LAKE CLASSIFICATION REPORT FOR ARROWHEAD LAKE, ADAMS COUNTY, WISCONSIN

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Background Information about Arrowhead Lake

Arrowhead Lake is located in the Town of Rome, Adams County, Wisconsin. The impoundment is 300 surface acres in size. Its maximum depth is 25.2’, with an average depth of 8’. The dam impounds Fourteen-Mile Creek downstream from the dams at Lower and Upper Camelot Lakes and Sherwood Lake, on its way to the Wisconsin River. The dams on these lakes are owned and operated by Adams County. There is a public boat ramp located on southwest side of the lake owned by The Adams County Parks Department, as well as a public swimming beach. Heavy residential development around the lake is found along most of the lakeshore. The first 100’ landward from the water is owned by the Lake Arrowhead Association, which also operates two golf courses, a restaurant, swimming pool and marinas around the lake for use by Lake Arrowhead property owners. The lake is managed by the Tri-Lakes Management District.

The primary soil type in the ground watershed is sand. The dominant soil type in the surface watersheds is loamy sand.

Loamy sands tend to be well-drained, with water, air and nutrients moving through them at a rapid rate. Runoff, when it occurs, tends to be slow. Loamy sands have little water-holding capacity and low natural fertility, although they usually have more organic matter present than do sandy soils. Both wind and water erosion are potential hazards with loamy sands, as is drought. There are difficulties with waste disposal and vegetation establishment because of slope and seepage.

Sandy soil tends to be excessively drained, no matter what the slope. Water, air and nutrients move through sandy soils at a rapid rate, so that little runoff occurs unless the soil becomes saturated. Although water erosion can be a problem, wind erosion may be more of a hazard with sandy soils, especially since these soils dry out so quickly. There are also draught hazards with sandy soils. Getting vegetation started in sandy soils is often difficult due to the low available water capacity, as well as low natural fertility and organic material. Onsite waste disposal in sandy soils is also a problem because of slope and seepage; mound systems are usually required.

Land Use in Arrowhead Lake Watersheds

Although the ground watershed for Arrowhead Lake is fairly small, the surface watershed is quite large. The two most common land uses in both the ground and surface watersheds are woodlands and residential.

Arrowhead Lake has a total shoreline of 6.9 miles (36,432 feet). Almost all of the shore is in residential use. Much of it is steeply sloping. Slightly under 50% of the shore has native vegetation. 6.4% of the shore has significant active erosion. The remaining shore is a combination of natural rock, sand beaches, rock riprap, hard structures (piers, etc.) and cultivated lawn. A survey in 2004 of the shore showed a substantial amount of substandard armoring and significant areas of sandy or eroded shores. In particular, many of the points formed by the backwater bays in Arrowhead Lake have high, heavily-eroded shores with falling trees and sloughing dirt.

A 2004 shore survey showed that some of Arrowhead Lake's shore had an "adequate buffer." An "adequate buffer" is a native vegetation strip at least 35 feet landward from the shore. Most of the "inadequate" buffer areas were those with rock or seawall, hard structures, beach, active erosion or mowed laws. In a few instances, those with insufficient native vegetation at the shoreline to cover 35 feet landward from the water line were also called "inadequate."

Adequate buffers on Arrowhead Lake in some places could be easily installed on the inadequate areas by either letting the first 35 feet landward from the water just grow without mowing it, except for a path to the water, or by planting native seedlings sufficient to fill in the first 35 feet or using biologs to protect the shore that are vegetated. Where areas are deeply eroded, such as the points that extend into the lake, shaping, revegetating and protecting the shores will be necessary to prevent further erosion.

Water Testing Results

Between 2004 and 2006, Adams County Land & Water Conservation Department gathered water chemistry and other water quality information on Arrowhead Lake. Overall, Arrowhead Lake was determined to be a mildly eutrophic lake with fair to good water quality and clarity

Measuring the phosphorus in a lake system provides an indication of the nutrient level in a lake. Increased phosphorus in a lake will feed algal blooms and also may cause excess plant growth. The 2004-2006 summer average phosphorus concentration in Arrowhead Lake was 18.62 micrograms/liter. This average is under the 30 micrograms/liter level recommended to avoid nuisance algal blooms. This concentration suggests that Arrowhead Lake is not likely to have nuisance algal blooms from excessive phosphorus. The state average for impoundments is 65 micrograms/liter.

Water clarity is a critical factor for plants. If plants don't get more than 2% of the surface illumination, they won't survive. Water clarity is measured with a Secchi disk.

Average summer Secchi disk clarity in Arrowhead Lake in 2004-2006 was 5.99 feet. This is fair water clarity.

Chlorophyll-a concentration provides a measurement of the amount of algae in a lake's water. Algae are natural and essential in lakes, but high algal populations can increase water turbidity and reduce light available for plant growth, as well as result in unpleasing odor and appearance. The 2004-200 growing season (June-September) average chlorophyll-a concentration in Arrowhead Lake was 9.55 micrograms/liter.

Arrowhead Lake water testing results showed "hard" water with an average of 156 milligrams/liter CaCO3. Hard water lakes tend to produce more fish and aquatic plants than soft water lakes because they are often located in watersheds with soils that load phosphorus into the lake water.

A lake with a neutral or slightly alkaline pH like Arrowhead Lake is a good lake for fish and plant survival. Natural rainfall in Wisconsin averages a pH of 5.6. This means that if the rain falls on a lake without sufficient alkalinity to buffer that acid water coming in by rainfall, the lake's fish cannot reproduce. That is not a problem at Arrowhead Lake, since its surface water alkalinity averages 130.7 milliequivalents/liter. The pH levels from the bottom of the lake to the surface hovered between nearly 7 and 8, alkaline enough to buffer acid rain.

Some of the water quality testing at Arrowhead Lake showed areas of concern. The presence of a significant amount of chloride over a period of time indicates there may be negative human impacts on the water quality present from septic system failure, the presence of fertilizer and/or waste, deposition of road-salt, and other nutrients. An increased chloride level is thus an indication that too many nutrients are entering the lake, although the level has to be evaluated compared to the natural background data for chloride. The average chloride level found in Arrowhead Lake during the 2004-2006 testing period was 11.33 milligrams/liter, elevated substantially above the natural level of 3 milligrams/liter for chloride in this area of Wisconsin. Prior studies also found elevated chloride levels in Arrowhead Lake. In fact, substantially elevated chloride levels have been found at Arrowhead Lake since records were kept (1985). The source of this ongoing elevation needs to be identified and the elevation reduced.

The sum of water testing results for nitrate, nitrite and ammonium levels of over .3 milligrams/liter in the spring can be used to project the likelihood of an algal bloom in the summer (assuming sufficient phosphorus is also present). Arrowhead Lake combination spring levels from 2004 to 2006 averaged .88 milligrams/liter, above the .3 milligrams/liter predictive level for nitrogen-related algal blooms. These elevations suggest that some of the algal blooms on Arrowhead Lake may be at least partly nitrogen-related. This issue should be further investigated.

In low-oxygen waters (hypoxic), sulfate can combine with hydrogen and becomes the gas hydrogen sulfate, which smells like rotten eggs and is toxic to most aquatic organisms. Sulfate levels can also affect the metal ions in the lake, especially iron and mercury, by binding them up, thus removing them from the water column. To prevent the formation of hydrogen sulfate, levels of 10 milligrams/liter are best. A health advisory kicks in at 30 milligrams/liter. Arrowhead Lake sulfate levels averaged 27.44 milligrams/liter during the testing period, above the level for hydrogen sulfate formation, but still slightly below the health advisory level. The overall average for the years in which sulfate testing was done is 26.63, still approaching the health advisory level. This is also an area of concern to be further investigated.

The average calcium level in Arrowhead Lake's water during the testing period was 42.37 milligrams/liter. The average Magnesium level was 18.04 milligrams/liter. Both of these are low-level readings. Both sodium and potassium levels in Arrowhead Lake are very low: the average sodium level was 3.6 milligrams/liter; the average potassium reading was 2.22 milligrams/liter.

Turbidity reflects water clarity. The term refers to suspended solids in the water column—solids that may include clay, silt, sand, plankton, waste, sewage and other pollutants. Turbid water may mask the presence of bacteria or other pollutants because the water looks murky or muddy. In general, turbidity readings of less than 5 NTU are best. Very turbid waters may not only smell, but also tend to be aesthetically displeasing, thus curtailing recreational uses of the water. All of the Arrowhead Lake's turbidity readings were below 5 NTU.

Phosphorus

Like most lakes in Wisconsin, Arrowhead Lake is a phosphorus-limited lake: of the pollutants that end up in the lake, the one that most affects the overall quality of the lake water is phosphorus. The amount of phosphorus especially affects the frequency and density of aquatic vegetation and the frequency and density of various kinds of algae, as well as water clarity and other water quality aspects.

The total phosphorus (TP) concentration in a lake is considered a good indicator of a lake's nutrient status, since the TP concentration tends to be more stable than other types of phosphorus concentration. For a man-made lake like Arrowhead Lake, a total phosphorus concentration below 30 micrograms/liter tends to result in few nuisance algal blooms. Arrowhead Lake's growing season (June-September) surface average total phosphorus level of 18.62 micrograms/liter is under that limit, suggesting that phosphorus-related nuisance algal blooms may occur only rarely.

