21.260	0.304	-

Source: University of Wisconsin-Milwaukee and Wisconsin Laboratory of Hygiene and USGS (2006)

As can be seen by the tributary data, Alto, Drew, and Cambra Creeks all have concentrations of organic nitrogen (TKN), nitrate/nitrite, and total phosphorus that exceed the statewide means. Concentrations of nitrate/nitrite in Drew Creek actually exceed the USGS maximum value for their 240 watersheds.

Alto Creek

Alto Creek was sampled at four sites starting at the headwaters at CTH CH (site No. 4), the snowmobile crossing east of Lakeland Road (site No. 3), Lake Emily Road (site No. 2) and CTH F (site No. 1). If we convert the concentration data to loadings by multiplying the concentrations times flow (Figure 7-7) we can see the total mass of material that is moving downstream. Figure 7-8 illustrates the loadings for total suspended solids (TSS) in milligrams per second (mg/s) for the five sample dates on Alto Creek. The three May dates represent storm events that range from 0.51 to 1.57 inches of rainfall in 24 hours. As we see on May 18, 2006, loadings start high at CTH CW and remain high as this mass of sediment moves downstream. On May 25, May 31, and June 19, loadings at CTH CW (site No. 4) start out low and increase downstream, with the largest increases between sites No. 3 (snowmobile crossing) and No. 2 (Lake Emily Road). The June 13 sampling represents base-flow conditions. During three of the four small storm events, TSS loadings drop as water moves through the water quality treatment weir at CTH F. TSS loading reductions during these three storm events range from 25% to 76%.

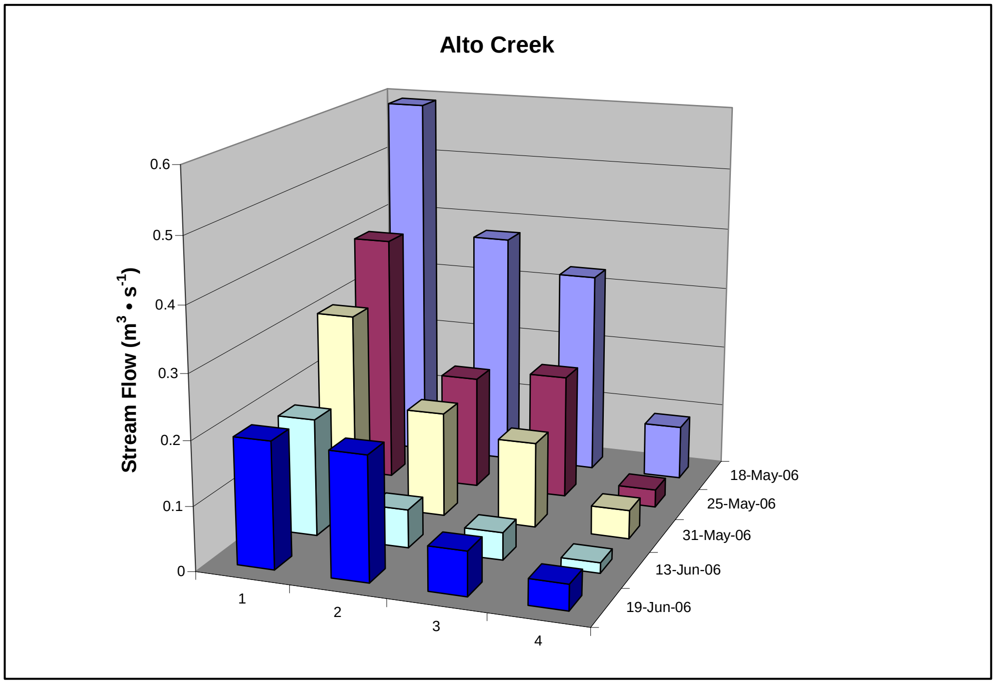

Figure 7-7
Alto Creek Tributary, Measured Flows on Five Sampling Dates

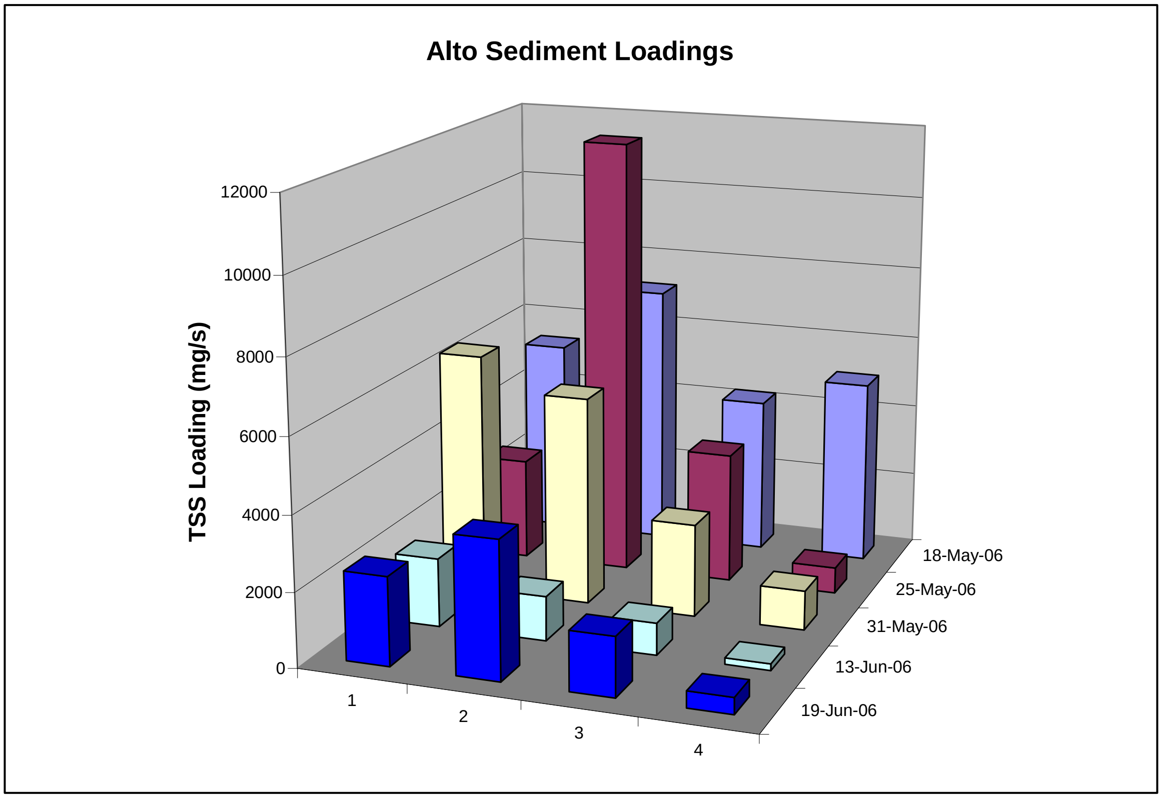

Figure 7-8
Alto Creek Tributary, Total Suspended Solids Loadings by Sampling Site

Figure 7-9 illustrates the loadings for total phosphorus. On all of the storm sampling dates, total phosphorus loadings start out low at CTH CW and see a dramatic increase at sampling site No. 3, indicating the likely source may be the unnamed tributary from the east. Figure 7-10 illustrates the loadings for dissolved phosphorus. Dissolved phosphorus makes up between 25% and 42% of the total phosphorus loading, indicating the potential phosphorus source may be animal waste.

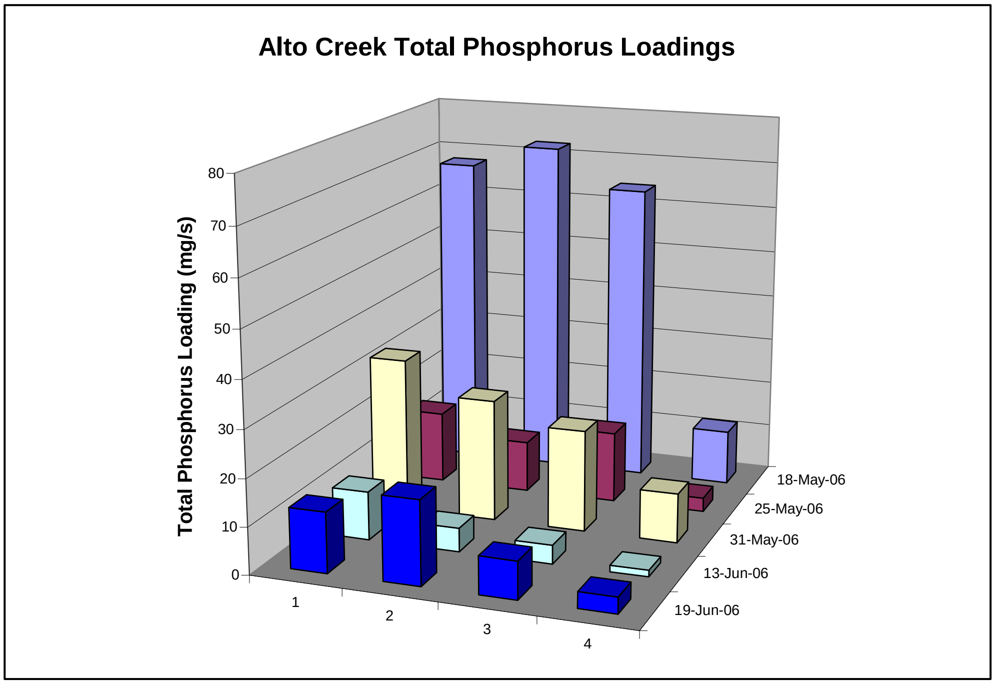

Figure 7-9
Alto Creek Tributary, Total Phosphorus Loadings by Sampling Site

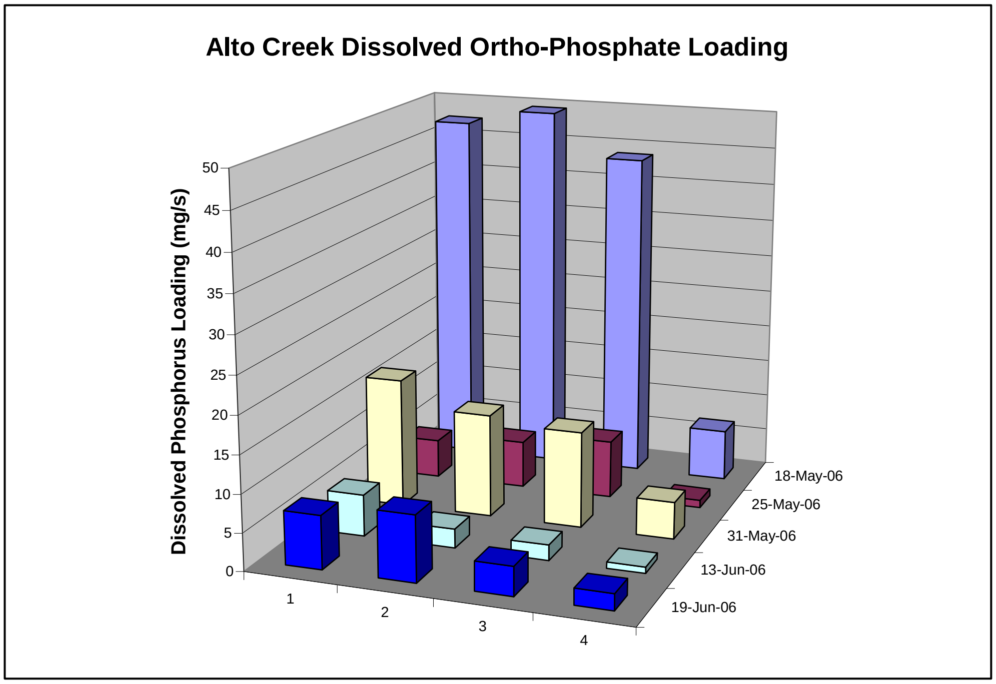

Figure 7-10
Alto Creek Tributary, Dissolved Phosphorus Loadings by Sampling Site

Figure 7-11 illustrates the loadings for total kjedahl nitrogen (TKN, organic + ammonia). TKN loadings increase from upstream to downstream, with largest increases at site No. 3, indicating again a potential animal waste problem in the eastern tributary. Figure 7-12 illustrates the loadings for nitrate/nitrite nitrogen. Nitrate/nitrite loading generally increase from upstream to downstream. Increases in downstream nitrate/nitrite loadings are due to the breakdown of TKN as it moves downstream.

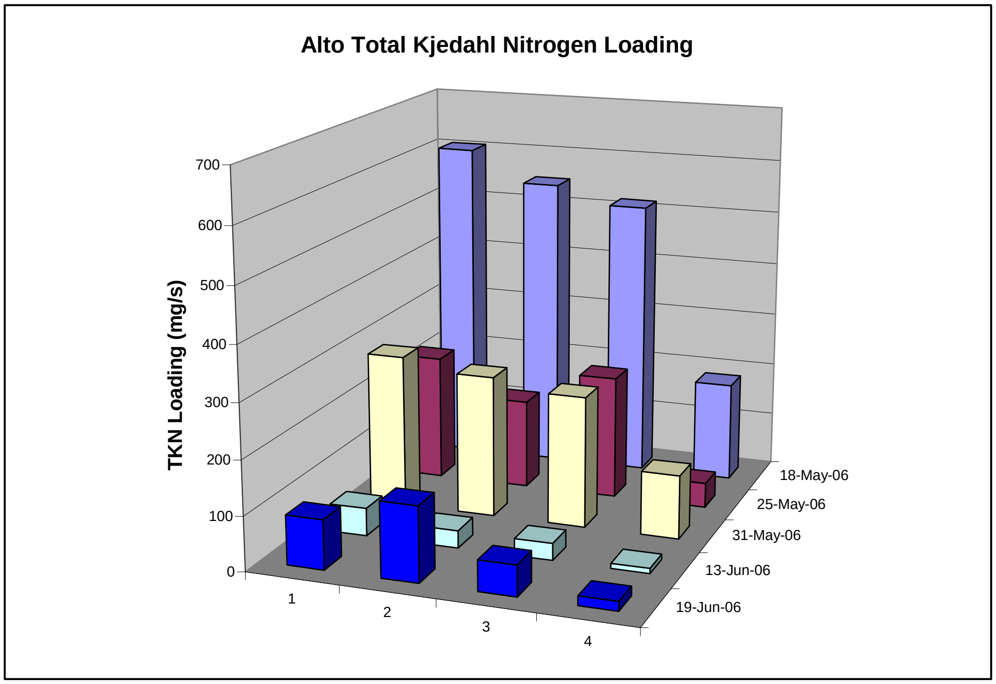

Figure 7-11
Alto Creek Tributary, Kjedahl Nitrogen Loadings by Sampling Site

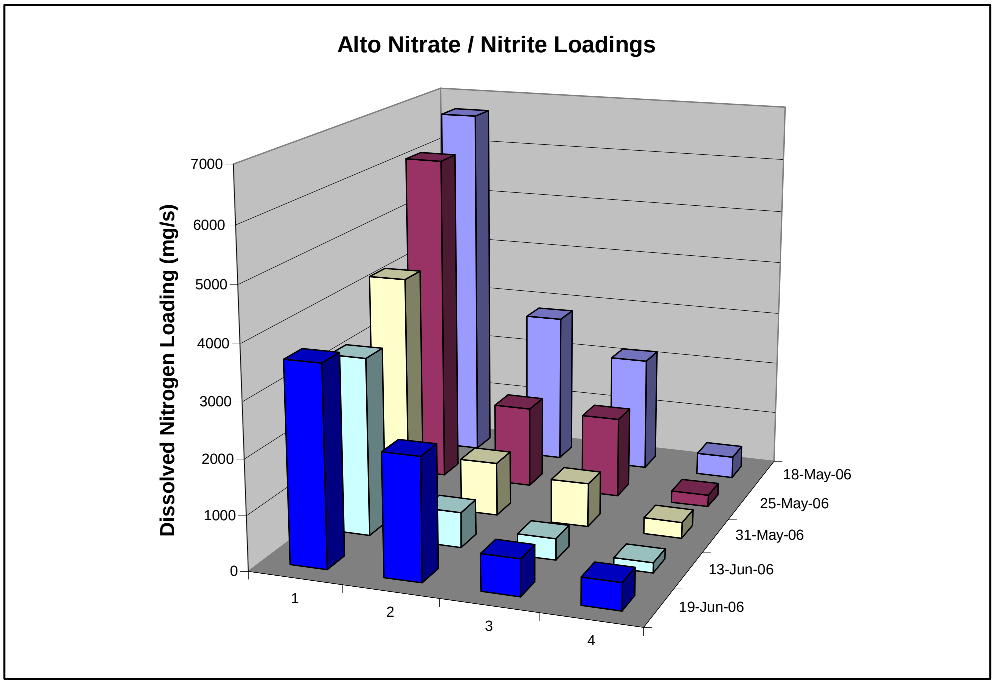

Figure 7-12
Alto Creek Tributary, Nitrate/Nitrite Nitrogen Loadings by Sampling Site

Drew Creek

Drew Creek was sampled at three sites. Site No. 3 was at Parish Road and represents the western tributary, site No. 2 was at Lake Emily Road and represents the confluence of both the western and eastern tributaries, and site No. 1 was on the mainstem at CTH F just upstream of the lake. Figure 7-13 illustrates flows measured on the five sample dates. As can be seen on most sample dates, most of the flow in Drew Creek comes from the eastern tributary which drains the northern half of the Fox Lake Correctional Facility property. Much of the flow from the eastern tributary is likely base-flow from the prison’s wastewater infiltration system. On most sampling dates there is a slight loss of flow from Lake Emily Road downstream to CTH F, this is likely due to infiltration of water into a sand lens along the stream.

Figure 7-14 illustrates the total suspended solids loadings for the five sample dates. On May 31, 2006, a storm of 1.57 inches in 24 hours, we see a large export of sediment from the western tributary, which drains the Drew and Zimmerman farms. The likely source is erosion off agricultural fields.