Land use plays a major role in phosphorus loading. The land uses around Arrowhead Lake that contribute the most phosphorus are residential and the ground watershed. Some phosphorus deposition cannot be controlled by humans. However, some phosphorus (and other nutrient) input can be decreased or increased by changes in human land use patterns. Practices such as shoreland buffer restoration along waterways; infiltrating stormwater runoff from roof tops, driveways and other impervious surfaces; using no phosphorus lawn fertilizers; and reducing phosphorus input to and properly managing septic systems will minimize phosphorus inputs into the lake. Such practices need to be implemented in all of the Tri-Lakes Watersheds in order for a significant impact on phosphorus reduction to occur.

Reducing the amount of input from the surface and ground watersheds results in less nutrient loading into the lake itself. Under the modeling predictions, reducing phosphorus inputs from human-based activities even 10% would improve Arrowhead Lake water quality by .6 to 4.1 micrograms/liter. A 25% reduction would save 1.6 to 10.25 micrograms/liter and could reduce the overall eplimnetic growing season total phosphorus to around the 30 micrograms/liter level to avoid nuisance algal blooms. These predictions make it clear that reducing current phosphorus inputs to the lake are essential to improve, maintain and protect Arrowhead Lake's health for future generations.

<u>Aquatic Plant Community</u>

The aquatic plant community is characterized by average quality for Wisconsin lakes, good species diversity and impacted by high levels of disturbance. Disturbances include invasions of exotic species, boat traffic, shoreline development, harvesting and past herbicide treatments.

Of the 28 species found in Arrowhead Lake, 25 were native and 3 were exotic invasives. In the native plant category, 9 were emergent, 3 were free-floating plants, and 13 were submergent species. Three exotic invasives, *Myriophyllum spicatum* (Eurasian Watermilfoil), *Phalaris arundinacea*, were found at Arrowhead Lake. Filamentous algae were found at 22.88% of the sample sites in 2006 and found at 15.6% of the sites in 2000.

Potamogeton pectinatus was the most frequently-occurring plant in Arrowhead Lake in 2006 (58.46% frequency). No other species reached a frequency of 50% or greater. Next closest in frequency of occurrence were *Chara* spp (40.00%), *Potamogeton zosteriformis* (38.46%), and *Najas flexilis* (36.92%). In 2000, no species reached a frequency of 50% of greater in the lake overall, although *Chara* spp had an overall occurrence frequency of 44.95%.

Potamogeton pectinatus was also the densest plant in Arrowhead Lake, with a mean density of 1.43 (on a scale of 1 to 4). In the lake overall, none of the aquatic vegetation had a mean density of over 2.0, meaning none occurred at more than average. There were no species at more than average density in any of the depth zones either. The densest-occurring plant in Depth Zone 1 (0-1.5') was *Chara* spp (1.53). Densest in Depth Zone 2 (1.5'-5.0') was *Potamogeton nodosus* (1.91). In Depth Zone 3 (5'-10') and Depth Zone 4 (10'-20'), *Potamogeton nodusus* and *Potamogeton pectinatus* tied, with 1.56 in Zone 3 and 1.73 in Zone 4.

Relative frequency and relative density are combined into a dominance value that demonstrates how dominant a species is within its aquatic plant community. Based on dominance value, *Potamogeton pectinatus* was the dominant aquatic "plant" species in Arrowhead Lake. Sub-dominant were *Najas flexilis* and *Chara* spp,.and *Potamogeton zosteriformis*. *Myriphyllum spicatum*, *Phalaris arundinacea* and *Potamogeton crispus*, the exotics found Arrowhead Lake, were not present in high frequency, high density or high dominance.

The Aquatic Macrophyte Community Index for both 2000 and 2006 is 56, but the Average Coefficient of Conservatism is lower than it was in 1979. Species Richness and the Floristic Quality Index went up between 2002 and 2006, as did the Simpson's Index of Diversity. But the Floristic Quality Index in 1979 was between the 2000 and 2006 scores. It appears, even using the limited information from 1979 and 1992, that increase in these figures may not necessarily indicate an ongoing increase in the quality of the aquatic plant community.

Further, when calculating the coefficient of similarity between the 2000 and 2006 surveys, they score as statistically dissimilar. Based on frequency of occurrence, the aquatic plant communities of the two years are only 53% similar. Based on relative frequency, they are 57% similar. Similarity percentages of 75% or more are considered statistically similar; obviously, Arrowhead Lake percentages are far from that.

It is worth noting that the report on the 2000 aquatic plant surveys mentioned the absence of emergent plants in Arrowhead Lake. The 2006 survey shows that emergent plants seem to be "coming back", i.e., are re-establishing in Arrowhead Lake. However, the occurrence of filamentous algae has also increased since 2000, as had the total occurrence and total density of aquatic plant growth in all depth zones. Further, the increase in free-floating plants may be due to increased nutrient loading.

Arrowhead Lake has three known invasive aquatic plant species: Curly-Leaf Pondweed (submergent); Eurasian Watermilfoil (submergent); and Reed Canarygrass (emergent). The lake gets a significant amount of transient boat traffic due to its location with a public beach and large public boat ramp. The Tri-Lakes Management District has a lake management plan that includes management of aquatic invasives. The lake has been using targeted harvesting for Eurasian Watermilfoil, emphasizing the harvesting of that plant in May and September, while harvesting the summer months for navigation, rather than control of Eurasian Watermilfoil. In 2008, some lake citizens were trained to monitor the aquatic invasives and participate in the Clean Boats, Clean Waters boater education program. The lake also has the invasive animals, Zebra Mussels and Rusty Crayfish.

Fish/Wildlife/Endangered Resources

The most recent fishery survey of Arrowhead Lake was done in October 2004. That inventory found that walleye and largemouth bass were abundant. Bluegill and white suckers were common. Both yellow perch and northern pike were scarce.

Muskrat are known to use Arrowhead Lake shores for cover, reproduction and feeding, mostly in the conservancy areas. Seen during the field survey were various types of waterfowl, and songbirds. Frogs and salamanders are known, using the lake shores for shelter/cover, nesting and feeding. Turtles and snakes also use this area for cover or shelter in this area, as well as nested and fed in this area. Upland wildlife feed and nest here as well.

Arrowhead watersheds contain a number of endangered natural communities, plants and animals. Natural communities in these watersheds include Alder Thicket, Northern Sedge Meadow, Northern Wet Forest, Pine Barrens and Shrub-Carr. Red-shouldered hawk, also in jeopardy, is known here. Plants of concern include Crossleaf Milkwort, Grassleaf Rush and Yellow Screwstem. The area is also good habitat for Karner Blue Butterflies.

Conclusion

Arrowhead Lake is currently impoundment impacted substantially by its position in the large surface watersheds of the Tri-Lakes, as well as significant disturbances. It is approaching the threshold of passing from an aquatic plant-dominated system to a turbid algae-dominated system. The Tri-Lakes Management District will need to regularly review and update its lake management plan in order to address its management issues in a logical, cohesive manner.

RECOMMENDATIONS

Lake Management Plan

- When the Tri-Lakes Management District revises the lake management plan, it needs to make sure the plan includes at least the following aspects concerning the management of the lake: integrated aquatic species management; control/management of invasive species; wildlife and fishery management; nutrient budgeting; shoreland protection; water quality protection.
- The Lake Arrowhead Association should participate in the revision process and implementation of the lake management plan.

Watershed Recommendations

- Since computer modeling results suggest that input of nutrients, especially phosphorus, are a factor that needs to be explored for Arrowhead Lake, it is recommended that both the surface and ground watersheds be inventoried, documenting any of the following: runoff from any livestock operations that may be entering the surface water; soil erosion sites; agricultural producers not complying with nutrient management plans and/or irrigation water management plans.
- If such sites are documented, a statement outlining the Arrowhead Lake Association and Tri-Lake Management District's encouragement to Adams County Land & Water Conservation Department and landowners to design and implement practices to address the sites.

Water Quality Recommendations

- All lake residents should practice best management on their lake properties, including keeping septic systems maintained in proper condition and pumped every three years, eliminating the use of lawn fertilizers, cleaning up pet wastes and not composting near the water.
- Reducing the amount of impervious surface around the lake and management of stormwater runoff will also help maintain water quality.
- Residents should become involved in the Citizen Lake Water Monitoring Program. This program includes water quality monitoring, invasive species monitoring, and Clean Boats, Clean Waters.
- Broad-scale restoration of native vegetation at the shore is needed to help improve water quality. Studies show that the frequency and density of the most

sensitive plant species is less at disturbed shores than at those with native vegetation. These plants are indicators of water quality. This will need to involve the Lake Arrowhead Association, which owns the first 100 feet landward around the lake, i.e. owns the actual shores & buffer areas.

- Further investigation of the sources of the elevated chloride, nitrogen and sulfate needs to be made to identify such sources and develop a plan to reduce those elevated levels.

<u>Aquatic Plant Recommendations</u>

- All lake users should protect the aquatic plant community in Arrowhead Lake by assisting in revising implementing an integrated aquatic plant management plan that uses multiple methods of control.
- The Tri-Lakes Management District should maintain exotic species signs at the boat landings and contact DNR if the signs are missing or damaged.
- The Tri-Lakes Management District should continue monitoring and control of Eurasian Watermilfoil and Curly-Leaf Pondweed, maintaining the most effective methods and modifying if necessary. The Arrowhead Lake Association should assist in these efforts. Residents may need to hand-pull scattered plants.
- Lake residents should get involved in the county-sponsored Citizen Aquatic Invasive Species Monitoring Program. This will allow not only noting changes in the Eurasian Watermilfoil pattern and Curly-Leaf Pondweed, but also for other invasives, including the zebra mussels already known to be present in Arrowhead Lake. Noting the presence and density of invasives early is the best way to take preventive action to keep them from becoming a bigger problem.
- Emergent vegetation, which is very sparse in Arrowhead Lake, should not be removed. In fact, removal of aquatic plants and shore plants should be kept to the maximum 30’ wide viewing/access corridor and navigation purposes. Leave as much vegetation as possible to protect water quality and habitat.
- Natural shoreline should be restored and eroded areas repaired. Disturbed shoreline covers too much of the shore and mowed lawn alone covers nearly half of the shore. This will require the participation of the Lake Arrowhead Association.
    a) Unmowed native vegetation reduces shoreline erosion and run-off into the lake and filters the run-off that does enter the lake thus reducing nutrient inputs.
    b) Shoreline restoration could be a as simple as leaving a band of natural vegetation around the shore by discontinuing mowing.
    c) Restoration could be as ambitious as extensive plantings of attractive native wetland species in the water and native grasses, flowers, shrubs and trees on the near shore area.

LAKE CLASSIFICATION REPORT
FOR ARROWHEAD LAKE, ADAMS COUNTY

INTRODUCTION

In 2003, The Adams County Land & Water Conservation Department (Adams County LWCD) determined that a significant amount of natural resource data needed to be collected on the lakes with public access in order to provide it and the public with information necessary to manage the lakes in a manner that would preserve or improve water quality and keep it appropriate for public use. In some instances, there was significant historical data about a particular lake; in that instance, the study activities concentrated on combining and updating information. In other instances, there was no information on a lake, so study activities concentrating on gathering data about that lake. Further, it was discovered that information was scattered among various citizens, so often what information was actually available regarding a particular lake was unknown. To assist in updating some information and gathering baseline information, plus centralize the data collected, so the public may access it. The Adams County LWCD received a series of grants from the Wisconsin Department of Natural Resources (WDNR) from the Lake Classification Grant Program.

Objectives of the study were:

- collect physical data on the named lakes to assist in assessing the health of Adams County lake ecosystems and in classifying the water quality of the lakes.
- collect chemical and biological data on the named lakes to assist in assessing the health of Adams County lake ecosystems and in classifying the water quality of the lakes.
- develop a library of lake information that is centrally located and accessible to the public and to City, County, State and Federal agencies.
- make specific recommendations for actions and strategies for the protection, preservation and management of the lakes and their watersheds.
- create a baseline for future lake water quality monitoring.
- Provide technical information for the development of comprehensive lake management plans for each lake
- provide a basis for the water quality component of the Adams County Land and Water Resource Management Plan. Components of the plan will be incorporated into Adams County's "Smart Growth Plan".
- develop and implement educational programs and materials to inform and education lake area property owners and lake users in Adams County.

METHODS OF DATA COLLECTION

To collect the physical data, the following methods were used:

- delineation & mapping of ground & surface watersheds using topographic maps, ground truthing and computer modeling;
- identification of flow patterns for both the surface & ground watersheds using known flow maps and topographic maps;
- inventory & mapping of current land use with orthographic photos and collected county information;
- inventory & mapping of shoreline erosion and buffers using county parcel maps and visual observation;
- inventory & mapping for historical and cultural sites using information from the local historical society and the Wisconsin Historical Society;
- identification & mapping of critical habitat areas with WDNR and Adams County LWCD staff;
- identification & mapping of endangered or threatened natural resources (including natural communities, plant & animal species) using information from the Natural Heritage Inventory of Wisconsin;
- identification & mapping of wetland areas using WDNR and Natural Resource Conservation Service wetland maps;
- preparation of soil maps for each of the lake watersheds using soil survey data from the Natural Resource Conservation Service.

To collect water quality information, different methods were used:

- for three years, lakes were sampled during late winter, at spring and fall turnover, and several times during the summer for various parameters of water quality, including dissolved oxygen, relevant to fish survival and total phosphorus, related to aquatic plant and algae growth;
- random samples from wells in each lake watershed were taken in two years and tested for several factors;
- aquatic plant surveys were done on all 20 lakes and reports prepared, including identification of exotics, identifying existing aquatic plant community, evaluation of community measures, mapping of plant distribution, and recommendations;
- all lakes were evaluated for critical habitat areas, with reports and recommendations being made to the respective lakes and the WDNR;
- lake water quality modeling was done using data collected, as well as historical data where it was available.

WATER QUALITY COMPUTER MODELING

Wisconsin developed a computer modeling program called WiLMS (Wisconsin Lake Modeling Suite) to assist in determining the amount of phosphorus being loaded annually into a lake, as well as the probable source of that phosphorus. This suite has many models, including Lake Total Phosphorus Prediction, Lake Eutrophic Analysis Procedure, Expanded Trophic Response, Summary Trophic Response, Internal Load Estimator, Prediction & Uncertainty Analysis, and Water & Nutrient Outflow. The models that various types of data inputs: known water chemistry; surface area of lake; mean depth of lake; volume of lake; land use types & acreage. This information is then used in the various models to determine the hydrologic budget, estimated residence time, flushing rate, and other parameters.

Using the data collected over the course of the studies, various models were run under the WiLMS Suite. These water quality models are computer-based mathematical models that simulate lake water quality and watershed runoff conditions. They are meant to be a tool to assist in predicting changes in water quality when watershed management activities are simulated. For example, a model might estimate how much water quality improvement would occur if watershed sources of phosphorus inputs were reduced. However, it should be understood that these models predict only a relative response, not an exact response. Modeling results will be incorporated into topic discussions as appropriate.

DISSEMINATION OF PROJECT DELIVERABLES

The results of this study will be distributed various agencies, organizations and the public as previously described. Based on the classification information, the Adams County Land and Water Conservation Department will identify assistance requests and determine the appropriate future activities, based on the classification determinations. To provide the requested assistance, Adams County Land and Water Conservation Department will incorporate the lake management plans goals, priorities and action items into its Annual Plan of Operations. Goals, priorities and action items may include educational programs, formation of lake districts, further development of lake management plans and implementation of lake management plans.

ADAMS COUNTY INFORMATION

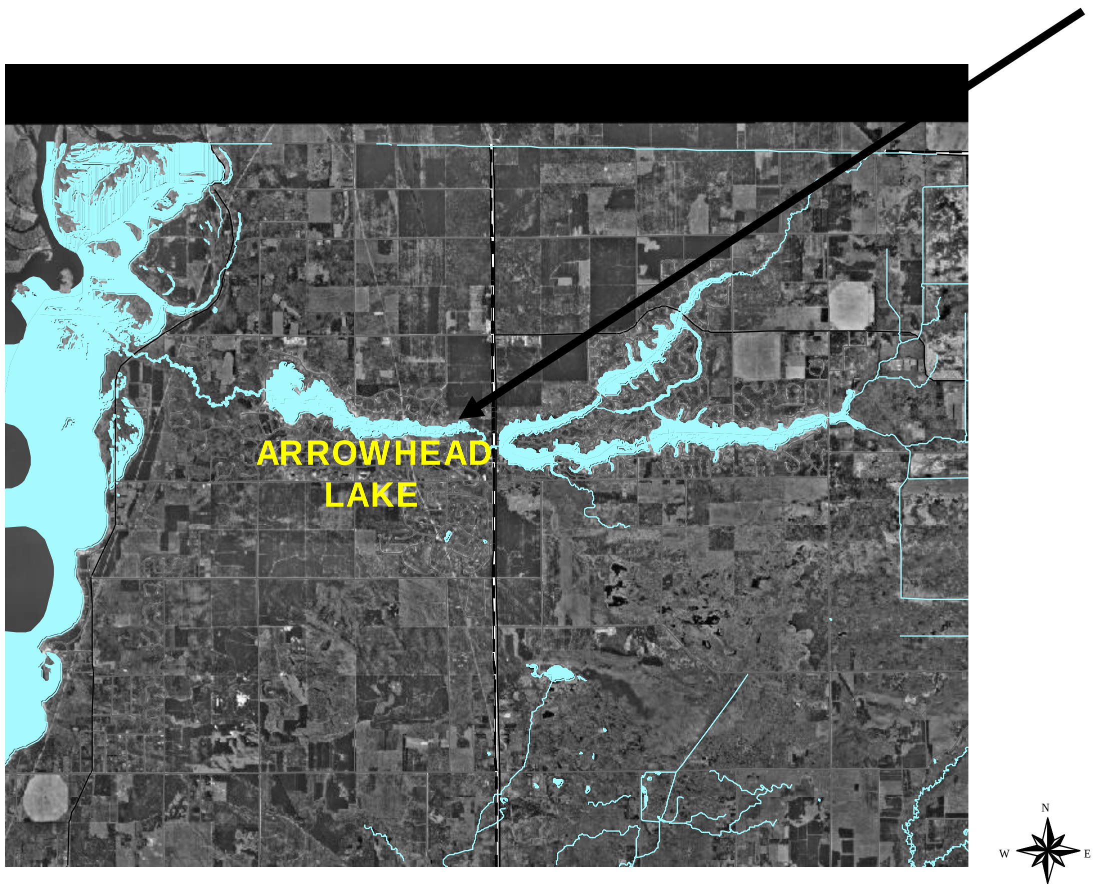
Adams County lies in south central Wisconsin, shaped roughly like the outline of Illinois. Adams County is a small rural county with a full-time population of about 20,000. Between 1980 and 2000, Adams County's population grew by more than 20%, with most of the population increase being located upon the lakes and streams. The population increase has resulted in a greater need for facilitation, technical assistance and education, including information on the lakes and streams.