Figure 7-15 and 7-16 illustrates the loadings for total and dissolved phosphorus. Phosphorus loadings are generally equally divided between the eastern and western tributaries of the stream. Dissolved phosphorus makes up approximately 40% of the total phosphorus.

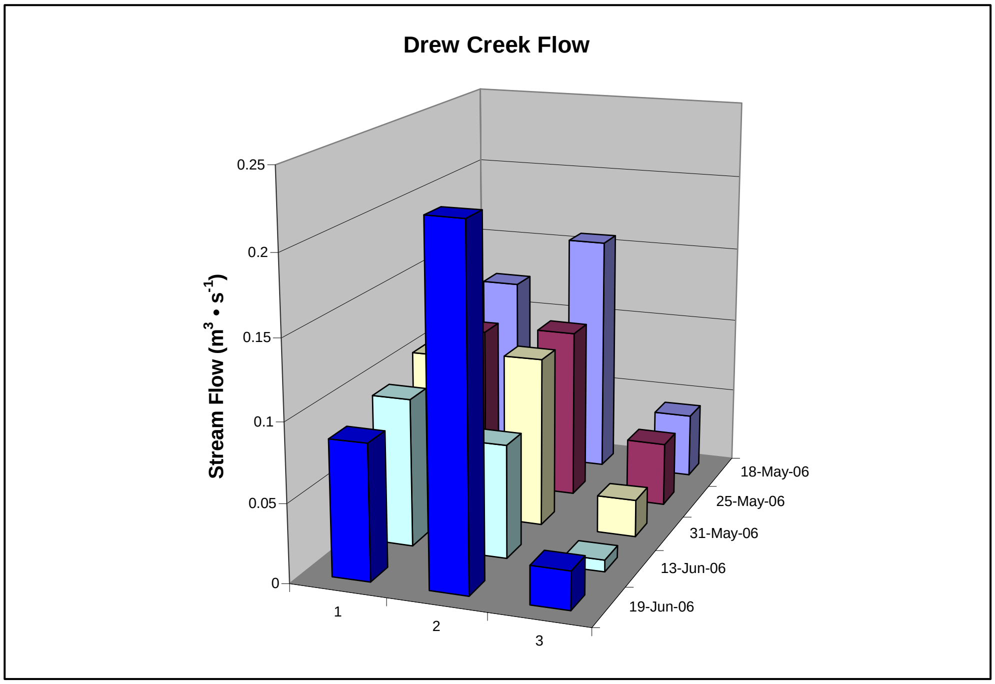

Figure 7-13
Drew Creek Tributary, Measured Flows on Five Sampling Dates

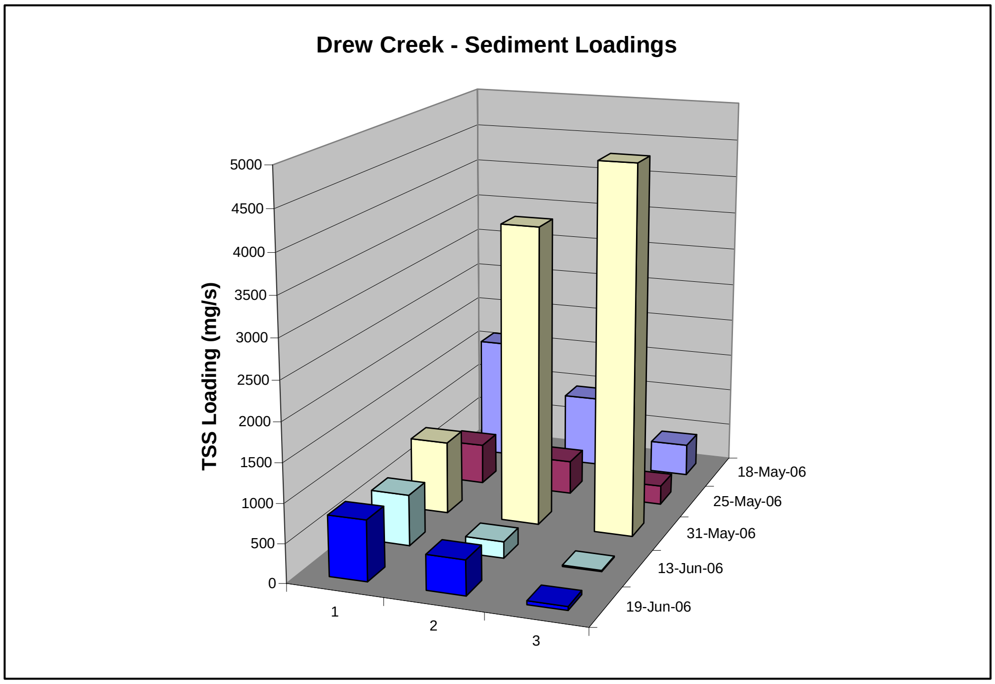

Figure 7-14
Drew Creek Tributary, Total Suspended Solids Loadings by Sample Site

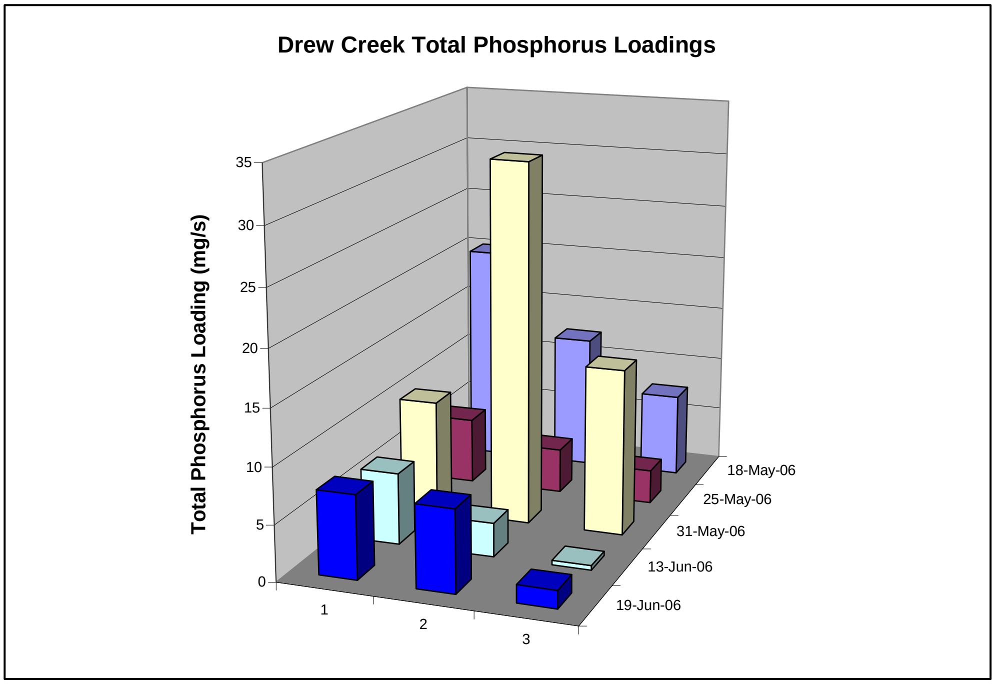

Figure 7-15
Drew Creek Tributary, Total Phosphorus Loadings by Sample Site

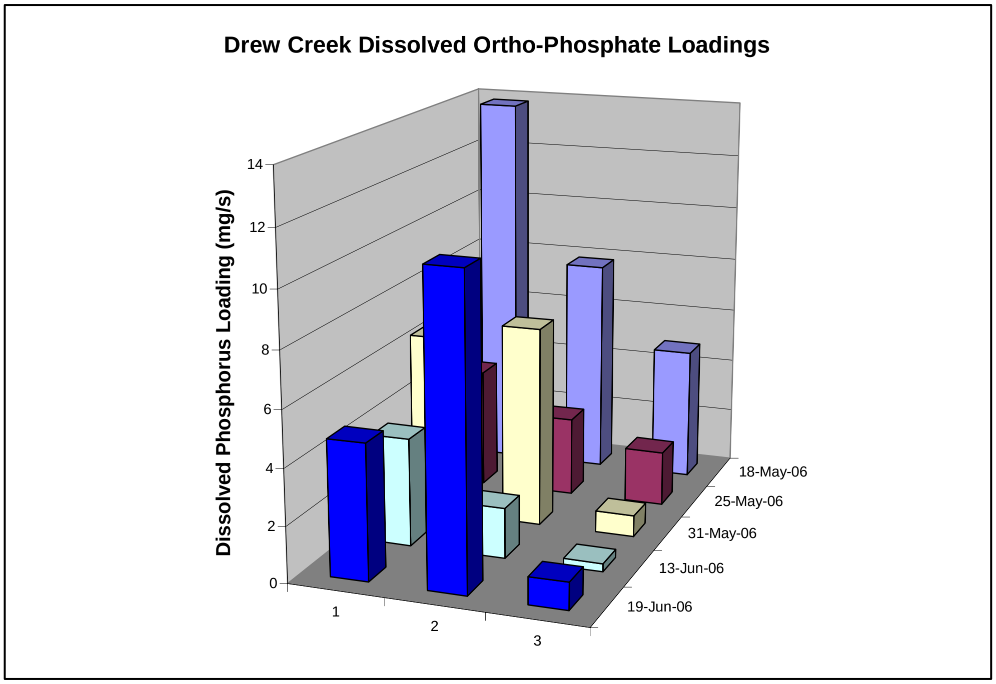

Figure 7-16
Drew Creek Tributary, Dissolved Phosphorus Loadings by Sample Site

Figure 7-17 illustrates the Drew Creek loadings for total kjedahl nitrogen (TKN, organic + ammonia). TKN loadings, like phosphorus, are generally equally divided between the eastern and western tributaries, except during base flow when the eastern tributary makes up most of the loadings. Figure 7-18 illustrates the loadings for nitrate/nitrite nitrogen. Nitrate/nitrite loadings are the greatest from the eastern tributary, likely due to base flow from the prison's wastewater treatment system. On two storm event samplings (May 31 and June 19) TKN and nitrate/nitrite loading decrease between Lake Emily Road and CTH F, this is due to the reductions in stream flow between the two sampling sites.

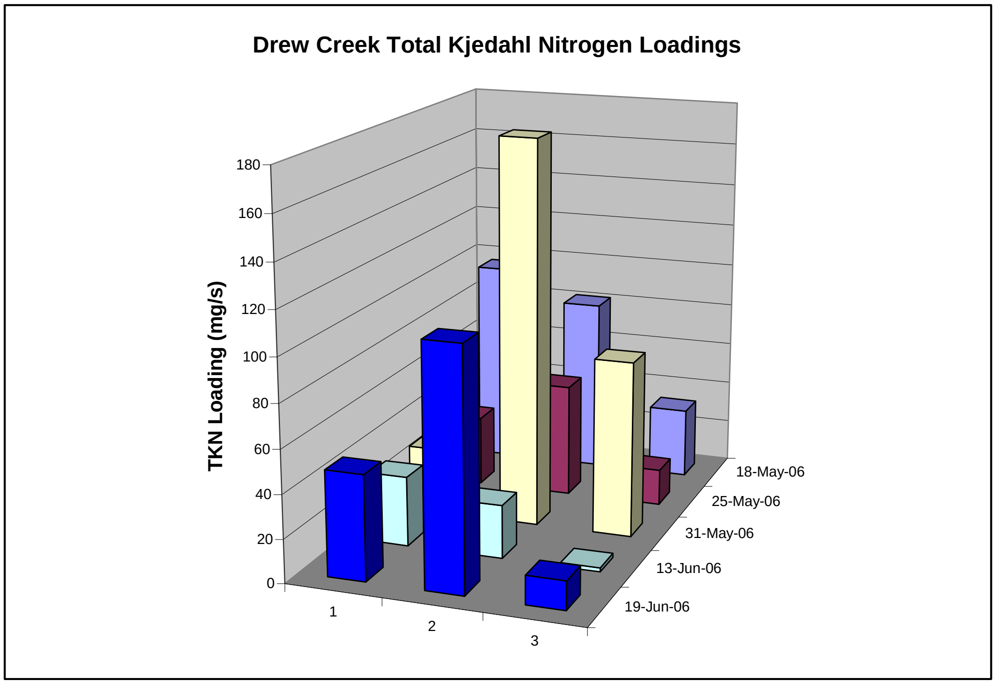

Figure 7-17
Drew Creek Tributary, Total Kjedahl Nitrogen Loadings by Sample Site

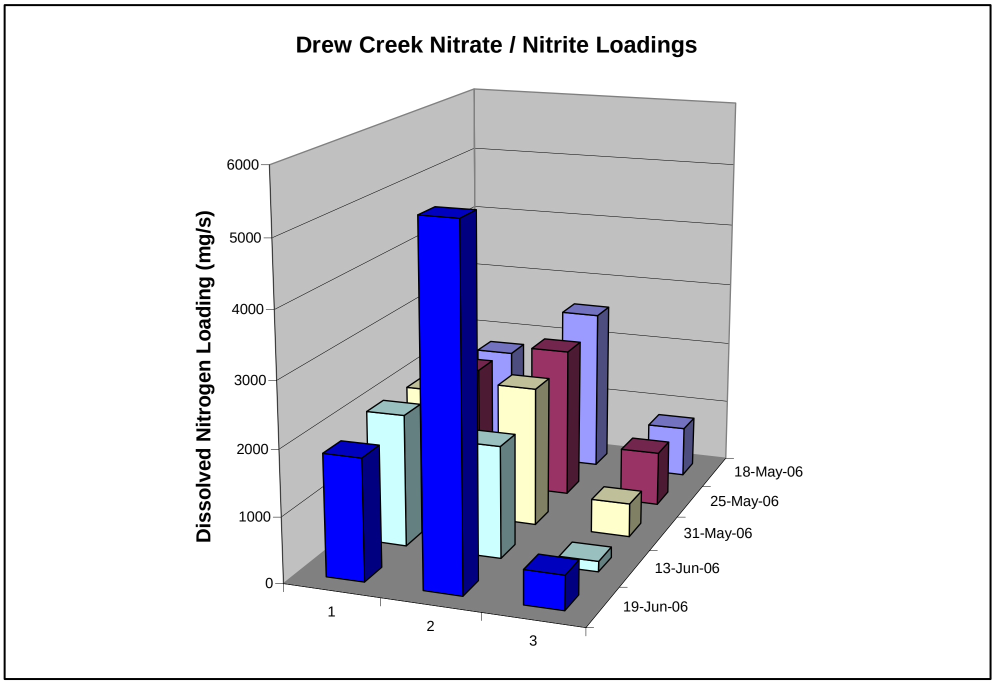

Figure 7-18
Drew Creek Tributary, Nitrate/Nitrite Nitrogen Loadings by Sample Site

Cambra Creek

Cambra Creek was sampled at four locations. Sample sites included the southern tributary at Canada Island Road (site No. 4), the southwest tributary at STH 73 (site No. 3), northwestern tributary at CTH F (site No. 2), and northern tributary at Wiersma Road (site No. 1). Figure 7-19 illustrates the flows measured on the five sampling dates. As we see, flows for each sampling date varied between the tributaries, likely due to different distributions of rainfall across the watershed on different dates. The northern tributary (site No. 1) had constant base flow, which varied little during storm events, indicating the storage impacts of the large amount of wetlands in this tributary.

Figure 7-20 illustrates the total suspended solids loadings for the four Cambra Creek tributaries. We see that on May 18, 2006, that both the southern tributary (site No. 4) and southwest tributary (site No. 3) contributed high sediment loadings. The source was likely erosion off agricultural fields.

Total and dissolved phosphorus loadings are illustrated in Figures 7-21 and 7-22, respectively. Dissolved phosphorus makes up between 9% and 45% of the total phosphorus depending on sample site and date. The largest loading of total phosphorus is from the southern tributary (site No. 4) and southwest tributary (site No. 3). Loadings were the highest on May 18, 2006, and are associated with high loading of suspended solids, indicating soil erosion is likely the source.