Figure 1: Adams County Location in Wisconsin

ARROWWOOD LAKE BACKGROUND INFORMATION

Arrowhead Lake is located in the Town of Rome, Adams County, Wisconsin. The impoundment is 300 surface acres in size. Its maximum depth is 25.2’, with an average depth of 8’. The dam impounds Fourteen-Mile Creek downstream from the dams at Lower and Upper Camelot Lakes and Arrowhead Lake, on its way to the Wisconsin River. The dams on these lakes are owned and operated by Adams County. There is a public boat ramp located on southwest side of the lake owned by The Adams County Parks Department, as well as a public swimming beach. Heavy residential development around the lake is found along most of the lakeshore. The first 100’ landward from the water is owned by the Lake Arrowhead Association, which also operates two golf courses, a restaurant, swimming pool and marinas around the lake for use by Lake Arrowhead property owners.

Figure 2: Arrowhead Lake location



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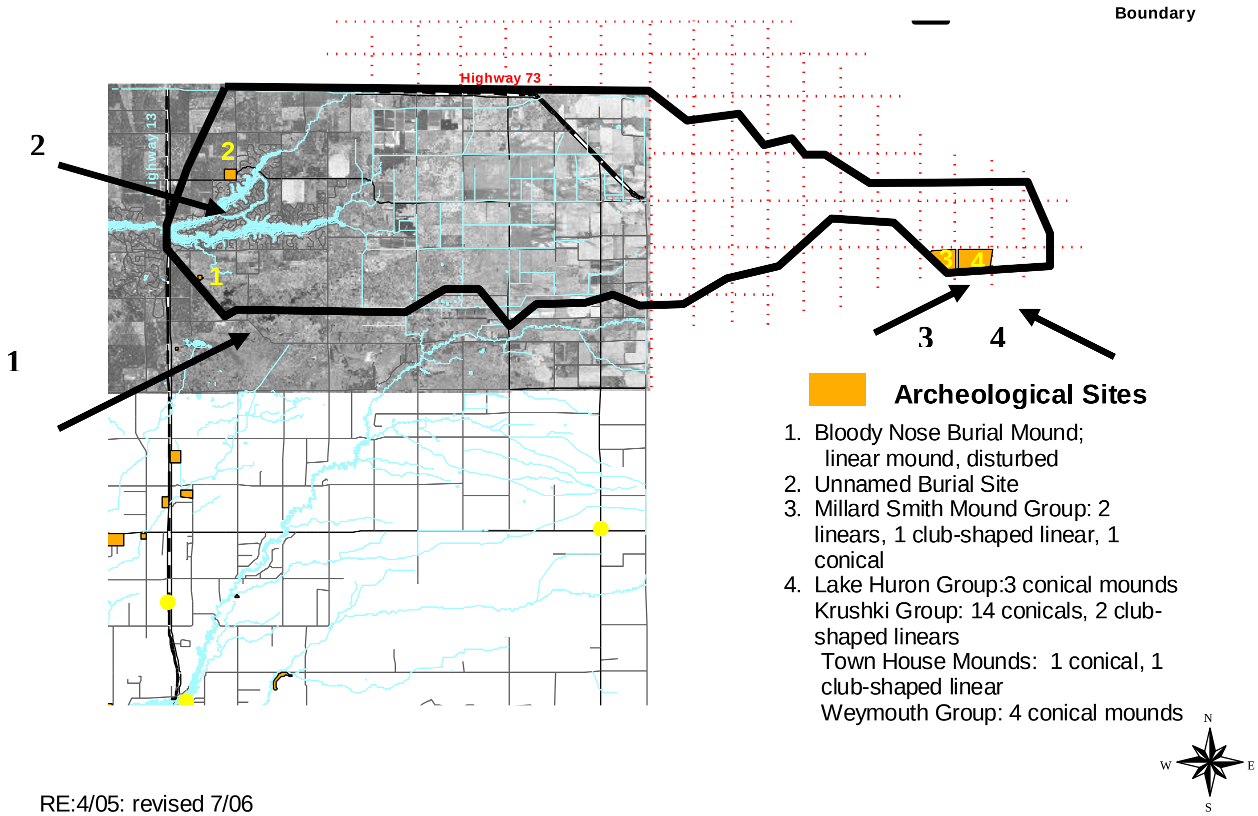
The Central Sand Plains, which contain Arrowhead Lake, are found in the Driftless Area of Wisconsin. The area is characterized by varying elevations, with numerous, usually flat-topped ridges & hills sometimes called "mounds." Deposits made by streams from the melting ice sheet cover large areas and usually consist of sand, clay and gravel.

Archeological Sites

Figure 3: Arrowhead Lake Archeological Sites



There are many Native American archeological sites in Adams County, with several being located right around in the Tri-Lakes watersheds. These mounds can be conical, linear or effigy (animal shapes) shapes. In order to preserve Native American heritage, federal and state laws on Native American burials require permission of the federal government and input from the local tribes before further disturbance.

Bedrock and Historical Vegetation

Bedrock around Arrowhead Lake is mostly sandstone, both weak and resistant, formed in the Cambrian Period of Geology (542 to 488 millions years ago). Bedrock may be 200 or more feet below the sand/clay/gravel deposits left by melting ice cover.

Original upland vegetation of the area included extensive wetlands of many types (including open bogs, shrub swamps & sedge meadows), as well as prairies, oak forests, savannahs and barrens. Mesic white pine & hemlock forests were found in the northwest portion of the region. Most of the historic wetlands were drained in the 1900s and used for cropping. The current forested areas are mostly oak-dominated, followed by aspen and pines. There are also small portions of maple-basswood forest and lowland hardwoods.

Soils in the Arrowhead Lake Watersheds

The primary soil type in the ground watershed is sand. The most common soil type in the surface watershed is loamy sand.

Sandy soil tends to be excessively drained, no matter what the slope. Water, air and nutrients move through sandy soils at a rapid rate, so that little runoff occurs unless the soil becomes saturated. Although water erosion can be a problem, wind erosion may be more of a hazard with sandy soils, especially since these soils dry out so quickly. There are also draught hazards with sandy soils. Getting vegetation started in sandy soils is often difficult due to the low available water capacity, as well as low natural fertility and organic material. Onsite waste disposal in sandy soils is also a problem because of slope and seepage; mound systems are usually required.

Loamy sands tend to be well-drained, with water, air and nutrients moving through them at a rapid rate. Runoff, when it occurs, tends to be slow. Loamy sands have little water-holding capacity and low natural fertility, although they usually have more organic matter present than do sandy soils. Both wind and water erosion are potential hazards with loamy sands, as is drought. There are difficulties with waste disposal and vegetation establishment because of slope and seepage.

The soil and soil slopes around lakes and streams are very important to water quality. They affect amount of infiltration of surface precipitation into the ground and the amount of contaminants that may reach the groundwater, as well as the amount of surface stormwater runoff. In addition, these two factors affect the amount and content of pollutants and particles (including soil) that may wash into a water body, affecting its water quality, its aquatic plant community and its fishery. Further, soil types and soil slopes help determine the appropriate private sewage system and other engineering practices for a particular site, since they affect absorption, filtration and infiltration of contamination from engineering practices.

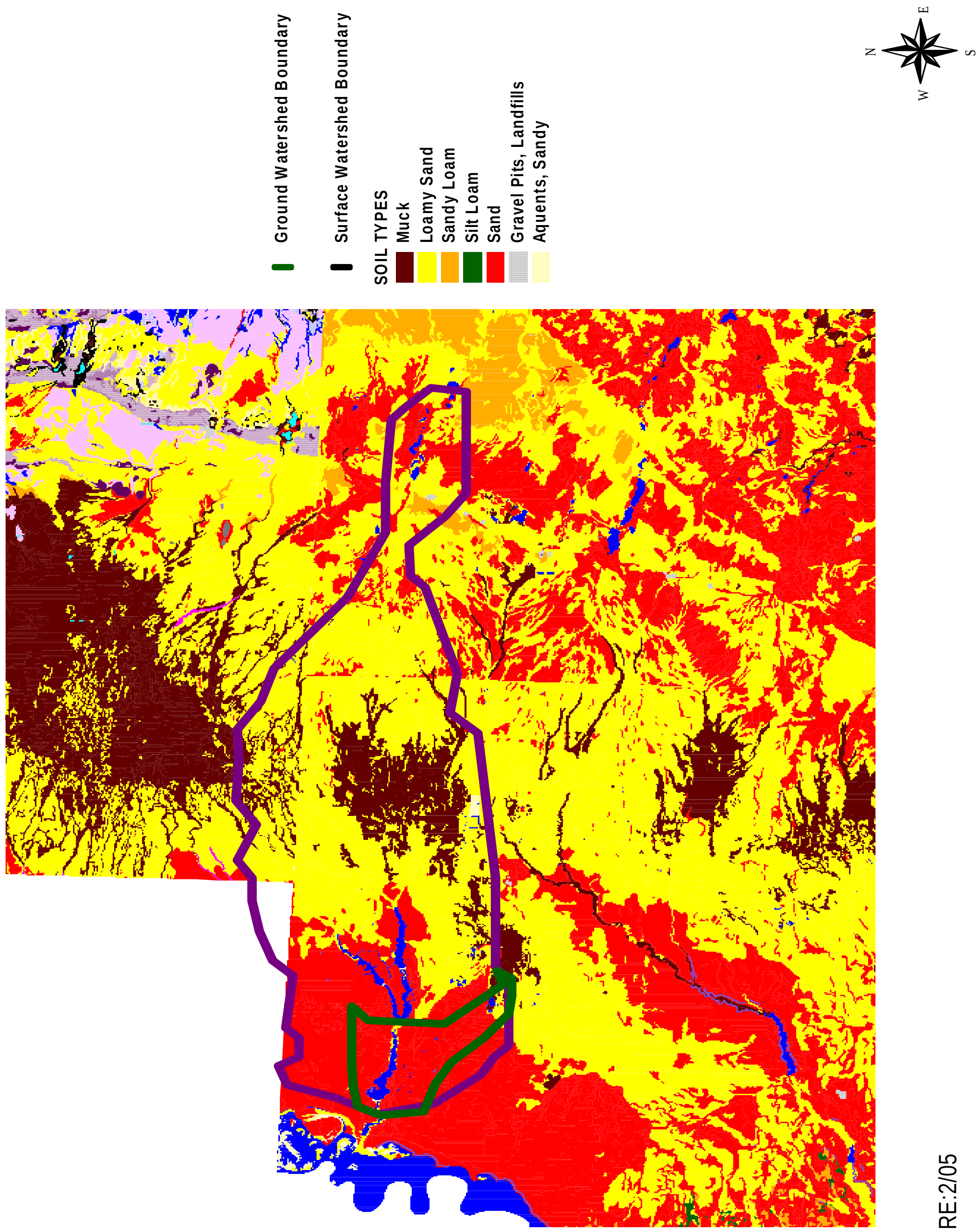


Figure 4: Arrowhead Lake Soils

PRIOR STUDIES OF THE TRI-LAKES AREA

The Tri-Lakes Area, including Arrowhead Lake, has been the subject of several different studies. In 1978, a "water management study" report, Fourteenmile Creek Watershed, was published by the University of Wisconsin-Madison, This summarized the results of a study done during the summer of 1978. The report noted that the first lake constructed in the system was Arrowhead Lake, on which construction started in 1967. The last lake constructed was Arrowhead Lake. The report noted that the bulk of Arrowhead Lake's water came from the Sherwood Dam, with only a small amount coming from groundwater and precipitation.

By 1978, all of the Tri-Lakes had been constructed. The upper watershed was used mostly for agriculture and commercial forest. 70% of the agricultural fields were irrigated. Because of the concerns expressed by the landowners in the lower watershed (around the lakes), the report concentrated on studying that area.

A survey of lakeshore owners indicated that water weeds were seen as the most severe problem, followed by erosion, algal blooms and oil slicks from boat motors. There were also complaints about water "muddiness." Over one-half of the respondents thought that contributors to these problems included leaking septic systems, oil from boat motors, silt & sand from shoreline erosion, construction erosion and fertilizers from lawns and fields. Researchers saw lakes Camelot and Sherwood as more vulnerable to eutrophy because of their shallowness, relative clarity and abundant nutrients to encourage dense aquatic plant and algal growth. Arrowhead Lake was considered the least vulnerable to eutrophy. They indicated that the main causes of erosion were waves stirred up by winds or boat wakes. Further study revealed that wind was responsible for three times as many waves as boat wakes, but that boat wakes created many more large waves.

Recommendations from this report included: (1) installation of shoreline protection practices to reduce erosion; (2) lakeside vegetation planting to reduce soil loss and help control erosion; (3) amendment of the Town of Rome boating ordinance to reduce the incidence of high energy, boat-generated waves by specifying speeds without certain distances from shores; (4) better enforcement of the current town boating ordinance to control boat speeds and water skiing issues; (5) continued stocking of game fish like pike & walleye, as well as fish habitat improvement within the lakes; (6) establishing a lake management district that included all the lakes.

In 1993, another report called Tri-Lakes, Adams County, Wisconsin: Lakes and Watershed Characterization was published. This study was funded by the WDNR and the Tri-Lakes Management District and performed by Blue Water Science of St Paul, Minnesota. Parameters researched during this study include collection of flow & total phosphorus data for the creek and ditches feeding into the Tri-Lakes; collecting lake water chemistry sample for one summer (1991); and estimating phosphorus load from various land uses and contribution sources. Runoff was estimated at 6.3 inches per year. Secchi disk readings for Arrowhead Lake ranged from 8 feet (June 1991) to 5.5 feet (July 1991). Hypoxia in the water column increased as the summer went on. Total phosphorus readings were 41.5 micrograms/liter in August 1989, 51 micrograms/liter in October 1989, 15 micrograms/liter in July 1990 and 27.5 micrograms/liter in August 1990. Chlorophyll-a readings ranged from 4 to 7 micrograms/liter in the same time period. Although total phosphorus levels were fairly low for an impoundment, nitrate Arrowhead Lake. These researchers calculated an overall total phosphorus load of nearly 3152.6 pounds per year to Arrowhead Lake at that time.

The report made several recommendations; (1) to continue efforts to reduce wind erosion through practices such as tree planting, snow fence planting, residue management, etc.; (2) to continue monitoring incoming stream water and lake water, examining at least total phosphorus, nitrate-nitrite, total Kjeldahl nitrogen and total suspended solids; (3) conduct bioassays on the 14-Mile Creek bedloads, since it was estimated that their phosphorus level was considerably higher than that of the creek surface water; (4) to continue a lake and watershed information & education program using activities such as newsletters, lake fair picnics, underwater video, demonstration projects, appointment of lake captains responsible for information distribution on their lakes; (5) to conduct plan surveys & monitor the amount of plant removal by monthly analyzing plants mechanically harvested for total phosphorus on each lake; (6) to install demonstration projects for aquatic plant control nearshore by methods other than herbicides; (7) to landscape lake shores for wildlife, shore protection & erosion control; and (8) to perform an on-site waste system evaluation and conductivity study, taking samples that were analyzed for fecal coliform & fecal streptococcus bacteria.

In April, 1999, Mid-State Associates Professional Services published the results of a septic study it had done of several septic sites around Arrowhead Lake. Houses tended to be within 100 feet of the waterfront, with lakeshores narrow and houses close together. MSA found that all of the Arrowhead septic sites were within code. However, testing of the soil underneath the absorption fields showed significant increases in phosphorus compared to the phosphorus levels of soil not under septic fields. Further, elevated phosphorus concentrations were found at depths greater than 3 feet below the base of the drainfields, with older sites have higher phosphorus concentrations. The report noted that the sandy soils in the drainfields had a low capacity to retain phosphorus. According to this report, previous studies in 1979 and 1993 had overestimated the sandy soils' ability to retain phosphorus. The report also indicated that septic systems phosphorus input was likely to grow as development increased and the sandy soils reached their phosphorus saturation point. The report recommended four alternatives to be considered in place on continuing to use many individual private septic systems: (1) centrally collect wastewater and discharge it outside the Tri-Lakes watersheds; or (2) centrally collect wastewater and pump it into an existing municipal sewage system; or (3) use cluster type wastewater collection with nutrient removal and discharge of treated water; or (4) use nutrient removal techniques in the individual on-site waste systems.

The results of a study of the algae in Arrowhead Lake were outlined in a report titled Phytoplankton Community Composition and Distribution in the Tri-Lakes Area, written by Dr. Robert Bell, UWSP-Biology Department, published in 2000. He found that Arrowhead Lake had the least taxonomically diverse algae of all the Tri-Lakes. The taxa found were generally unremarkable and were seen as typical of a mesotrophic of slightly eutrophic lake. Dr. Bell felt that at that time, heavy aquatic plant growth was more of a problem than seasonal algal blooms, but that he expected the levels of cyanobacteria (blue-green algae) to increase as the algal community shifted from one roughly equally spot of cyanobacteria, ochrophytes (pigmented algae) and green algae to one of predominately cyanobacteria. He made the following recommendations: (1) reduce the upstream input of pesticides & growth-promoting nutrients by using sediment traps or lagoons; (2) remove in-lake nutrients via sediment and/or plant biomass removal; (3) reduce residential nutrient input by improved septic/ sanitation systems and shoreline vegetation filter strips.

In December 2001, a report titled Assessment of Shallow Groundwater Flow & Chemistry & Interstital Water Sediment, Aquatic Macrophyte and Chemistry for the Tri-Lakes, Adams County, WI, was published. It was written by B. Shaw, C. Sparacio, J. Stelzer and N. Turyk of UWSP. Objectives of this study were: (1) to compare groundwater flow patterns during full & drawn-down conditions; (2) to examine water quality after heavy summer use; (3) to monitor groundwater entering back bays in Camelot & Arrowhead Lakes for local impacts such as septics and/or lawns; (4) to determine nutrients & biomass of aquatic macrophytes as they relate to nutrients in interstitial water & lake sediments; and (5) to determine quantity of phosphorus and nitrogen held by plant tissues to estimate harvest removal. This study found that Arrowhead Lake had the most complex groundwater system of the 4 lakes in the Tri-Lakes system. Upwelling was found in the conservancy area. However, the east half of the lake was split between no-welling sites and upwelling sites. The west half contained all downwelling sites (groundwater flowing out). When the Camelot and Arrowhead Lakes were drawn down in the winters, there were more upwelling sites in the east half of Arrowhead Lake (the part closest to Arrowhead Lake). Such an increase in upwelling sites increased the potential for input of nutrients from local sources. The study concluded that the fall drawdown & spring refill of Sherwood Lake and the Camelot Lakes resulted in nutrients being released from anaerobic sediments and negatively impacted lake water quality. The high reactive phosphorus and ammonium levels suggested that nutrient transport to the lake was significant, especially from the fall drawdown, which increased groundwater discharge to the lake. The report stated that there was nutrient availability from several sources, including (1) the anaerobic release of ammonium and phosphorus from high organic matter sediments; (2) the nutrient flux from groundwater inflow; and (3) the cycling of nutrients from lake to sediment to groundwater and back again.