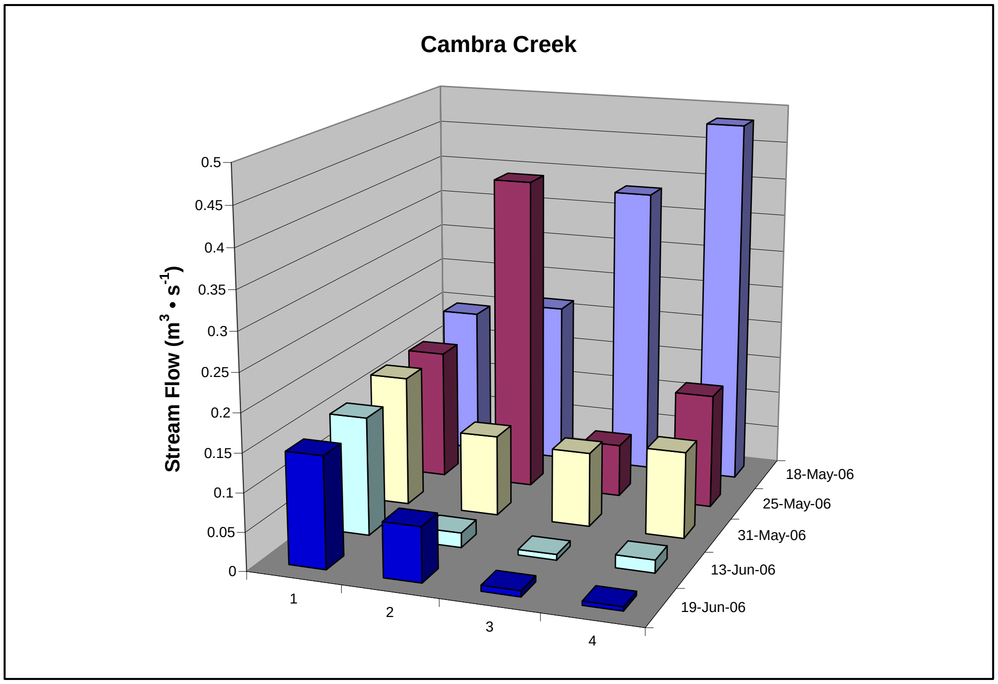

Figure 7-19
Cambra Creek Tributary, Measured Flows for Five Sampling Dates

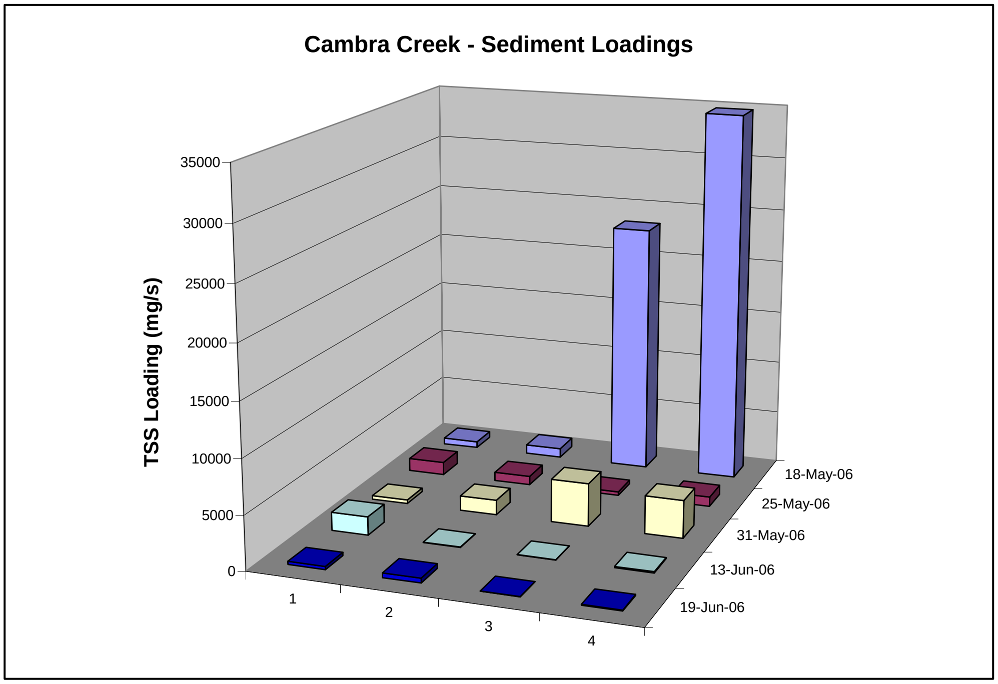

Figure 7-20
Cambra Creek Tributary, Total Suspended Solids Loadings by Sample Site

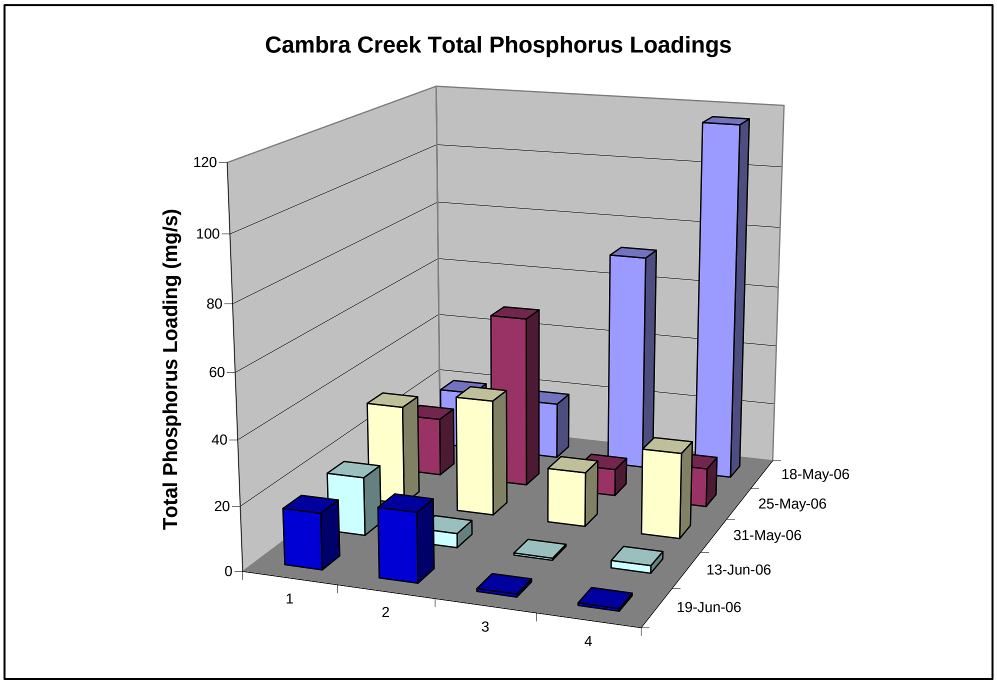

Figure 7-21
Cambra Creek Tributary, Total Phosphorus Loadings by Sample Site

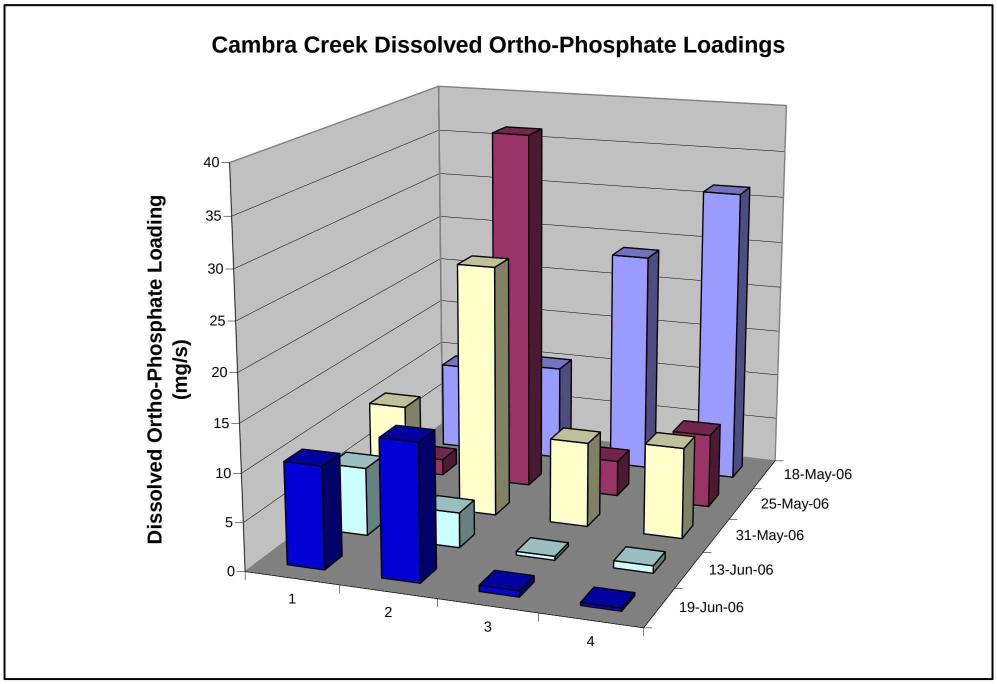

Figure 7-22
Cambra Creek Tributary, Dissolved Phosphorus Loadings by Sample Site

Figures 7-23 and 7-24 illustrate the Cambra Creek loadings for total kjedahl nitrogen (TKN) and nitrate/nitrite, respectively. Both TKN and nitrate/nitrite loadings are highest on May 18, 2006, from the southern tributary (site No. 4) and southwest tributary (site No. 3). The likely source of these high nitrogen loadings is fertilizer or manure applied to agricultural fields as part of spring planting.

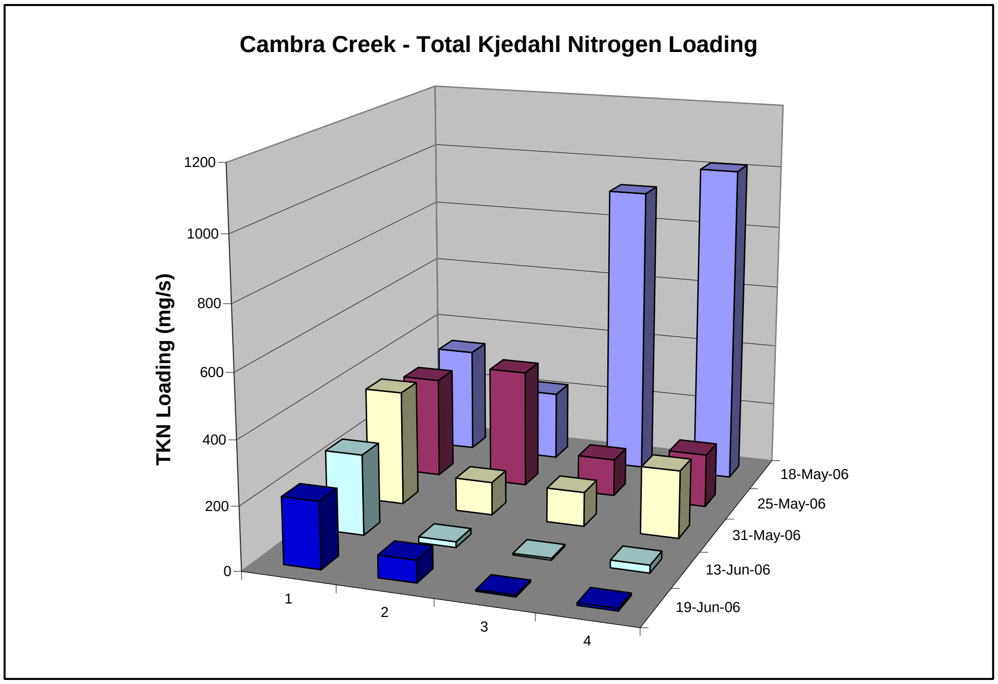

Figure 7-23
Cambra Creek Tributary, Total Kjedahl Nitrogen Loadings by Sample Site

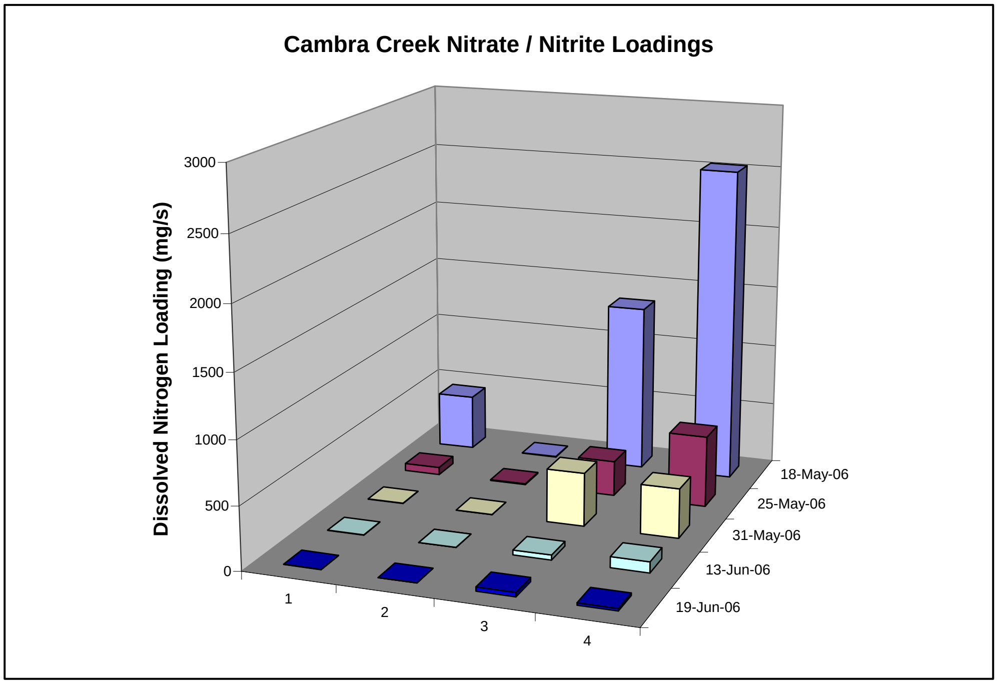

Figure 7-24
Cambra Creek Tributary, Nitrate/Nitrite Nitrogen Loadings by Sample Site

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CHAPTER 8: RECOMMENDATIONS

INTRODUCTION

As outlined in the previous chapters, Fox Lake is a hyper-eutrophic shallow lake that fluctuates between clear-water, macrophyte-dominated conditions and turbid, algae-dominated conditions. The factors that result in which condition the lake exists in are multiple and include:

- Presence or absence of rooted submerged aquatic plants
- Abundance of key game and panfish species such as largemouth bass and bluegill
- Abundance of plankton eating fish such as crappie
- Spring runoff conditions which favor aquatic plants during drought years such as 2005 and 2006.

In 1995 the Fox Lake Inland Protection and Rehabilitation District (FLILPRD) in cooperation with the Wisconsin Department of Natural Resources (WDNR), Dodge County, Town of Fox Lake and City of Fox Lake prepared a *Lake Long-Range Planning Strategy for the Rehabilitation of Fox Lake, Dodge County* (R. A. Smith and Associates, Inc. 1996). As part of the plan, the goal statement developed by an advisory committee of the partners and public was as follows:

> *Restore and protect the fishery, wildlife and recreational values of Fox Lake by implementing a sustainable, ecologically-based management plan that promotes increased water clarity, aquatic plant diversity and lake stability.*

To achieve the above goal, the following objectives were established. To achieve the objectives the actions outlined below were implemented:

1. *Halt the degradation of the lake through the control of nonpoint source pollution.*
    a. Several combined weir control structures and wetlands restoration projects were installed that have improved conditions on Alto Creek by reducing phosphorus by 40% and suspended solids by nearly 70%.
    b. A number of nonpoint source control practices have been installed in the watershed, including manure storage, buffer strips, waterways, wetland scraps, and conservation tillage. However, the goals of the Beaver Dam Priority Watershed Project, based on monitoring during the evaluation project, have not been achieved.

2. *Protect and enhance environmentally-sensitive areas such as wetlands.*
    a. An aquatic plant management plan was developed to protect environmentally sensitive areas related to submergent vegetation in the lake such as those used frequently by wildlife or for fish spawning.
    b. The Town of Fox Lake and Dodge County zoning ordinances have placed all remaining riparian wetlands into conservation zoning for long-term protection from development.
    c. The Town of Fox Lake has adopted a no-wake boating ordinance that places the all of the shallow areas in the eastern half in to protected status from high speed boating activities.

3. *Reduce inlake phosphorus concentrations to pre-1950 levels.*
    a. This goal has not been met but improvements have been made. Figure 5-33 in the evaluation report illustrates that mean phosphorus prior to the biomanipulation project in 1996 was approximately 200 ug/l, in the past decade TP concentration have dropped to approximately 140 ug/l. Limited data from 2006 and 2007 suggests a continued pattern of improvement.

4. *Reduce the occurrence of nuisance algae blooms.*
    a. During 2005, 2006 and 2007 there was one nuisance algal bloom indicating hyper-eutrophic conditions (chl-a > 100 ug/l or TSIchl-a > 70) recorded on Fox Lake, indicating that in the short-term this goal has been achieved.

5. *Re-establish the aquatic macrophyte community.*
    a. The aquatic plant community has been re-established in the lake since at least 2004 (see Figure 6-9). In fact, Fox Lake has a current aquatic plant management plan to address nuisance levels of plant growth.

6. *Restore lost wetland areas.*
    a. Wetland restoration has taken place in the watersheds of Alto and Cambra Creek.
    b. Restoration of riparian wetlands on Fox Lake has not been achieved.

7. *Rehabilitate the degraded sports fishery.*
    a. The sports fishery at Fox Lake has improved significantly. Sportfish (largemouth bass and walleye) and panfish (bluegill, black crappie, and yellow perch) numbers have increased dramatically since 2000.

8. *Remove sediment deposits from the front of the Town Park, lake inlet and lake outlet.*
    a. In 1998 a dredging project in front of the Town of Fox Lake Park took place to facilitate boat access from the launch to open water of the lake. Resident in the lake inlet (Cambra Creek area) and outlet (Mill Creek) rejected moving forward with dredging projects due to cost.

9. *Maintain and improve the economic base of the area through enhancement of recreational opportunities.*
    a. The improved fishery in Fox Lake has increased lake usage by anglers. Increased use of the lake is indicated by the increased number of boats launching at the Town and City of Fox Lake boat launch in the last five years. While no formal economic studies have been conducted, antidotal information from the local Chamber of Commerce indicates increased economic activity since improvement in the lake fishery.

10. *Develop a management plan for lake level management.*
    a. A lake level management plan for Fox Lake has not been developed. Currently the Town and City of Fox Lake are maintaining the lake level with in the current Public Service Commission order.

11. *Control boating activities in environmentally sensitive areas.*
    a. Much of the eastern portion of the lake has been designated as slow no wake to encourage aquatic plant growth.

Many of the above objectives have been achieved; others are still in the process of implementation. After a decade of aggressive fish management, watershed nonpoint source controls, better lake level management, and a few dry springs, Fox Lake achieved a clear-water state in 2004 through 2006. In 2006, in response to the return of rooted aquatic plants, the FLILPRD prepared a long range aquatic plant management plan that protects the majority of the aquatic plants in the lake while facilitating control of nuisance plants near piers and in navigation channels.

The following chapter will provide a summary of the University of Wisconsin-Milwaukee and WDNR water quality and fish monitoring and provide recommendations based on other shallow lake management on how to manage Fox Lake in a more stable clear-water state.

DISCUSSION OF CURRENT SHALLOW MANAGEMENT LITERATURE AND SUMMARY OF STUDY FINDINGS

Shallow eutrophic lakes present a complex suite of problems with respect to the development and implementation of management plans to achieve and maintain high water quality (Gulati and Van Donk 2002, Moss et al. 1996). This is truly the case for Fox Lake, where nutrient supply, macrophyte abundance, algal production, zooplankton grazing and the relative abundance of planktivorous and predatory fish species exist in an intricate balance (Stephen et al 2004). This balance can lead to multiple equilibria that can exist either within a turbid-water, alga-dominated state or alternatively within a clear-water, zooplankton-dominated state (Byers et al. 2006, Guilati and van Donk 2002, Scheffer et al. 1993). Understanding the dynamics of the oscillations within each state and the factors that contribute to the shifts between alternative equilibrium states (Genkai-Kato and Carpenter 2005) is key to establishing effective management for eutrophic lakes.

Nutrient Dynamics and Sediment Management

Classic limnological models that were developed for deep oligotrophic lakes suggest that reducing controlling point- and diffuse-source inputs of nutrients is a critical primary practice necessary for restoring lakes to a clear-water state (Moss et al 1996). However, the reduction in external nutrient loading may not be sufficient to produce enough change to meet water quality goals. External nutrient loading (predominantly phosphorus and nitrogen) from surrounding catchments over a prolonged time frame produces a situation where the release of biologically available phosphorus from highly enriched lake sediments to the water column results in significant internal nutrient loading (Spears et al. 2007). As such, efforts to control internal loading using techniques such as dredging or treatment with binding agents like Alum are sometimes suggested as a secondary practice, but these can be costly and may need to be repeated for continued effectiveness.

The results from our nutrient balance analysis indicate that between 60% and 80 % of the phosphorus budget for Fox Lake comes from internal sources. Internal cycling of phosphorus is a natural part of lake nutrient dynamics and involves both nutrients being released from the sediment and through settling of detritus from both inorganic and organic sources (Wetzel 2001). Sediment release of P is dependent upon numerous factors--the three most important being: 1) the presence of an oxygenated sediment surface which promotes P precipitation in combination with Fe++, 2) minimizing re-suspension by stabilizing sediment, and 3) promoting direct uptake.

Aeration can increase oxygenation and combat anoxia, thereby reducing the flux of P into the water. Fox Lake does experience times of low dissolved oxygen, as evidenced by the low oxygen levels observed during the winter and the efforts for aeration should be continued. However, aeration requires constant maintenance and its effects are localized in the lake. The frequency of dissolved oxygen monitoring in the winter should be increased during periods of heavy snow cover, thick ice, or cloudy weather. Efforts should be made to ensure adequate aeration during critical periods.

Macrophyte beds can play an important role in both stabilizing sediment and promoting direct nutrient uptake. The effectiveness of macrophytes depends greatly on lake morphometry, with a maximum impact observed in shallow lakes (Genkai-Kato and Carpenter 2005) where they can take up phosphorus and inject oxygen into the sediments around their roots. In addition, their roots serve to stabilize sediments, reduce turbulent mixing in the water and generally prevent wind-driven sediment re-suspension (Byers et al. 2006).

Spears et al. (2007) found that the result of natural variation in a Scottish Lake was a seasonal fluctuation in P fluxes between the sediment and water column producing the highest water column concentrations of Total P in late summer and lowest in early spring. Conversely, sediment Total P is highest in mid winter and lowest in late summer. They further suggest that management to reduce internal P loading should look to facilitate flushing during times when sediment release to the water column is high and promote settling during times of sediment uptake. It is possible that management of lake levels could impact internal P in Fox Lake. However the study we conducted on Fox Lake did not examine nutrient release and uptake from the sediments directly and additional research would be necessary.

Water Level Management

Historic water level management on Fox Lake has been relatively high with respect to the current management regime. The recommended winter water level is 89.25 while the recommended spring-fall water level is 89.75. Figure 8-1 shows the available water record for Fox Lake. No data is currently available for 1996-2000. The boxplot represents the distribution of the monthly average lake level recorded. It is clear that the lake level has generally fallen within the recommended stage since 1995 when the Department of Natural Resources ordered the Town and City of Fox Lake to manage the lake within the State Public Service Commission designated levels. While it is not possible to show the impacts of lake level management during the key time period from 1996-2000, it is likely that the current practices have been at minimum supportive of other lake and watershed improvement efforts in maintaining aquatic vegetation and the clear water state.

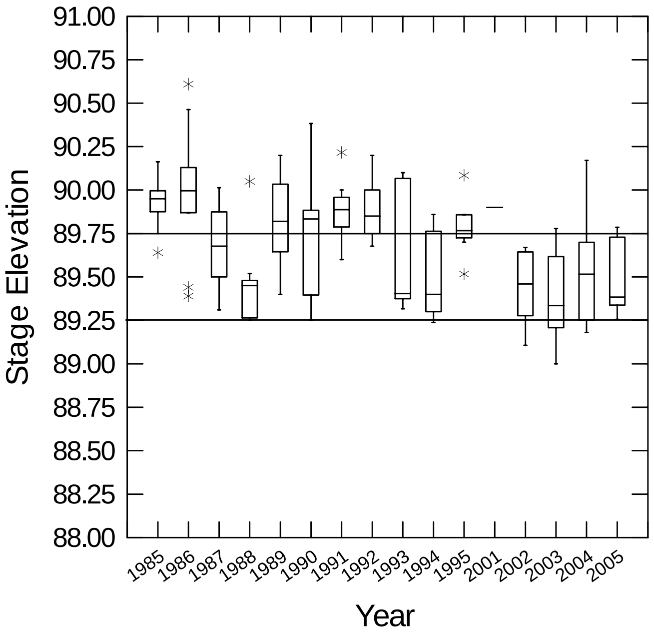

Figure 8-1
Boxplot of Monthly Mean Lake Level 1985-2005
(Horizontal lines indicate desired maximum spring-fall and minimum winter stage)

Biological Conditions and Biomanipulation

Because of the high percentage of internal nutrient recycling in Fox Lake, food-web manipulations that impact algal abundance have the potential to cause dramatic shifts in the equilibrium status of the lake. As a hyper-eutrophic lake, the ecological balance of algae and zooplankton grazers is delicately linked with the maintenance of the abundance of top predators with planktivores. A large and growing body of literature is pointing to the critical role of fish trophic structure as a driving force in shallow lakes (e.g. Meijer et al. 1999), leading to increased emphasis on biomanipulation as a management tool in dealing with water clarity in hyper-eutrophic systems (e.g. Olin et al. 2006). In addition, the structural role of macrophyte beds is critical by providing structural habitat for fish and shading effects that result in lower light levels and reduced algae growth (Byers 2006). Studies suggest that the reduction in water turbulence caused by macrophytes can result in a shift in algal communities from larger taxa like diatoms and green algae which tend to settle out in calm water toward smaller and more active swimming taxa like chrysophytes which are less susceptible to sinking.

These linkages are well demonstrated by the work of Vakkilainen et al. (2004) in mesocosm experiments across Europe. Their work demonstrated the role that large crustacean grazers play in the establishment and maintenance of water clarity, but also showed that macrophytes play a critical role in providing refuge for zooplankton from planktivorous fish and allow populations to persist throughout the warm summer months. An over-abundance of planktivorous fish can play a critical role in shifting the relative abundance of zooplankton trophic guilds from large-bodied to small-bodied forms that have less of an ability to control phytoplankton biomass. Macrophyte beds provide habitat for populations of large-bodied vegetation-dwelling taxa such as Diaphanosoma and Simocephalus. It is important to note that the abundance of Diaphanosoma increased in 2005 during the late summer period when large Daphnia were in decline. It is our hypothesis that this maintained a grazer-driven control of phytoplankton during this period. This pattern was unlike 1995 when in the absence of an established macrophyte community, a summer clear-water period was followed by a late summer algal bloom. In 2005 the established macrophytes provided critical habitat necessary to allow for a species replacement of Daphnia by Diaphanosma.

The biological role of macrophytes in promoting shifts to clear-water equilibria in shallow lakes is well established, but there is significant debate as to whether fish manipulation can push a lake toward a clear-water state in the absence of macrophytes. Lambardo (2005), in a comparative study of seven Ohio lakes, argues that aggressive food-web biomanipulation of fish can be effective as a management technique in some cases, but more often macrophyte-driven, grazer-mediated clear-water stable state may establish on its own after water clarity conditions are brought above a "threshold" for plant growth. Watershed-oriented best management practices for reduction in nutrient loading in combination with fortuitous weather conditions might allow for the initial establishment of macrophytes, which then makes the synergistic and linked effects that lead to the movement toward a quasi-stable equilibria possible.

Beyond low light levels caused by nutrient-fueled algal productivity, there are other factors that can prevent the (re)establishment of macrophytes. Suspended sediment caused by physical disturbance will not allow macrophytes to grow (Byers 2006), leading to the need for more aggressive efforts to establish vegetation using structural features such as windbreaks and wave barriers (e.g. Backman et al. 1999). Efforts to eradicate carp in shallow lakes were motivated largely by the desire to reduce their impact on sediment suspension (Zambramo et al. 2006).

On another level, Jones and Sayer (2003) demonstrated that high levels of periphyton biomass are negatively correlated with macrophyte biomass, and they suggest that insectivorous fish can cause a decrease in macrophytes by reducing the abundance of invertebrate grazers (e.g. snails) on periphyton in macrophyte beds. In such a scenario, it is not only important to manage fish populations to control the abundance of planktivores (e.g. crappie), but also molluscivores (e.g. pumpkinseed)

It is clear from the literature that once vegetation establishes, the management of fish populations can be used in combination with the control of external nutrient loading to effectively manage shallow lakes to remain in a clear-water state to variable degrees of success (Gulati et al. 2002). Changes in rainfall will consistently result in variability in the external input of phosphorus (P) and nitrogen (N) to the lake. Nutrient levels in the lake, even if external sources can be controlled, will continue to be high due to P loading from the P-rich sediments and bio-release by the metabolic activities of benthivorous and planktivorous fish. Decreases in chlorophyll-a content in these shallow lakes did not set off an immediate increase in lake transparency because of resuspension of seston and inorganic suspended matter from the lake bottom by both wind-induced waves and fish foraging activity. In addition, studies in Europe in shallow lakes indicate that even a major reduction in P levels may not lead to improved water clarity and decreases in cyanobacteria without concomitant biological changes in trophic structure (Gulati and Van donk 2002).

Fish management in Fox Lake has predominantly involved reducing the existing benthivore population (carp) through commercial netting and rotenone treatments, and planktivore population (Crappie) by enhancing piscivores such as northern pike, walleye, and largemouth bass. Maintaining a zooplankton peak in spring with large-bodied grazers is a key first step in promoting a clear-water phase. Following this, summer light conditions facilitate growth conditions for macrophytes, which serve to promote water clarity by both competing successfully with phytoplankton for nutrients, stabilizing sediment resuspension, and providing zooplankton refugia. Most successful restoration in recent years has been attributed to the success of aquatic macrovegetation.

Galati and van Donk (2002) argue that most failures in biomanipulation are generally linked not only to insufficient or no decrease at all in the autochthonous or in-lake nutrient loadings, but also to rapid increase of the planktivorous fish in the years following their reduction. They claim that the goal of a 75% reduction in the existing planktivore populations may not be sufficient and that reductions to <50 kg FW ha(-1) may sometimes be necessary. Other strategies used in the Netherlands include enhancement of shoreline vegetation to prevent erosion and improve land-water interfaces, excavation of 20-30 m deep holes in shallower lake areas to allow wind-induced shifting of the nutrient-rich upper sediment layers, and burial in the pits in order to reduce releases of P. Artificial islands have been created in some lakes to reduce the wind fetch factor and erosion, combined with water-level management to enhance shoreline macrovegetation to develop. Such management in Fox Lake would require extending the upper and lower limits for permissible annual water-level fluctuations and exploring the effects of transient draw-downs.

RECOMMENDATIONS

Aquatic Plant Management

The presence of submerged aquatic plants in Fox Lake has been a critical factor in promoting clear water in the lake. Macrophytes have been shown by this study to provide important refuge for zooplankton that, when abundant, can control nuisance algal blooms. In addition to refuge for zooplankton, macrophytes have provided improved habitat and spawning success for largemouth bass and bluegill--major predators on carp and crappie which contribute to poor water clarity in Fox Lake. In 2006 the FLILPRD prepared the *Fox Lake Long-Range (2007-2010/12) Aquatic Plant Management Plan* (Hey and Associates, Inc., 2006). The recommendations in the plan fall into the following categories:

- Develop an integrated plant management strategy to facilitate lake access and recreational use in nearshore areas and navigation channels that minimizes impacts to the overall aquatic plant community and protects ecologically significant areas of the lake
- Develop and implement a lake-wide Eurasian water-milfoil management/native plant restoration strategy if it is determined the aquatic plant community is stable
- Establish a long-term monitoring strategy
- Educate the public on the value of a healthy native aquatic plant community and shallow lake ecology

Integrated Plant Management Strategy

An integrated aquatic plant management strategy (Figure 8-2) applies a number of different methods to effectively allow recreation while maintaining ecological benefits. For Fox Lake, this management strategy will require a combination of low and high level manipulation including herbicides and mechanical harvesting. This strategy should focus on minimizing impacts to native plants, reducing EWM whenever possible, and promoting lake access and recreational use.

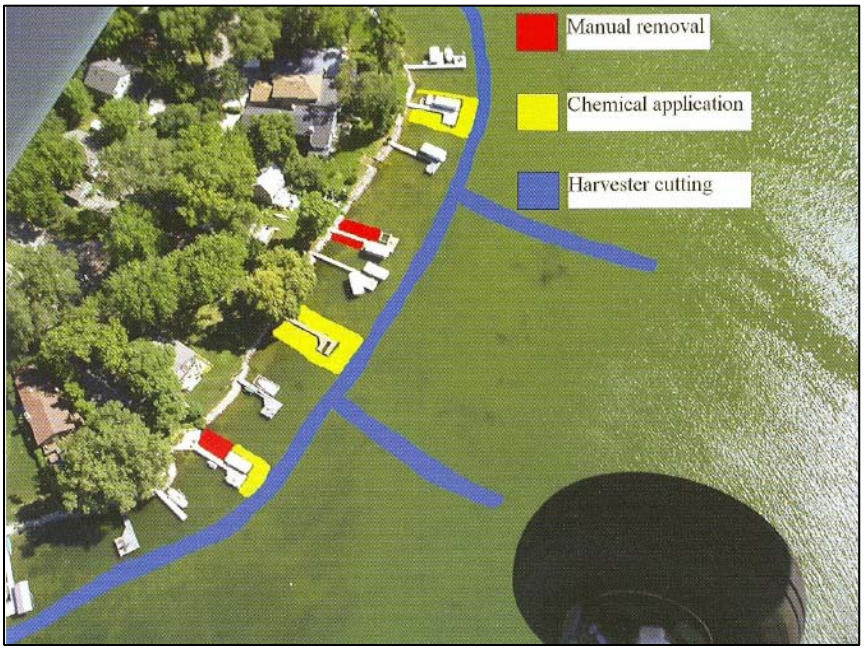

Figure 8-2
Integrated Aquatic Plant Management Strategy
Source: NALMS and WDNR

Nearshore Areas

Control techniques will be limited to hand-pulling or raking, selective chemical treatments targeting Eurasian water-milfoil and Coontail, or relatively small treatments with contact herbicides to control native aquatic plants (other than Coontail). All financial obligations for plant management in nearshore areas are the responsibility of the local riparian homeowner. Whenever possible, treatments that affect non-nuisance native plants should be avoided. Fox Lake is a highly productive lake so it is unrealistic to expect shallow areas of the lake to be plant free. Normal levels of native aquatic plants do not restrict navigation or recreation and should not be managed in any way. It is essential that beneficial native plants such as Elodea or pondweeds are not removed or minimally removed because they may restrict the spread of Eurasian water-milfoil. Visual evidence suggests Elodea is competing well with Eurasian water-milfoil. Sago pondweed is a high value aquatic plant for fish and wildlife and should not be removed. Plants also provide the added benefits of reducing shoreline erosion and improving water clarity.

To ensure adequate protection of native plants, all properties that request aquatic plant management by chemical methods should be inspected prior to chemical treatment to determine the optimal management strategy. The inspection will include using a rake type sampler to determine the types and density of plants present at each management site. Results of the inspection should be recorded to ensure the chemical application reports are accurate to track aquatic plants at each property from year to year. If inspections cannot be conducted by the WDNR, an independent third party will be hired by the Fox Lake Inland Lake Protection and Rehabilitation District to supervise the chemical treatments.

Manual removal methods, such as hand-pulling or raking, that focus on selective removal of Eurasian water-milfoil and Coontail are preferred. Residents are allowed to remove native and non-native plants without a permit in a 30-foot wide area around their piers to allow for navigation and recreation. Eurasian water-milfoil may be selectively removed (hand-pulled or raked) outside of the 30-foot area without a permit, but other plants are limited to a 30- foot wide area. All removed plants must be disposed of on dry land in a manner that will not allow the plants to wash back into the lake and infest other areas. Composting is one way to dispose of plant material.

Chemical treatments will be allowed for property owners affected by Eurasian water-milfoil or Coontail as a secondary option. All chemical treatments require a permit from the Wisconsin Department of Natural Resources. The selective herbicide 2,4-D will be used to treat Eurasian water-milfoil- and Coontail-dominated sites while contact herbicides may be used to treat sites where non-nuisance plants are causing recreational nuisances.

Eurasian water-milfoil or Coontail will be treated using a 2,4-D so beneficial native plants will be largely unaffected. The 2,4-D treatments should occur early in the growing season to minimize competition between EWM and native plants. EWM grows much earlier than many native plants, so its removal early in the growing season should facilitate growth of native plants. Follow-up treatments may occur as necessary to remove EWM or Coontail. Granular formulations should be used to promote longer relief and extended contact time with target plants. Residents may treat the least of 1) their entire frontage or 2) a 50-foot wide by 150-foot long channel with 2,4-D. Permits may be issued with more restrictive areas allowed, per the discretion of the Wisconsin Department of Natural Resources.