A survey was done of Tri-Lakes property owners during 2001. Although 72% of the respondents felt that the lakes' water quality was "good" or "fair", 74% felt the water quality had declined since they started coming to the lake. The top three causes attributed by respondents were input from cranberry growers, fertilizer use and heavy recreational use. The presence of algal scum and reduced water clarity were cited as the top two water quality problems, with aquatic plant growth scoring near the bottom. Nearly 66% of the respondents fertilized their lawn, with only 25% using non-phosphorus fertilizer. 74% mowed over 25% if their lawn at their lakefront. 83.8% if the houses had 2 or 3 bedrooms. Main activities on the lake included swimming, boating and fishing. The three most common boat types were pontoon, fishing and skiing, with 56.7% of the respondents having a boat motor 50 horsepower or larger.

A report titled Limnological Investigations of Camelot, Sherwood and Arrowhead Lakes, WI, was written by W.F. James, J. Barko & H. Eaken of the U.S. Army Corps of Engineers in 2002. Field work for this report included evaluating total sediment, total nitrogen and total phosphorus loads in the lakes. This was done by sediment collecting & testing, as well as water quality monitoring and computer modeling. The report noted that total phosphorus and chlorophyll-a levels increased as one went west in the lake chain, with the Camelot Lakes having the lowest levels and Arrowhead Lake having the highest level, with Arrowhead Lake between the two. Summer anoxia in the lower levels of the lake was noted in July and August, especially near the Arrowhead Dam. Secchi disk readings were lowest in August and September. There appeared to be little correspondence between elevated phosphorus loading and algal blooms. Camelot Lakes had the lowest algal bloom rates, while Arrowhead Lake had the highest. All of the Tri-Lakes were considered susceptible to declining water quality conditions with the expected increase of phosphorus loading.

CURRENT LAND USE

Although the ground watershed for Arrowhead Lake is fairly small, the surface watershed is quite large. The two most common land uses in both the ground and surface watersheds are woodlands and residential. (See Figures 5 through 7).

Figure 5: Arrowhead Lake Watersheds Land Use in Acres and Percent of Total

	Surface		Ground		Total	
Arrowhead Lake	**Acres**	**% Total**	**Acres**	**% Total**	**Acres**	**% Total**
Agriculture--Non Irrigated	0	0.00%	87.84	1.83%	87.84	0.97%
Agriculture--Irrigated	0	0.00%	0	0.00%	0	0.00%
Government	219.7	5.11%	21.6	0.45%	241.3	2.65%
Grassland/Pasture	158.24	3.68%	154.08	3.21%	312.32	3.43%
Recreational	501.38	11.66%	0	0.00%	501.38	5.51%
Residential	1714.85	39.90%	484.8	10.10%	2199.65	24.17%
Water	422.26	9.82%	0	0.00%	422.26	4.64%
Woodland	1282.58	29.83%	4051.68	84.41%	5334.26	58.63%
total	4299.01	100.00%	4800	100.00%	9099.01	100.00%

Prior information on the watersheds shows how land use has changed over the years. After a substantial increase in agricultural land use between 1978 and 1986, agricultural changes appear to have leveled off and are no longer increasing in acreage. Residential use in the watersheds has decreased overall, although residential use directly around the Tri-Lakes has increased. Woodlands have increased slightly.

Studies have shown that land use around a lake has a great impact on the water quality of that lake, especially in the amount and content of surface runoff. (James, T., 1992, I-10; Kibler, D.F., ed. 1982. 271) For example, while natural woodland may (on the average) absorb 3.5" out of a 4" rainfall, leaving only .5" as runoff, a residential area with quarter-acre lots may absorb only 2.3" of the 4", leaving 1.7" to run off the land into the lake—the same amount as may be expected to run off from a corn or soybean field. 1.7" of runoff translates into 46,200 gallons per acre ending up in the lake! Percentage of impervious surface, the soil type, vegetation present and slope of the site can all affect runoff volume. (Frankenberger, J, ID-230). The changes in the Arrowhead watershed land use are therefore likely to significantly increase the runoff in volume and content unless protection steps are taken.