Contact herbicides that may also affect native plants should be avoided, but may be used as a tertiary option in areas where aquatic plants other than Eurasian water-milfoil and Coontail are a nuisance. No contact herbicides should be used when the primary management target plants are either Eurasian water-milfoil or Coontail. Contact herbicides create disturbed areas on the lake bottom where the fast growing Eurasian water-milfoil may gain a competitive advantage. Treatment areas using contact herbicides should be limited to a 30-foot wide by 150-foot long area. Contact herbicide treatments should not occur until early summer to provide temporary relief from native plants impeding recreation.

Typically chemical treatments are centered on piers, but an alternate strategy that may provide more relief would be to center the treatment on the property boundary between parcels (Figure 8-3A). This would increase the average size of the remaining plant beds. If an adjacent property owner does not need or want a chemical treatment, then piers may be used as the treatment centerline (Figure 8-3B). It is the responsibility of the homeowner to determine where the center of their treatment area should be located and accurately represent its location on their permit application.

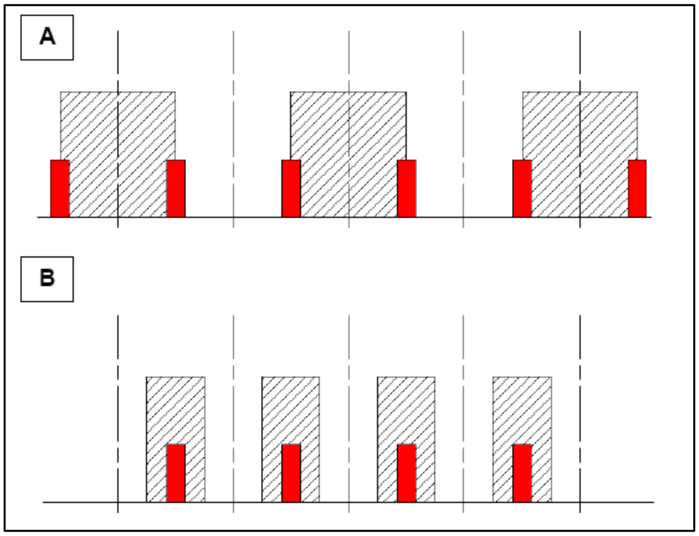

Figure 8-3
Alternate Contact Herbicide Application Strategy (not to scale)
Source: Hey and Associates, Inc.

It is important to note that treatment strategies are NOT additive. Riparian property owners may NOT treat 50-feet of frontage with herbicides and hand-pull plants from an additional 30-foot wide area. Plant management is only allowed in either: 1) a 30-foot wide area for contact herbicide treatment or manual removal, or 2) a 50-foot area for selective herbicide application. Situations creating a total management area in excess of the above specifications are illegal. The only exception to this rule is that Eurasian water-milfoil may be selectively removed by hand-pulling anywhere along a property's frontage. Plant removal using multiple methods is allowed if it is confined to a single 30-foot wide area where plants closest to shore are manually removed and plants in deeper water are chemically treated (Figure 8-2).

Finally, it would be in the best interest of the lake residents for a central entity such as the District to oversee all plant management permit applications. This would allow management to be negotiated under a single contract with a reputable applicator and efficient inspection of proposed management sites. Multiple permit applications and herbicide applicators would make it more difficult to schedule the suggested site monitoring activities and result in higher costs to residents.

Navigation Channels

Due to the dominance of aquatic plants in shallow littoral areas in Fox Lake, actions to facilitate navigation to deep water areas will be required. The proposed location of navigation channels on the lake correspond to the areas of highest plant density, population density, and minimal depth requirements for operation. Areas with dense plants, numerous residents, and areas of at least 3-foot depth are the highest priority (Figure 8-4). These areas were determined during planning meetings open to the public. An additional channel may be cut through the Mill Creek outlet (not pictured) to facilitate boat traffic from the City of Fox Lake boat launch if funding is available.

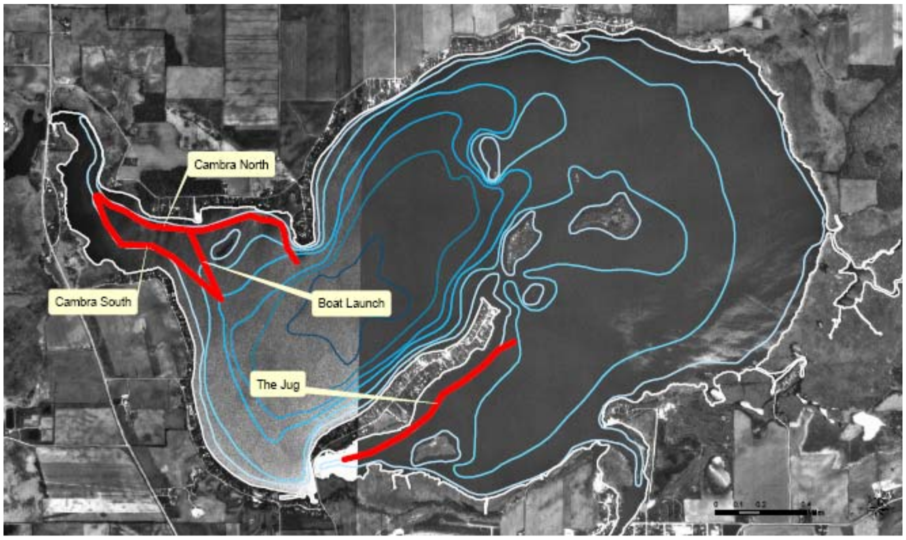

Figure 8-4
Proposed Navigation Channel Locations
Source: Hey and Associates, Inc.

Harvesting should be conducted by a contractor and no plans should be made to purchase equipment over the duration of this plan. It is uncertain whether Fox Lake will remain in the clear-water state and a large capital investment is premature. The District will need to develop loading and unloading sites for harvesting equipment and disposal sites for harvested materials prior to implementing the program. Due to the large size of the lake, at least two loading and unloading locations will be needed to correspond with the Cambra Creek area and the Jug. In addition, a large-scale permit (including application fee) will be required under NR 109 prior to commencement of any harvesting activities.

The financial obligation of creating and maintaining navigation channels is the responsibility of the Fox Lake Inland Lake Protection and Rehabilitation District. A summary of the total acreage and costs for a single harvest of the desired channels is located in Table 8-1. Estimates assume a 25-foot wide channel at a rate of $300 per acre. Typically, harvesting is repeated on an as-needed basis 2 to 5 times over the growing season. Areas experiencing regular boat traffic, such as the boat launch channel, may not require harvesting. Use of cut channels by boaters should be encouraged to reduce the number of cuttings (and cost) required to maintain the channels.

Table 8-1
Proposed Navigation Channel Acreage and Cost Estimates
Source: Hey and Associates, Inc.

Site	Acres	Cost
Cambra North	3.2	$959
Cambra South	2.2	$661
Boat Launch	1.0	$298
The Jug	2.8	$835
Totals	9.2	$2,752

It is recommended that additional side channels be cut into areas of dense plant growth to facilitate feeding by predatory fish and angler navigation (Figure 8-5). The best location of side channels is to the southeast of the proposed channel in the Jug and would consist of a single pass of the harvester. The width of an angler channel would only be ~10 feet. These side channels would be located at the discretion of the Fox Lake Inland Lake Protection and Rehabilitation District and are of the lowest priority of any harvesting activities.

Figure 8-5
Potential Secondary Angler Navigation Channel Locations
Source: Hey and Associates, Inc.

Lake-wide Eurasian water-milfoil Management Native Plant Restoration Strategy

Due to the expansion of Eurasian water-milfoil in Fox Lake, a lake-wide management strategy should be implemented to limit the ecological impacts of this exotic invasive species once it is determined that the aquatic plant community is stable i.e. not at risk in shifting back to the turbid water state. Eurasian water-milfoil has spread to most of the lake (Figure 8-6). Priority areas for a lake-wide management strategy should focus on areas with the densest infestation (Figure 8-7) and progress to areas of lesser density. A total of 635 acres would benefit from EWM management combined with native plant community restoration.

Recent U.S. Army Corps of Engineer (ACOE) research suggests that the best strategy to control EWM and promote the native plant community is through spring herbicide treatments. The advantage of spring treatments is that they will allow native plants the chance to occupy areas formerly colonized by EWM. Spring treatments should occur before native plants begin growing for the year when the water temperature is between 53-59 ^{0}F. Research has shown significant reductions in EWM biomass using spring 2,4-D treatments, increased native species frequencies in treatment areas within 3-4 years post-treatment, and no detectable impacts to fish communities. The impacts of spring EWM removal on water quality and fish spawning are currently undocumented. Funding through the Aquatic Invasive Species Grants from the Wisconsin Department of Natural Resources is available on a competitive basis. Limited funding is also available through the ACOE. Initial cost estimates range from ~\$100,000 - \$500,000 to treat EWM beds present within the initial 625-acres identified as potentially containing EWM in 2006.

Any efforts to control established should not take place until it is well documented that the lake has shifted to a stable clear water state and that native plants are well established in the lake.

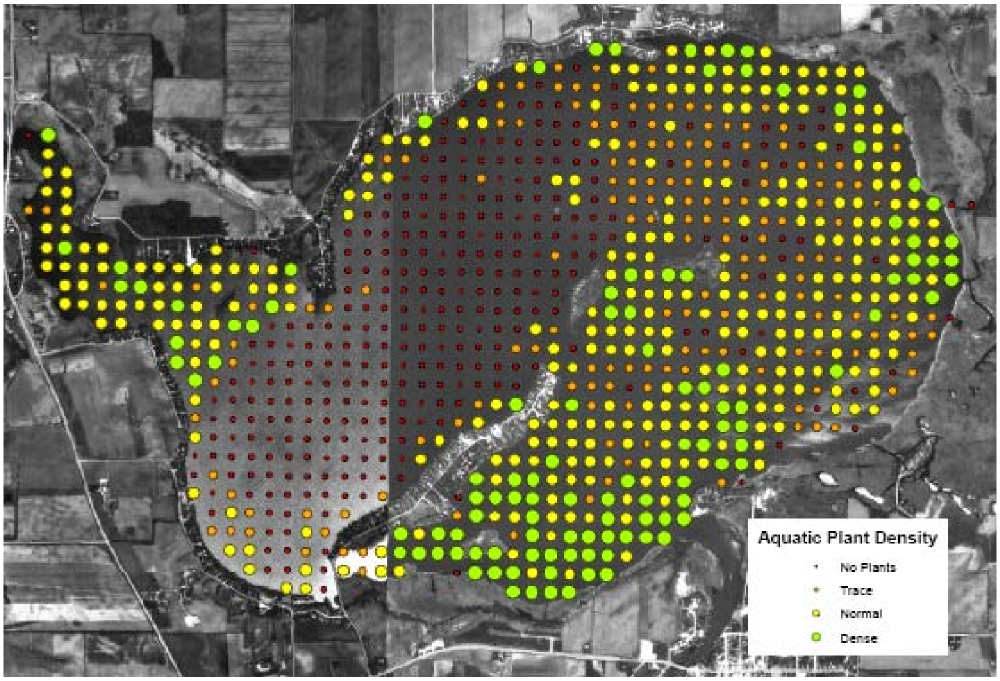

Figure 8-6
Lake-wide Eurasian water-milfoil Distribution 2006
Source: Hey and Associates, Inc.

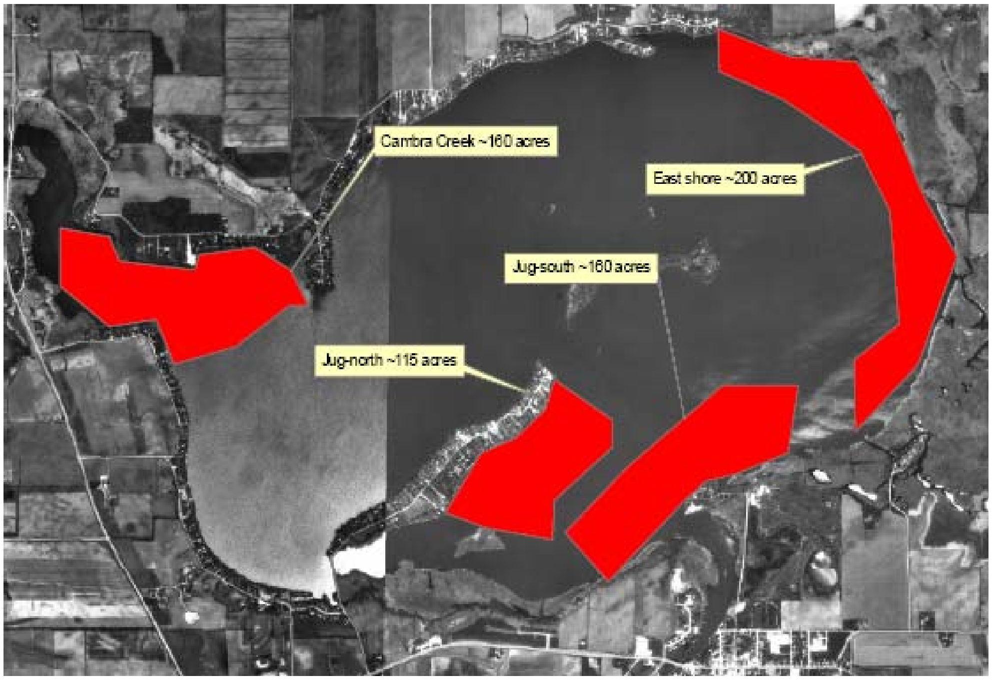

Figure 8-7
Priority Lake-wide Eurasian water-milfoil Management and Native Plant Restoration Areas
Source: Hey and Associates, Inc.

Monitoring Strategy

Due to the sensitive nature of the aquatic plant community in Fox Lake exhibited by its tendency to alternate between the turbid and clear water states, a comprehensive aquatic plant survey should occur on an annual basis during initial phases of aquatic plant management activities. If the lake remains in the clear water state over the plan's duration (3 to 5 years), the frequency of monitoring should be scaled back to once each time the plan is renewed or concurrent with any lake-wide management activities. Due to the past intensity of monitoring activities, it is unlikely that cost-sharing funds will be available for future plant community monitoring. As a result, the District should assume an additional $10,000 per year will be required for a comprehensive survey.

Fishery Management

The clear water state that existed in 2004 through 2006 was due in part to changes in the trophic status of the Fox Lake fishery. As outlined in Chapter 6, in recent years Fox Lake has seen a major increase in largemouth bass and bluegill populations due to natural reproduction and increases in walleye due to artificial stocking. White and Black crappie, major consumers of beneficial zooplankton, have declined during the same period. The current fish community facilitates the maintenance of a more abundant zooplankton population and in effect clearer water. To help maintain the current status of the fish populations, the following management recommendations are made:

- Efforts to reduce the abundance of the dominant planktivores, white and black crappie, should be continued both by maintaining an aggressive bag limit and by promoting predator fish species.

- The relative changes in walleye and largemouth bass abundance should be monitored and walleye stocking should be reduced if bass populations decline. Efforts to encourage shoreline woody structures (e.g. tree falls) may assist in promoting bass populations.

- Stocking efforts to introduce musky should be put on hold until it can be determined if the increases in submerged vegetation in the lake will promote increased reproduction of northern pike.

- Yellow perch year-class strength should be monitored and potential relationships to walleye stocking should be examined and evaluated.

- At present, carp do not appear to be a major contributor to trophic problems in Fox Lake, and continued commercial harvest subsidies do not seem necessary. Efforts to capture and eradicate carp moving upstream into tributaries may be possible, but logistic issues may not make this feasible.

- Comprehensive fish surveys should be conducted more regularly to better evaluate fish community structure.

- Continue winter monitoring of dissolved oxygen levels and use of aeration in the deep hole of the lake to prevent winter kill conditions.

In-lake Nutrient Control

Fox Lake is hyper-eutrophic with an annual mean in-lake total phosphorus concentration of 0.144 mg/l, more than 4 times the state average. As outlined in Chapter 7, between 60% and 80 % of the in-lake phosphorus in Fox Lake comes from internal sources. Internal sources include chemical release from bottom sediments, biological decomposition of algae, and aquatic plants. Phosphorus build-up in the sediments of Fox Lake is the result of years of material from the watershed entering the lake and accumulating in the bottom mud. In two literature articles on shallow lake management, it was documented that shallow lakes with phosphorus concentrations less than 100 ug/l can be more easily managed as clear-water systems through active management (Scheffer, et al, 1993, and Hosper and Meijer, 1992). Lakes with phosphorus concentrations greater than 100 ug/l typically are dominated by algae and exist in turbid conditions. Lowering Fox Lake's in-lake total phosphorus concentration to below 100 ug/l will require more than watershed controls alone.

From 2004 through 2006, Fox Lake has existed in a clear-water state as the result of recent establishment of aquatic plants and active bio-multination of the fishery. It is unknown at the current high phosphorus levels if the clear-water state can be maintained. Lower in-lake phosphorus levels in the lake would reduce the potential of the lake shifting back to an alga-dominated, turbid state. If the lake begins to start shifting to a turbid state, action may be required to force the system into a clear-water condition to help maintain the existing rooted macrophyte community. One method that has been used on several lakes to achieve a rapid shift from turbid to clear water is to artificially reduce in-lake phosphorus concentrations using a phosphorus binding compound such as alum.

Alum (aluminum sulfate) is a nontoxic material commonly used in water treatment plants to clarify drinking water. In lakes, alum is used to reduce the amount of phosphorus in the water. Alum is used primarily to control this internal recycling of phosphorus from the sediments of the lake bottom. On contact with water, alum forms a fluffy aluminum hydroxide precipitate called floc. Aluminum hydroxide binds with phosphorus to form an aluminum phosphate compound ($AlPO_4$) . This compound is insoluble in water under most conditions so the phosphorus in it can no longer be used as food by algae organisms. As the floc slowly settles, some phosphorus is removed from the water. The floc also tends to collect suspended particles in the water and carry them down to the bottom, leaving the lake noticeably clearer. On the bottom of the lake, the floc forms a layer that acts as a phosphorus barrier by combining with phosphorus as it is released from the sediments.

A number of case studies have been conducted on lakes that have undergone nutrient inactivation with alum. Eugene Welch and Dennis Cooke (1995) evaluated the effectiveness and longevity of treatments on twenty-one lakes across the United States. They concluded that the treatments were effective in six of the nine shallow lakes, controlling phosphorus for at least eight years on average. At Bass Lake, Wisconsin, an alum treatment resulted in reducing the average phosphorus concentrations from 490 µg/L to 10 µg/L (USEPA, 2002).

An evaluation of six shallow Washington State (USA) lakes (Walch et al., 1994) treated with alum in the 1980s has shown that treatment effectiveness ranged from 50 to 80% and lasted for at least five years. Such effectiveness/longevity makes alum a highly cost-effective, in-lake treatment for shallow lakes. However, alum may be completely ineffective, or effectiveness may be short-lived, if much of the lake is covered with macrophytes that senesce during summer and contribute phosphorus (P) to the water. The sharp reduction in blue-green algae following alum treatments suggests that inhibition of the sediment-to-water migration rate of blue-greens may be an important mechanism for alum's effect in oxic shallow lakes. That is in contrast to the primary mechanism in stratified anoxic lakes, which involves the complexation of P in the alum floc layer under reducing conditions.

Studies have been conducted to determine the toxicity of aluminum for aquatic biota. Kennedy and Cooke (1982) indicate that, based on solubility, dissolved aluminum concentrations, regardless of dose, would remain below 50 ug Al/L in the pH range 5.5 to 9.0, a dose producing post treatment pH in this range could also be considered environmentally safe with respect to aluminum toxicity. Guidelines for alum application require that the ph remain with the 5.5-9.0 range. Narf (1990) assessed the long-term impacts on two softwater and three hardwater Wisconsin lakes. He found that benthic insect populations either increased in diversity or remained at the same diversity after treatment. The treatment of lakes with alkalinities above 75 mg/L as $CaCO_3$ is not expected to have chronic or acute effects to biota. Fox Lake has a mean alkalinity of 190 mg/l as $CaCO_3$, indicating the lake is a hardwater lake and that the potential for toxicity problems are unlikely. Fish related problems associated with alum treatments have been primarily documented in soft water lakes.

Costs of alum application would depend on the goals of the treatment. An alum treatment at Fox Lake could take two potential approaches; one to just remove water column phosphorus to create a temporary clear-water condition to protect the existing macrophyte community, or a treatment of the sediment to reduce internal recycling for a number of years.

Under the first option, only the phosphorus in the water column during the spring would be removed. At discussed in Chapter 5, total phosphorus concentrations in Fox Lake are the highest in the winter and spring, with the highest levels found in the shallow areas. In the spring of 2005, total phosphorus concentrations were over 600 ug/l in the shallow southeast bay and 252 ug/l at the surface in the deep hole. Removal of this spring mass of phosphorus could help prevent a spring algal bloom allowing rooted aquatic plants to dominate. The estimated cost of a spring treatment of the water column would only be between $30,000 and $50,000. This treatment would likely only produce short-term results as new phosphorus from decomposing plants and release from the bottom sediments would raise phosphorus concentrations to pre-treatment levels by the following year. The treatment could be used as a potential low-cost alternative to help the aquatic plant community survive a year of high spring algal concentrations.

A more long-term solution to reducing internal phosphorus recycling would be an alum treatment designed to trap phosphorus in the bottom sediments. In this type of project, enough alum would be added to the lake to adsorb several years of sediment phosphorus release. A blanket of alum would be placed in the top layer of the sediment to capture phosphorus before it can move upward into the overlying water column. Based on calculations in Chapter 7, in 2005, internal sources of total phosphorus were estimated at 14,960 kg/year. The cost of applying enough alum to absorb 8 years of sediment release is estimated at $500,000. This type of treatment on other shallow lakes has shown 8 to 12 years of reduced in-lake phosphorus concentrations. Phosphorus levels will, with time, increase in the lake as new sediment is deposited on top of the treated sediment. The time period a large scale alum treatment will last will depend on nutrient discharges from the watershed and the amount of accumulation of decaying aquatic plants. A successful alum treatment has occurred on Wind Lake in Racine County. The results of this project should be used as a means to assess potential success on Fox Lake in subsequent planning efforts.

At this it is recommended that an environmental assessment of the potential impacts and benefits of an alum treatment at Fox Lake be explored.

Watershed Sediment and Nutrient Control

In the past two decades, many efforts have been made by the WDNR, DATCP, Dodge County Land Conservation Department and FLILPRD to reduce sediment and nutrient exports from the Fox Lake watershed as part of the Beaver Dam Priority Watershed Project. However, as outlined in Chapter 7, concentrations and loading of nitrogen and phosphorus from the watershed are still much higher than state-wide averages identified in a recent state-wide study by the U. S. Geological Survey (Robertson et al., 2006). Drew Creek has nitrate/nitrite concentrations that are above the maximum level measured by USGS in their state-wide study. Tributary monitoring shows that problem areas still exist in the headwaters of Alto Creek above CTH AW and in the unnamed eastern tributary above Lake Emily Road, in the east and west branches of Drew Creek, and the southern tributaries of Cambra Creek. High concentrations of organic nitrogen (TKN) and nitrate/nitrite indicate that problems with barnyards and manure-handling practices still exist in all of the monitored watersheds. High concentrations and loadings of total phosphorus and suspended solids in the Cambra Creek watershed indicate that soil erosion is still a major problem.

A bright spot in the results of tributary monitoring in Alto Creek is that a series of wetland restoration projects implemented by installation of a series of weir structures on the mainstem of the creek are reducing mean total suspended solids concentrations by 69% and total phosphorus by 40%. During three of four small storm events monitored in 2006, TSS loadings drop as water moves through the water quality treatment weir at CTH F. TSS loading reductions during these three storm events range from 25 to 76%.

Continued implementations of the recommendations outlined in *A Nonpoint Source Control Plan for the Beaver Dam River Priority Watershed Project* (WDNR, 1993) are still needed in the Fox Lake watershed. While many landowners have implemented agricultural conservation practices, monitoring indicates that a few bad actors still exist. Many attempts have been made by staff of the County Land Conservation Department and FLILPRD to get the remaining problem landowners to take advantage of cost-share programs offered by the state and federal government. It is the opinion of the authors of this report that Dodge County and the WDNR should consider implementation of the “Bad Actor” provisions of Wisconsin Administrative Code NR151 and NR243. Data provided in Chapter 7 can be used to help identify critical properties that need to be targeted for potential enforcement action. Cost for implementation of management actions would need to be based on property-specific management plans. Cost for implementation should be born by the landowner with technical and financial assistance from state and federal government agricultural agencies.

Public Education

The FLILPRD has had a long history of public education to keep residents informed about major issues that affect the lake. Public education efforts have included a quarterly newsletter, public forums, and newspaper articles. The lake district should continue these important public education efforts. Potential future public education topics may include:

- Put and take fishing
- Protection of aquatic plants
- Lawn care (fertilizer and pesticide control)
- Control of exotic species
- Annual state of the lake

Monitoring

Fox Lake is an important recreational and economic resource that, due to its shallow depth and high nutrient levels, will always require management to maintain desired water quality conditions. To guide future management, information on the status of the lake is needed. To effectively manage the lake, the following data should be collected on a periodic basis:

- In-lake water quality on a monthly basis
- Tributary runoff data during base-flow and runoff events
- Annual fall fish elecrofishing surveys
- Comprehensive fish surveys ever three to five years
- Aquatic plant survey every three years

Summary of Plan Recommendations

Table 8-2 summarizes the recommendation of this plan to maintain Fox Lake's clear-water state. The table summarizes the major recommendations, their cost, the agency that should be responsible for implementation, funding source, and an implementation schedule to assist in prioritizing management activities.

Table 8-2
Summary of Fox Lake 2007 Management Plan Major Recommendations and Implementation schedule

Recommendation	Estimated Cost	Implementing Agency	Funding Source	Implementation Schedule
Aquatic Plant Control				
1. Harvesting of navigation lanes	$25,000/year	FLILPRD	FLILPRD	Annual
2. Herbicide treatment around piers	$20,000/year	Private landowners	Private landowners	Annual
Fishery Management				
1. Continued stocking of game fish	$5,000/year	WDNR	FLILPRD/ other local groups	Annual
2. Continued fall electroshocking surveys	$2,500/year	WDNR	WDNR	Annual
3. Comprehensive fish surveys	$50,000/every 3 years	WDNR	WDNR	2009 then every 3 years

Table 8-2 (continued)

Recommendation	Estimated Cost	Implementing Agency	Funding Source	Implementation Schedule
In-lake Nutrient Control				
1. Conduct alum treatment feasibility analysis	$10,000	FLILPRD/WDNR	FLILPRD/Lake Planning Grant	2008
2. Conduct alum demonstration projects	~$25,000	FLILIPRD/WDNR	FLILRPD/Lake Protection Grant	2008/2009
3. Alum treatment to promote clear water conditions and aquatic plant growth	$50,000 per treatment	FLILRPD/WDNR	FLILRPD/Lake Protection Grant	As needed basis depending on climate, lake condition and results of alum feasibility study
4. Alum treatment to seal bottom sediments	$500,000/every 8 to 12 years	FLILPRD/WDNR	FLILPRD/Lake Protection Grant	Dependent on results of alum feasibility study
Watershed Sediment and Nutrient Control				
1. Implement barnyard manure management on critical farms	$120,000	Landowner/Dodge County/DATCP/NRCS	ASCS, State and Local Landowners	2009
2. Implement conservation practices on agricultural fields	$15,000/year	Landowner/Dodge County/DATCP/NRCS	ASCS, State and Local Landowners	2009
Public Education				
1. Continue quarterly newsletter	$5,000/year	FLILPRD	FLILPRD	Annual
2. Conduct two education forums per year	$3,000/year	FLILPRD	FLILPRD	Annual
Monitoring				
1. In-lake water quality	$5,000/year	FLILPRD/WDNR	FLILPRD/Lake Planning Grant Program	Annual
2. Tributary runoff	$4,000/subwatershed assessment	FLILPRD/WDNR	FLILPRD/Lake Planning Grant Program	2008
3. Aquatic plants	$10,000/every year	FLILPRD/WDNR	FLILPRD/Lake Planning Grant Program (APM Plan Updates)	Annual until APM plan update in 2010-2012 then as recommended

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APPENDIX A

FOX LAKE ALTERNATE STABLE STATES MODEL AND THE ROLES OF LAKE LEVEL, WIND, AND PRECIPITATION ON LAKE ECOLOGY

APPENDIX A: FOX LAKE EVALUATION REPORT

FOX LAKE ALTERNATE STABLE STATES MODEL AND THE ROLES OF LAKE LEVEL, WIND, AND PRECIPITATION ON LAKE ECOLOGY

INTRODUCTION

Following discussion at the Fox Lake District meeting occurring on September 19, 2007, it was determined that additional data related to lake level and long-term precipitation trends should be incorporated into the final evaluation report. To meet this requirement the available lake level, precipitation data, and wind data for Fox Lake was compiled and re-analyzed in its relation to the aquatic plant community and water clarity expressed as Secchi depth or total suspended solids.

Our current hypothesis is that the ecology of Fox Lake is seasonally and alternately dominated respectively by abiotic in the spring transitioning to biotic conditions in the summer and fall. Abiotic conditions in the spring determine the initial trajectory towards the clear or turbid water state by encouraging or discouraging the persistence of aquatic plants which is followed by a transition to a biotic-dominated state related to aquatic plant frequency which in turn initiates a number of associated trophic cascades (zooplankton persistence, competition with algae, water clarity promoting young of the year carp predation, etc.) into the summer and fall. An alternate stable states model was adapted from Scheffer's (1990) original shallow lakes model to reflect Fox Lake's unique conditions and borderline hyper-eutrophic/eutrophic nutrient status to use as a conceptual tool to illustrate how management actions may impact overall lake ecology.

Hysteresis is well documented for shallow lakes such as Fox Lake's and is one basis for the shallow lake model. Hysteresis is defined as having any number of states which arise independently where path-dependence, or the prior system state, is very important to the current state. In short, if the system has hysteresis the current state cannot be predicted without knowledge of previous states. This concept is well documented and can be used to deduce at least a portion of the events occurring during the hypothesized abiotic-dominated spring phase. 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 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 of return non-wintergreen aquatic vegetation (Scheffer 1998). In the case of Fox Lake this applies largely to Eurasian water-milfoil and 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 (Smith and Barko 1990, Van Driesche et al 2002, and Madsen et al 1991). When the biomass of overwintering structures, such as coontail or curly-leaf pondweed (Borman et al 1997), 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 (Scheffer 1998).

We will show that the amount of rainfall in the spring and spring water clarity are both highly correlated to the frequency of aquatic plants in years following 1995 in Fox Lake; however, precipitation and water clarity are not highly correlated suggesting other more complex mechanisms are operating on Fox Lake. The two other potential environmental factors affecting Fox Lake which contribute to its ecological complexity are lake level and wind intensity. We will attempt to address each of these potential factors, but in some cases data is a limiting factor. We will also show that in clear water years where aquatic plants establish, the clear water state persists throughout the summer. This is evident as greater Secchi depths in late summer (August) are correlated to both spring water clarity and aquatic plant frequency. In years where plants do not establish, water clarity is poor due to algal dominance and possibly sediment resuspension.

DATA SOURCES

Lake level data was available, with some interruptions, for Fox Lake from 1985-2006. Data was collected from two stations on the lake located at Chief Kuno Trail and the State Street Bridge, but only data from Chief Kuno Trail was reported due to large gaps in data at the State Street Bridge site.

Precipitation data was downloaded from the NOAA website from 1965 to present and compiled for the Beaver Dam weather station. Data for Beaver Dam may be found in a historical context dating back to 1891, but 40 years of data was deemed sufficient for the current analysis. Average precipitation reported is for the period from 1965 to present and may not reflect the longer term average for Beaver Dam. Wind data was acquired from the NOAA website at the Fond du Lac airport.

ALTERNATE STABLE STATES MODEL FOR FOX LAKE

The alternate stable states model for Fox Lake is different from typical alternate stable states models because the desired and current (clear water) state is less probable than the alternative (turbid water) state due to the hyper-eutrophic nutrient status. Figure A-1 depicts the working model for Fox Lake. The black circles show the starting point or propensity to shift towards clear or turbid water based on 1) the hysteretic biotic effects of the previous year due to the presence of overwintering spring aquatic plants and 2) the conditions related to spring precipitation and water clarity. The green arrows in the model are a reference to the influence of biotic factors such as abundant aquatic plants and a healthy zooplankton community promoting the clear water state. The yellow arrows are in reference to potential abiotic factors such as calm winds or management actions which would promote higher water clarity independently of biotic factors. In both cases, only positive influences are illustrated. Negative impacts such as carp activity would be associated with gravitating towards the turbid water state. The red arrows indicate the eventual outcome of the interaction of the biotic and abiotic factors and the resultant stable state in any given year for Fox Lake.

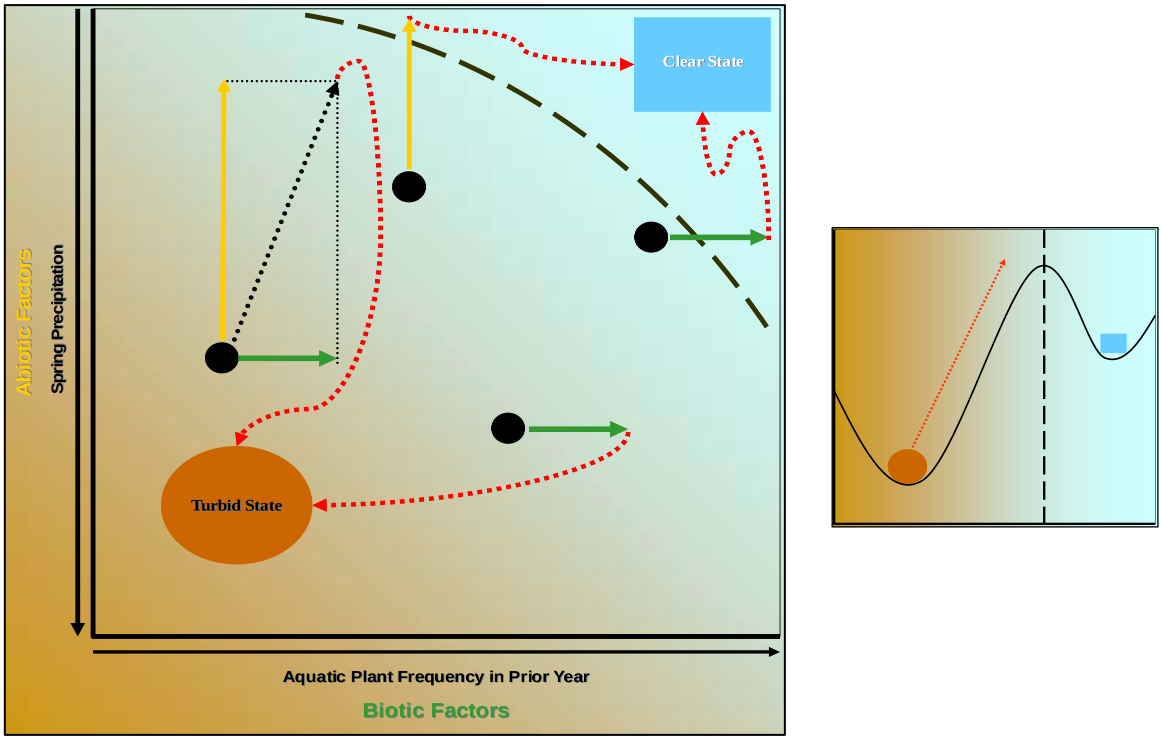

Figure A-1
Alternate Stable States Model for Fox Lake
Source: Modified from Scheffer et al. 1990 and Byers et al. 2006

The axes for the Fox Lake model were selected due to the existence of a strong negative correlation between the amount of spring precipitation (March and April) and the frequency of aquatic plants in Fox Lake from 1995 to 2007 (Figure A-2). It must be noted that no definite mechanism has been identified to explain this relationship. Our hypothesis is that some factor related to spring precipitation such as wind induced resuspension, nutrient loading, and/or water level is important. In other words to date we have identified spring precipitation as a surrogate or indicator for the frequency of plants found in the littoral zone of Fox Lake. Years prior to 1995 were not included in this portion of the analysis based on Secchi depth data which suggests that Fox Lake shifted to the clear water state in 1995 due to an unusually clear water year (Figure A-3). Subsequent years may be viewed as Fox Lake's oscillation while in the clear state. The intent of this analysis is to understand how Fox Lake operates while in the clear water state so management options can be developed to maintain this desired current condition and likewise prevent a shift back to the turbid, algal dominated state.