Figure 6a: Land use in Arrowhead Lake Surface Watershed

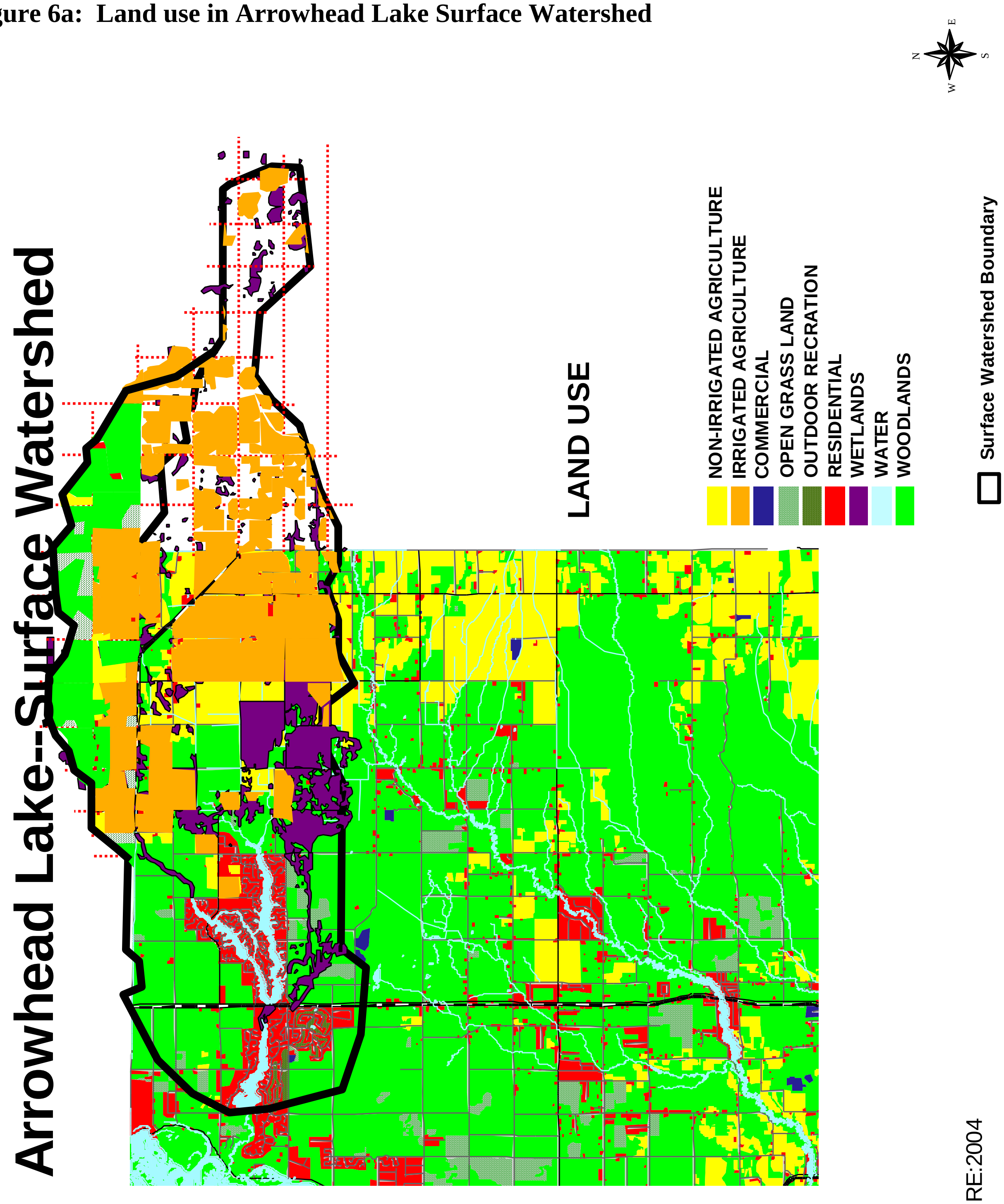
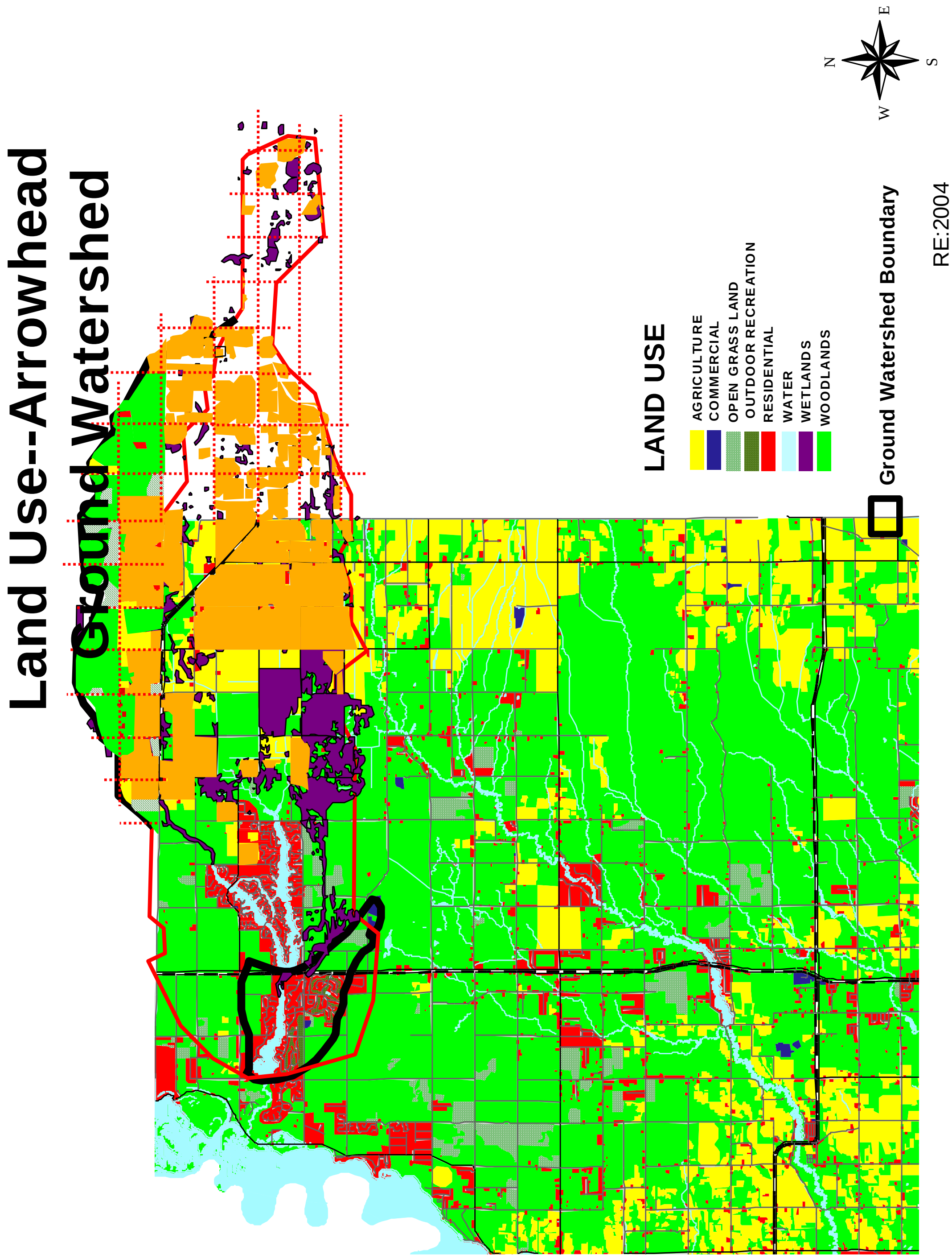
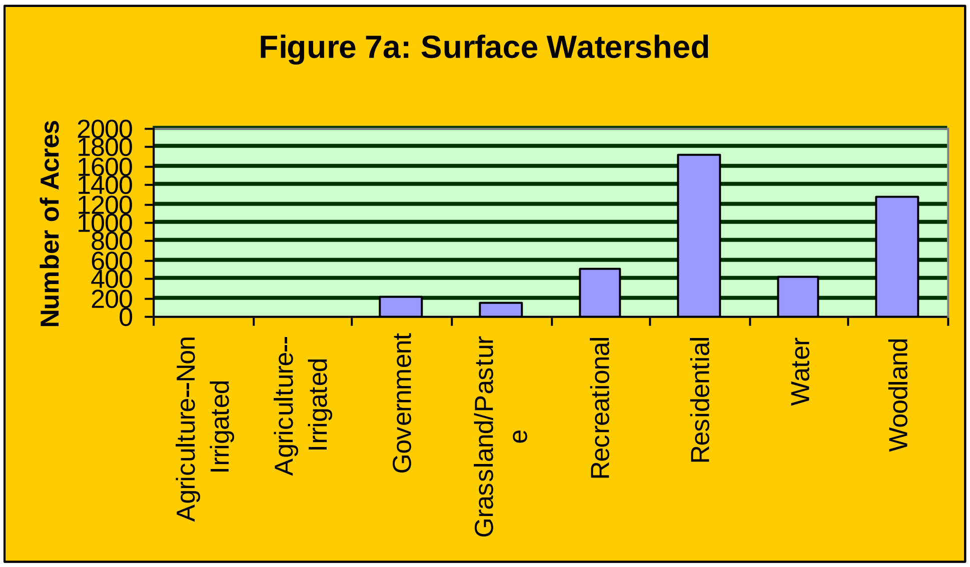
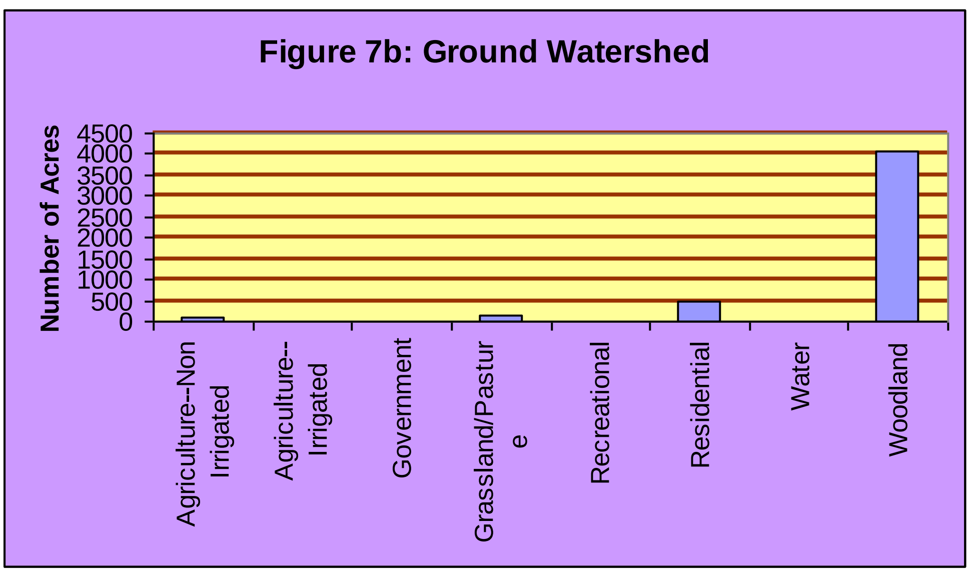


Figure 6b: Land Use in Arrowhead Lake Ground Watershed



When water runs over a surface, it picks up whatever loose pollutants—sediment, chemicals, metals, exhaust gas, etc—are present on that surface and takes those items with it into the lake. Increased development around a lake tends to increase the amount of pollutants being carried into the lake, thus negatively affecting water quality. Residential development areas with lots of one-quarter acre or less may deliver as much as 2.5 pounds of phosphorus per year to the lake for each acre of development.





There are two specific kinds of land use—wetlands and shorelands--that are so important to water quality that they will be separately discussed.

WETLANDS

Most of the wetlands in the Arrowhead Lake area are located in the designated conservancy area. In the past, wetlands were seen as "wasted land" that only encouraged disease-transmitting insects. Many wetlands were drained and filled in for cropping, pasturing, or even residential development. In the last few decades, however, the importance of wetlands has become evident, even as wetlands continue to decline in acreage.

Wetlands play an important role in maintaining water quality by trapping many pollutants in runoff and flood waters, thus often helping keep clean the water they connect to. They serve as buffers to catch and control what would otherwise be uncontrolled water and pollutants. Wetlands also play an essential role in the aquatic food chain (thus affecting fishery and water recreation), as well as serving as spaces for wildlife habitat, wildlife reproduction and nesting, and wildlife food.

The large areas of wetlands in the Arrowhead Lake watersheds serve as filters and traps that help keep Arrowhead Lake as clean as it is. It is essential to preserve these wetlands for the health of all the Tri-Lakes.

Figure 8: Example of lake end wetland

SHORELANDS

Arrowhead Lake has a total shoreline of 6.9 miles (36,432 feet). Almost all of the shore is in residential use. Much of it is steeply sloping. Slightly under 50% of the shore has native vegetation. 6.4% of the shore has significant active erosion. The remaining shore is a combination of natural rock, sand beaches, rock riprap, hard structures (piers, etc.) and cultivated lawn. A survey in 2004 of the shore showed a substantial amount of substandard armoring and significant areas of sandy or eroded shores. In particular, many of the points formed by the backwater bays in Arrowhead Lake have high, heavily-eroded shores with falling trees and sloughing dirt.