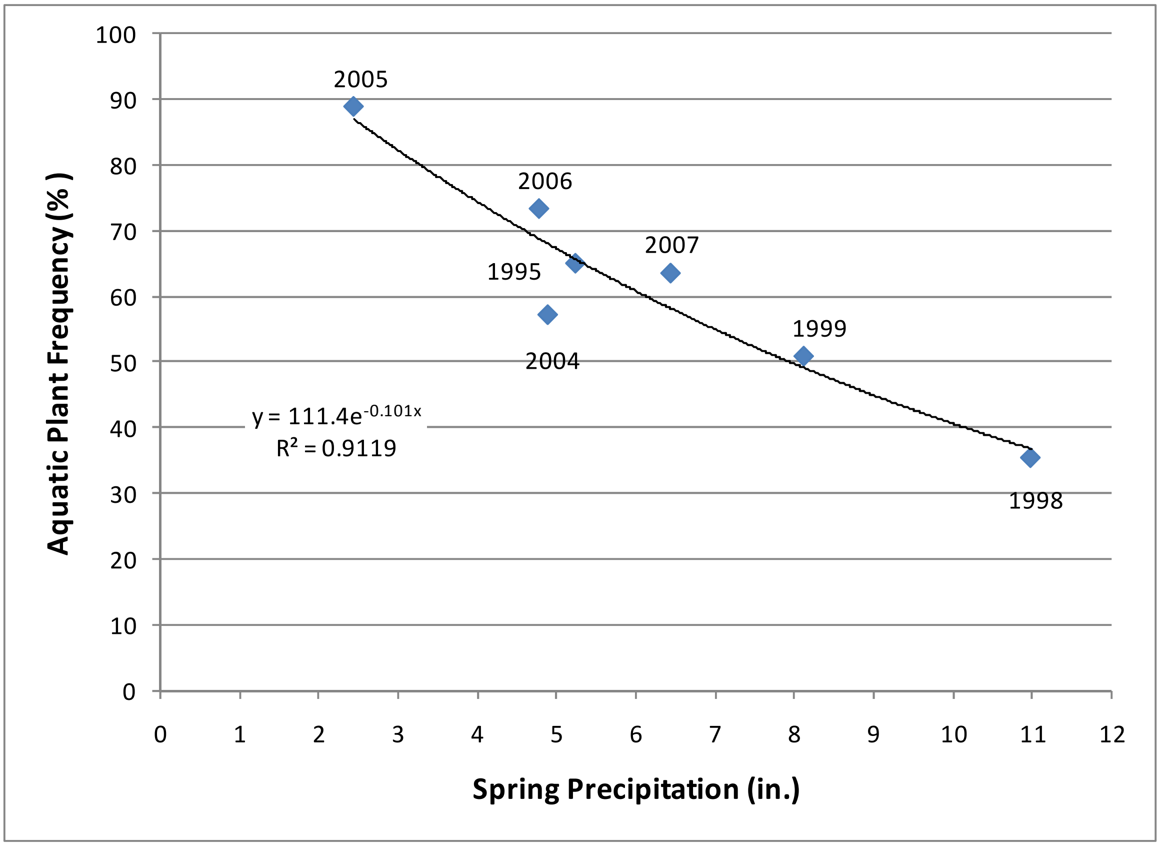

Figure A-2
Aquatic Plant Frequency versus Spring Precipitation (March and April) for Fox Lake 1995-2007
Source: Hey and Associates, Inc., WDNR, and NOAA

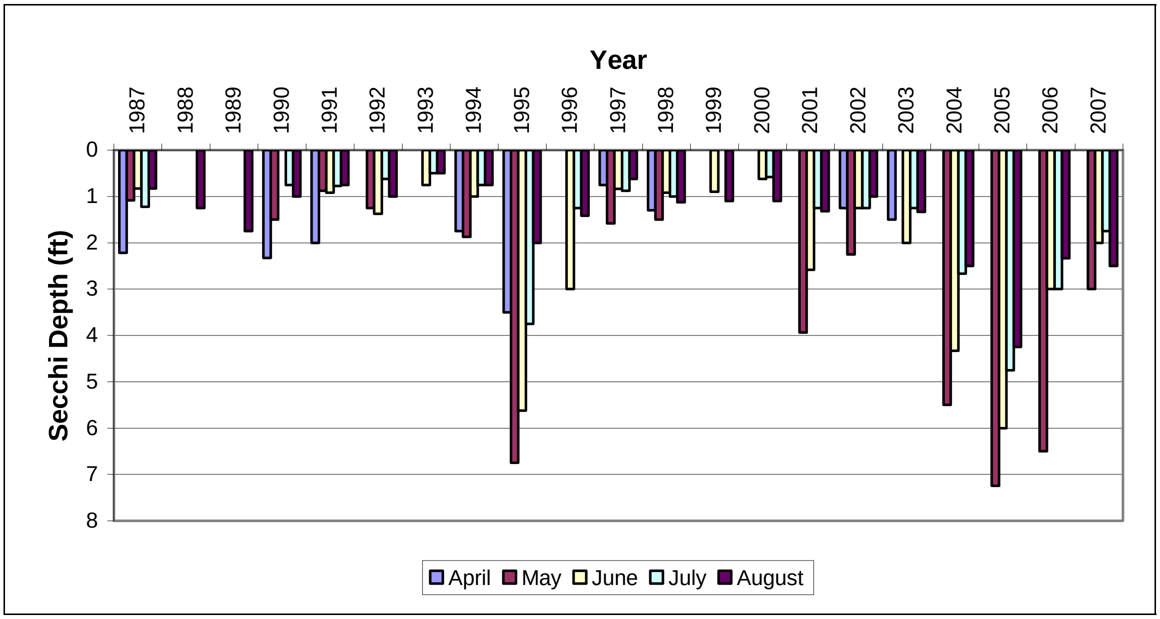

Figure A-3
Secchi Depths for Fox Lake
Source: WDNR Baseline Monitoring Program, WDNR Self-Help, UW-Milwaukee, and Hey and Associates, Inc.

The relationships between spring precipitation and water clarity are not detected when all years are evaluated. This is likely due to the inclusion of multiple turbid water years (1989-1994) which confound the analysis because of differing ecological responses of Fox Lake to internal and external environmental stimuli (Figure A-4). If the data is isolated between clear and turbid water years, patterns show a no relationship between water clarity and rainfall in clear years (Figure A-5) and a strong negative relationship in turbid years. Combined these results further suggest a significant shift in Fox Lake's ecological response to spring precipitation starting in 1995.

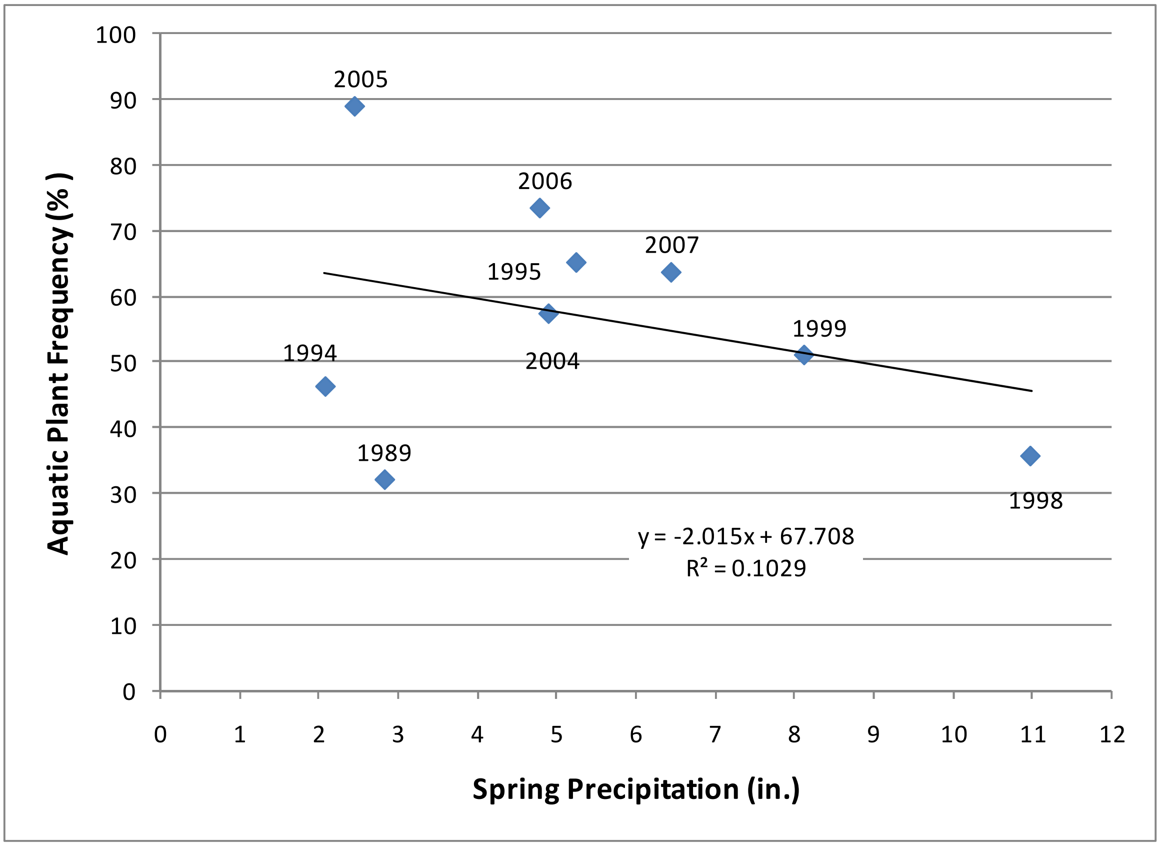

Figure A-4

Spring Precipitation versus Aquatic Plant Frequency for Fox Lake

Source: NOAA, WDNR, and Hey and Associates, Inc.

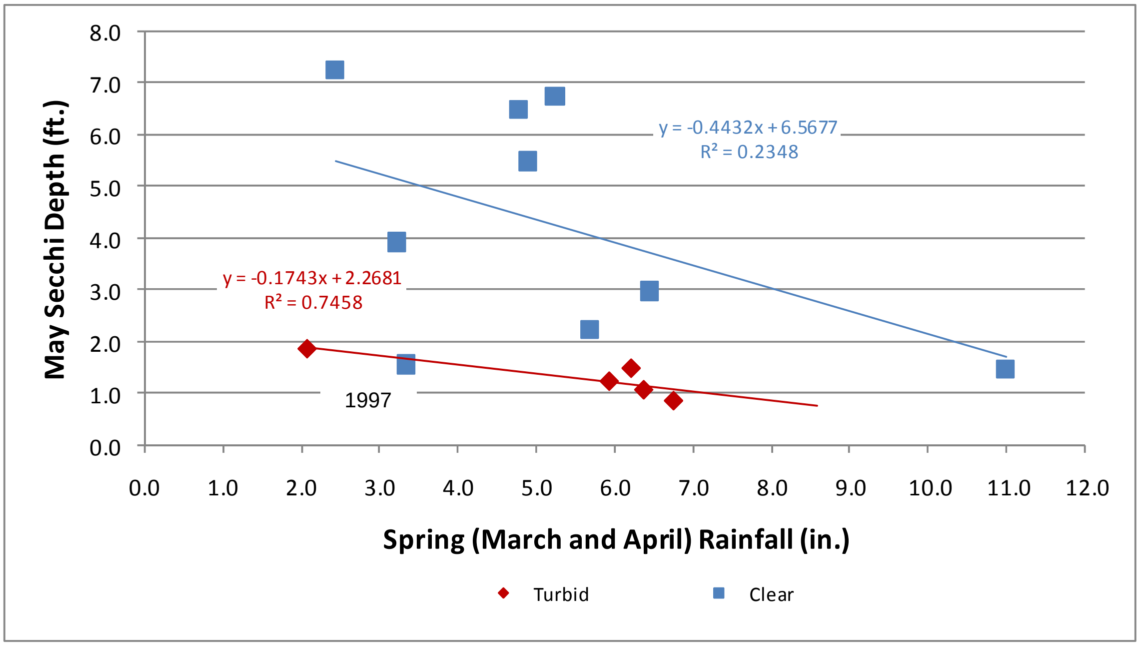

Figure A-5
May Secchi Depth versus Spring Precipitation for on Fox Lake (1989-2007); Turbid = pre-1996 vs. Clear = post-1996
Source: NOAA, WDNR, UW-Milwaukee, and Hey and Associates, Inc.

The role of wind was addressed by comparing the average monthly spring wind speed to Secchi depths and aquatic plant frequency for available data. The results showed that there is a weak relationship between May Secchi depth and mean spring wind speed (Figure A-6).

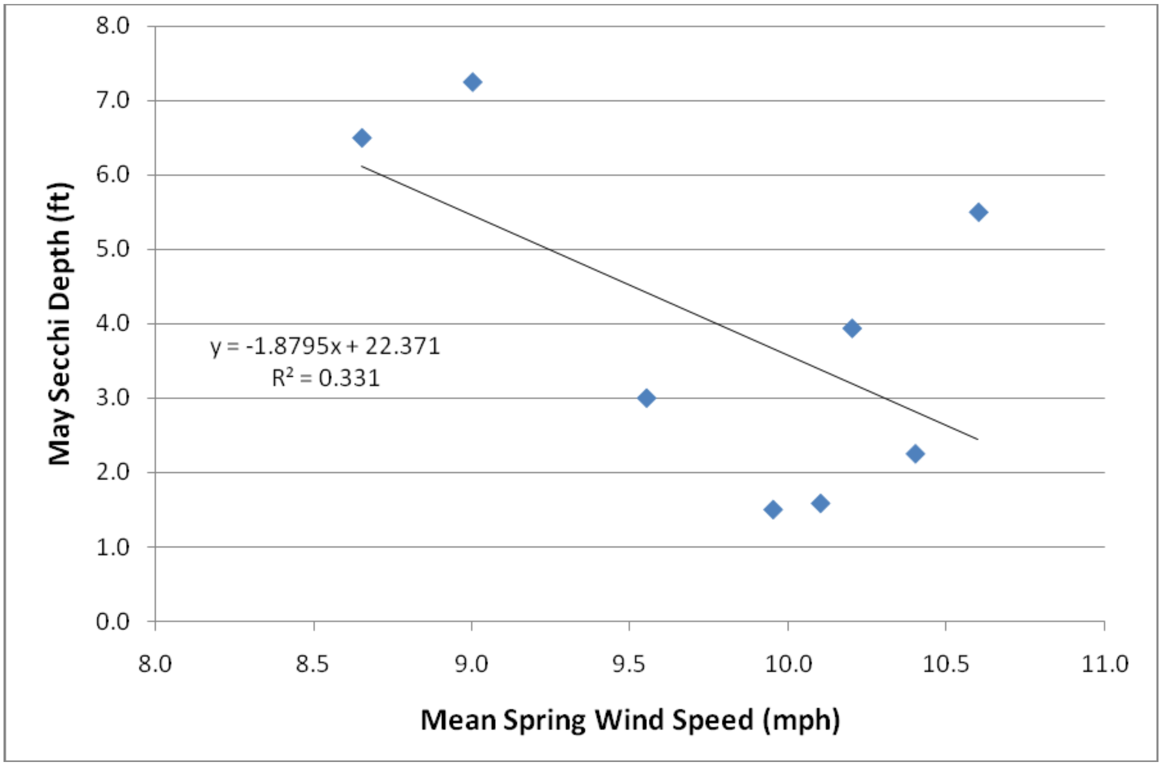

Figure A-6
May Secchi depth versus Mean Spring (March & April) Wind Speed for Fox Lake (Dodge Co.), WI
Source: NOAA, Hey and Associates, Inc., and WDNR

Comparing the mean spring wind speed to aquatic plant frequency shows some relationship between wind and aquatic plant frequency exists, but is generally poorer than other factors (Figure A-7). A similar relationship was found between wind speed and May Secchi depth (Figure A-8).

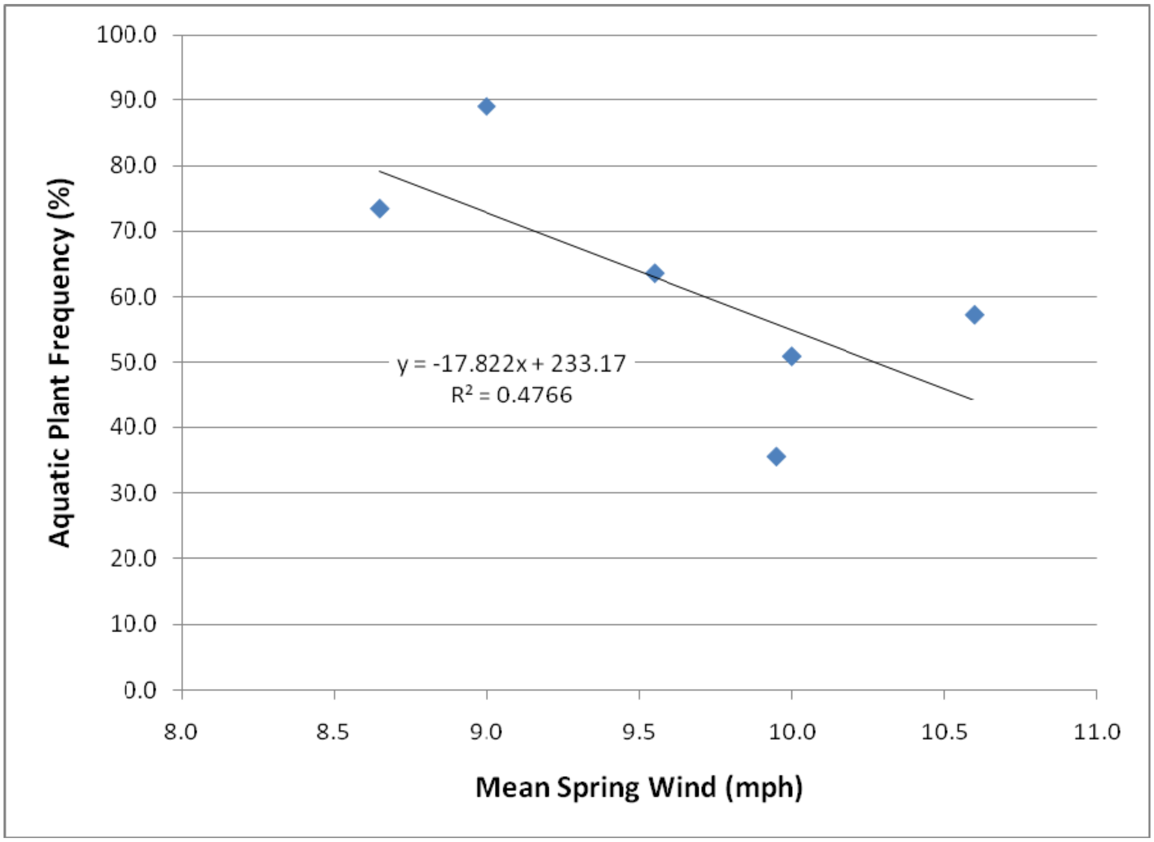

Figure A-7
Aquatic Plant Frequency versus Mean Spring Wind Speed for Fox Lake (Dodge Co.), WI
Source: NOAA, Hey and Associates, Inc., and WDNR

To assess the potential impact of lake level management on water clarity and aquatic plant frequency, the mean spring lake level was compared to May Secchi depth and aquatic plant frequency. Figure A-9 shows a relatively moderate correlation between May Secchi depth and spring water level indicating water level plays some role in managing the lake. Figure A-10 shows strong relationship between spring water level and aquatic plant frequency further suggesting that lake level management is an important management component; however, the years from 1995 through 2000 are not available.

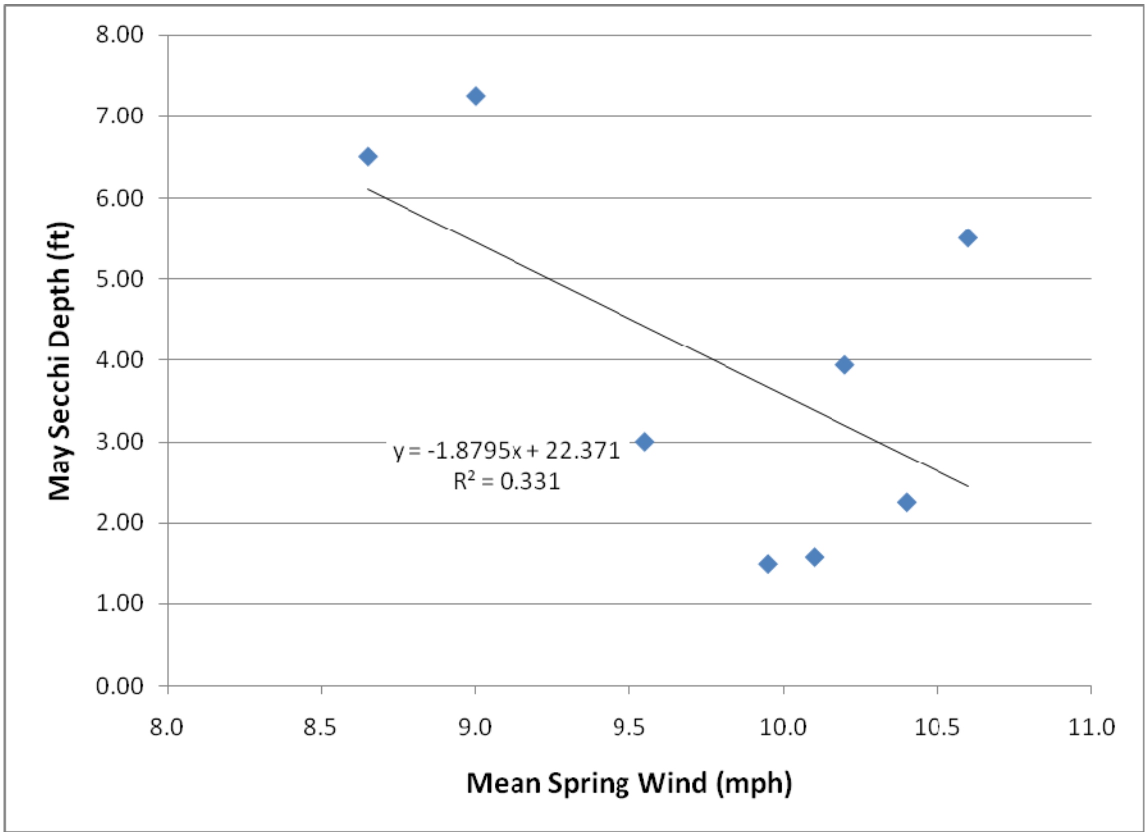

Figure A-8
Mean Spring Wind Speed versus May Secchi Depth for Fox Lake (Dodge Co.), WI
Source: NOAA and WDNR

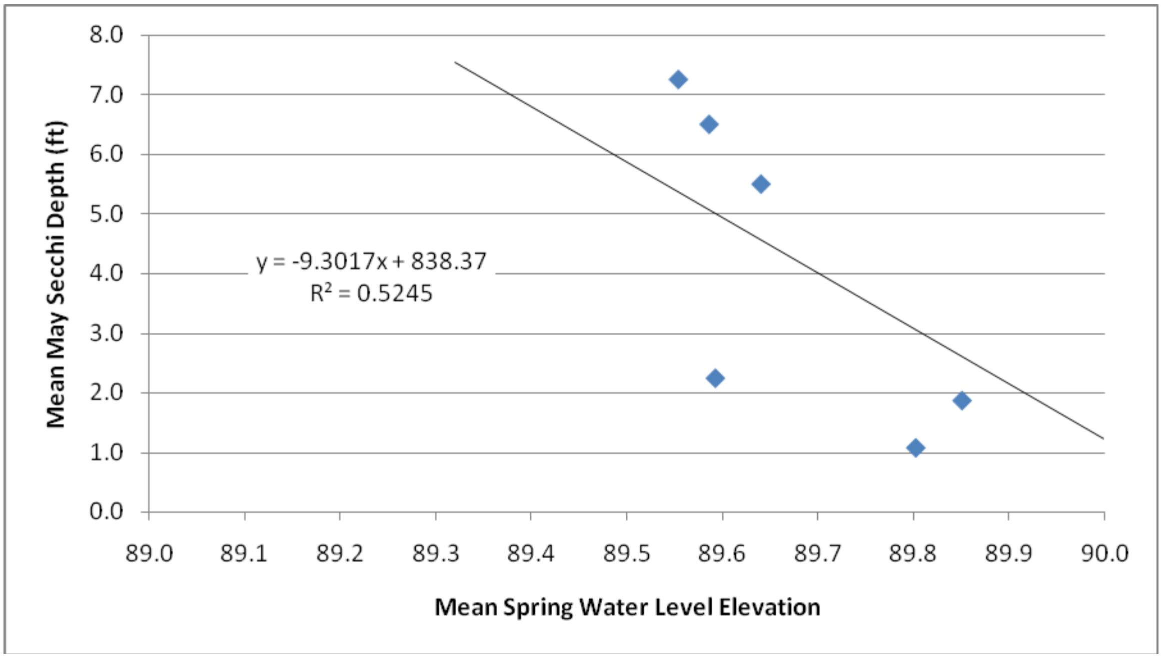

Figure A-9
May Secchi Depth versus Mean Spring Water Level Elevation for Fox Lake (Dodge Co.), WI
Source: Town of Fox Lake, Hey and Associates, Inc., and WDNR

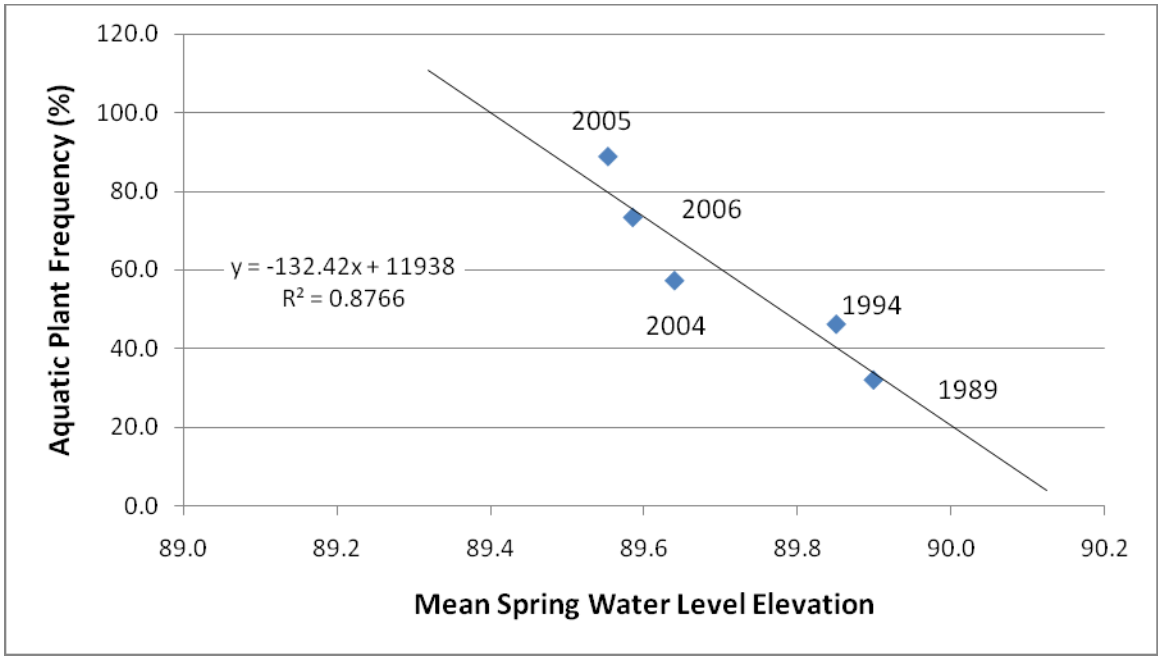

Figure A-10

Aquatic Plant Frequency versus Mean Spring Water Level

Source: Town of Fox Lake, Hey and Associates, Inc., and WDNR

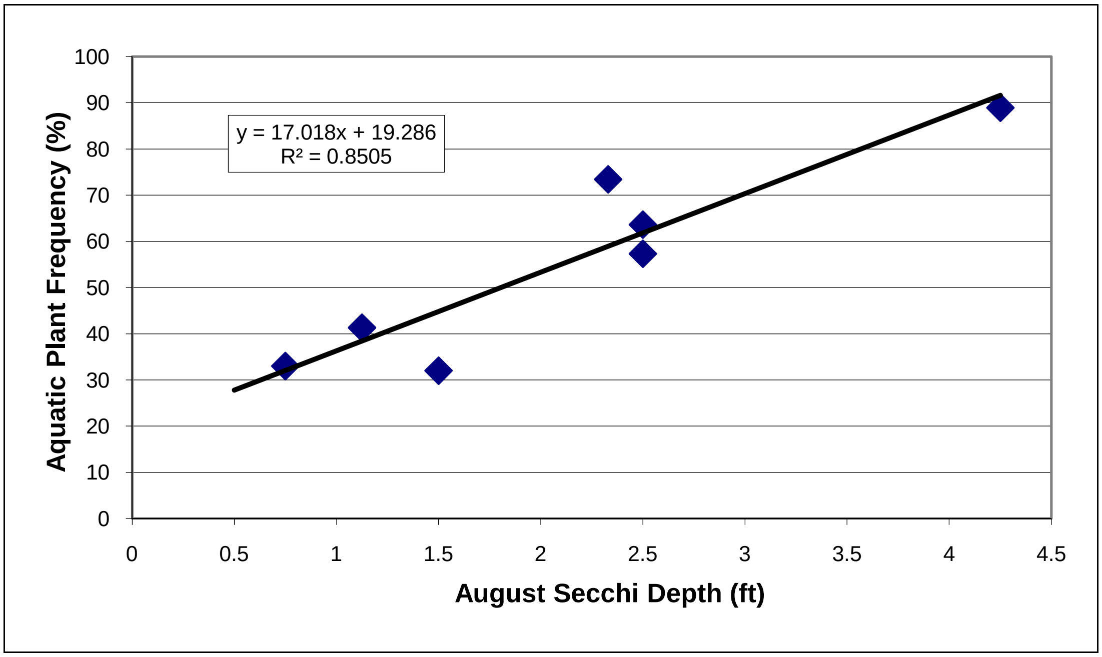

Figure A-11

Aquatic Plant Frequency and August Secchi Depth for Fox Lake (1989-2007)

Source: WDNR and Hey and Associates, Inc.

Finally, the importance of aquatic plants as a means to sustain the clear water state in Fox Lake is illustrated in Figure A-11. There is a direct positive relationship between the frequency of aquatic plants and the resulting water clarity in August. This relationship holds true for years exhibiting both the clear and turbid water states. Figure A-12 shows the long-term spring precipitation record for Fox Lake. It shows periods of high and low spring rainfall. The time periods with high or low rainfalls may act as a mechanism to initiate the shifts between clear and turbid water states. In addition, if the clear water state model is applicable to Fox Lake (Figure A-2) it can be expected to support 50-60% frequency of aquatic plants in the average year.

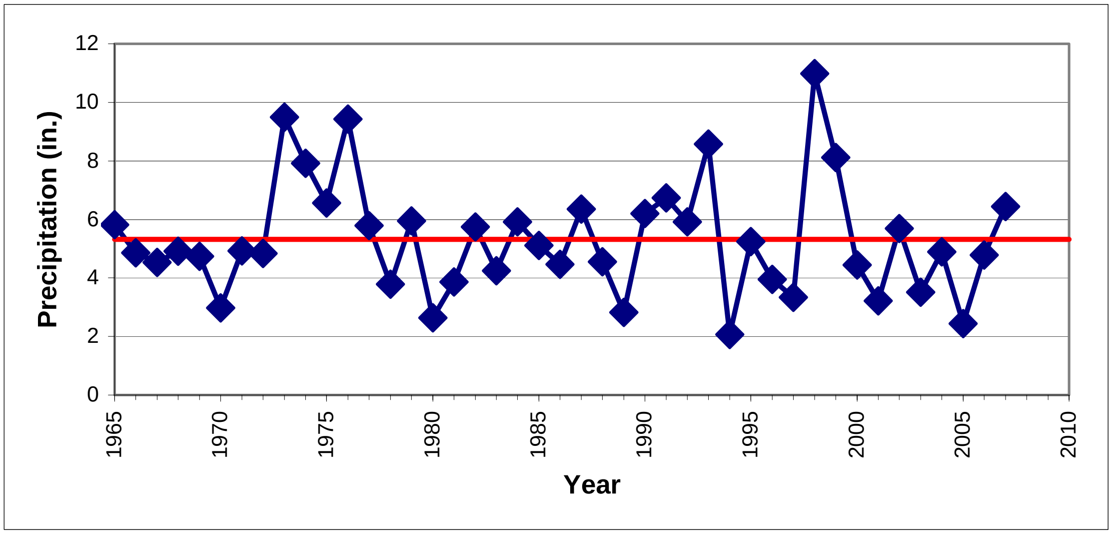

Figure A-12

Long-term Spring (March and April) Precipitation for Fox Lake; Average of Record Indicated by Red Line = 5.32 in.

Source: NOAA

SUMMARY

The proposed alternate stable states model for Fox Lake illustrates the precarious position related to the persistence of the clear water state. It is likely that the ecology of Fox Lake is initially strongly influenced by abiotic factors related to spring precipitation, water clarity, and lake level. This conclusion is supported by the high correlation between spring precipitation levels, May Secchi depth, and aquatic plant frequency when Fox Lake is in the clear water state. The current hypothesis is that precipitation related events (rainfall, wind, and resultant water clarity) allow plants to establish early in the growing season. Plants then enhance water clarity directly by reducing suspended solids and competing for light (reducing algae growth) and create conditions that support zooplankton populations which further improve water clarity. The aquatic plants provide a buffering mechanism against further abiotic influences on Fox Lake by persisting in subsequent years. Secchi depth measurements in August for combined turbid and clear water years showed a high correlation between aquatic plant frequency and water clarity illustrating the importance of clear water in the spring. If the proposed model is a predictor of conditions while Fox Lake is in the clear water state, 50-60% of the lake bottom in the littoral zone should be expected to support aquatic plants. This roughly corresponds with research stating a minimum of 50% of the lake bottom is required to support aquatic plants to maintain the clear water state (Scheffer 1998).

In conclusion, management actions to maintain the current spring water level regime and enhancing water clarity are two means to maintain the clear water state on Fox Lake.

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