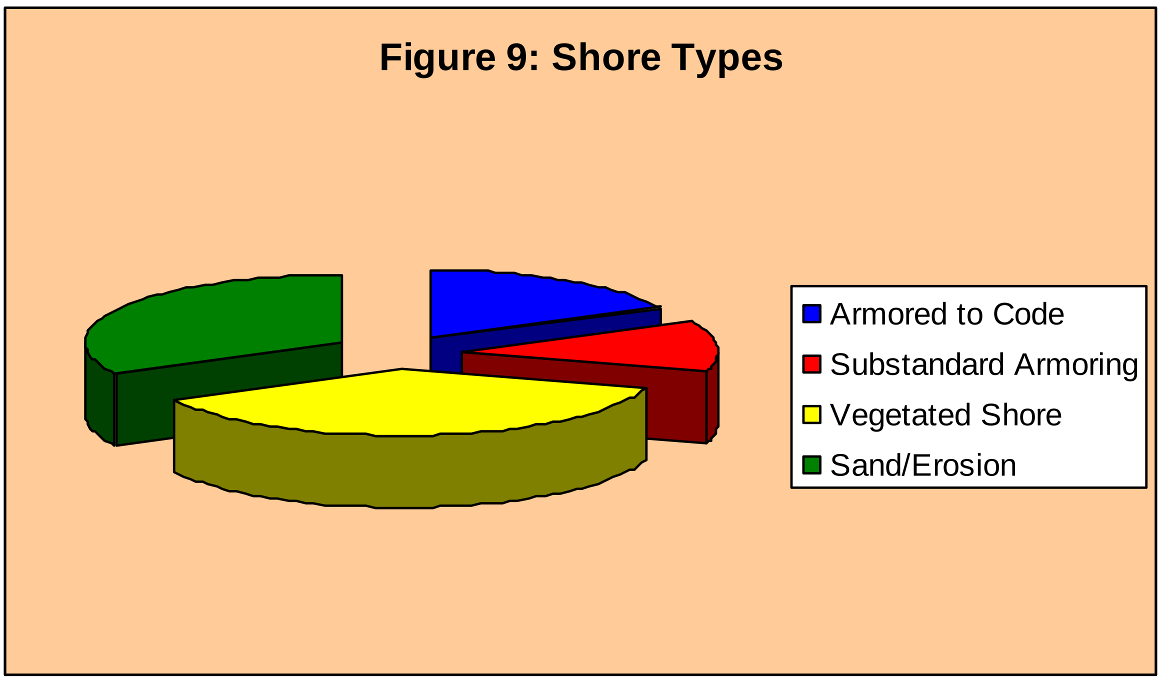
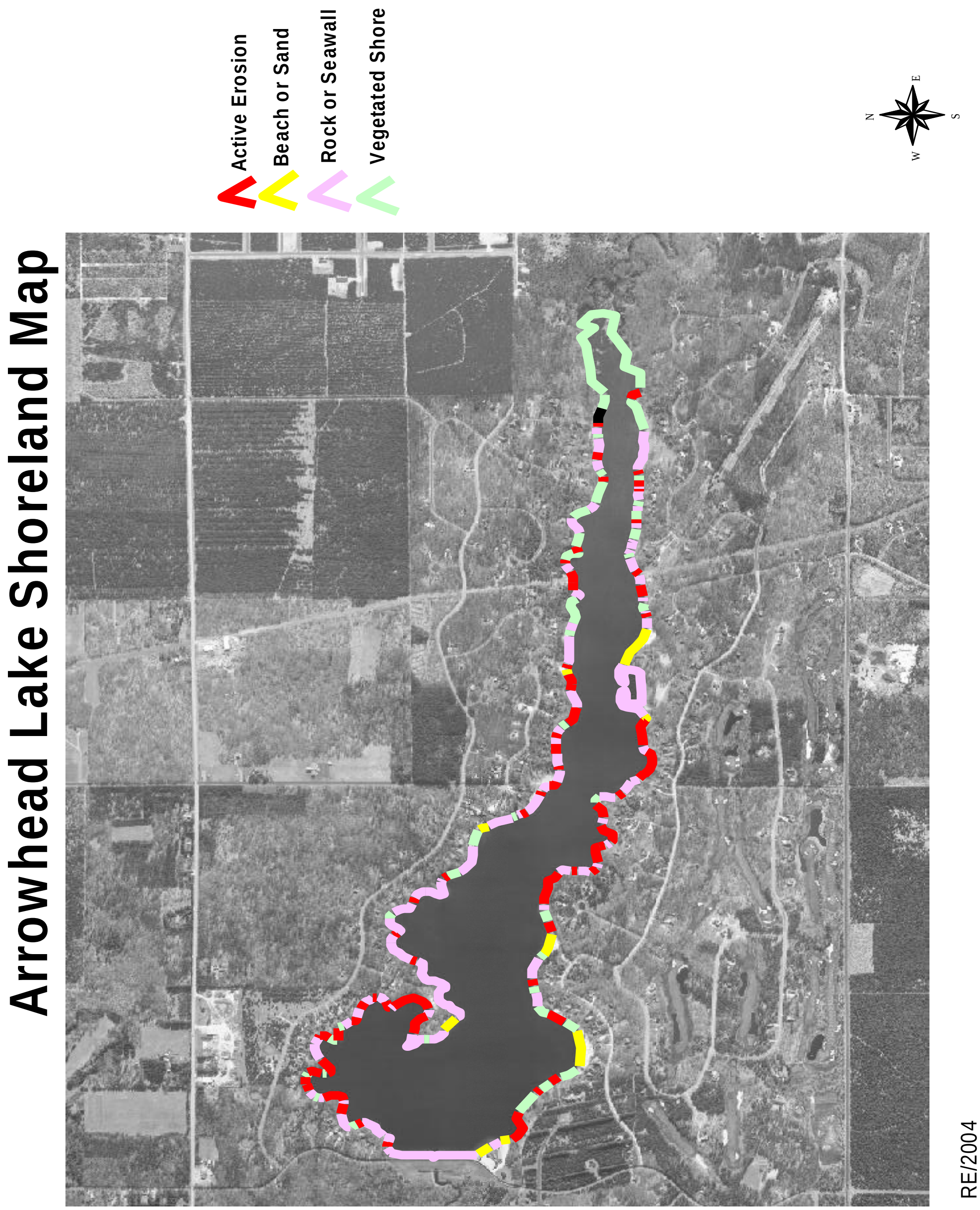


Figure 10: Shoreland Map of Arrowhead Lake (2004)

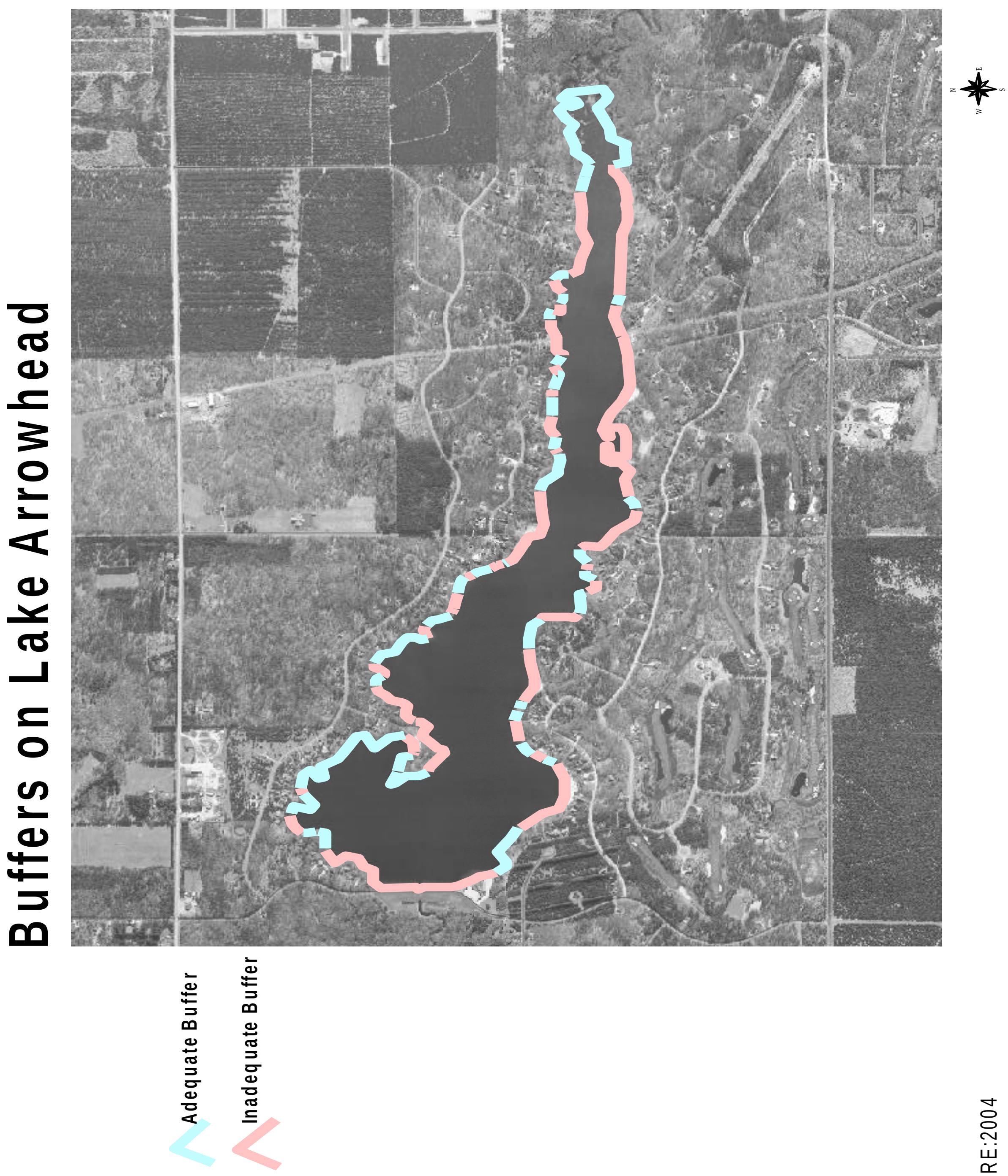


The Adams County Shoreline Ordinance defines 1000' landward from the ordinary high water mark as "shoreland". Under the ordinance, the first 35 feet landward from the water is a "buffer." Shoreland buffers are an important part of lake protection and restoration. These buffers are simply a wide border of native plants, grasses, shrubs and trees that filter and trap soil & similar sediments, fertilizer, grass clippings, stormwater runoff and other potential pollutants, keeping them out of the lake. A 1990 study of Wisconsin shorelines revealed that a buffer of native vegetation traps 5 to 18 times more volume of potential pollutants than does a developed, traditional lawn or hard-armored shore.

A 2004 shore survey showed that some of Arrowhead Lake's shore had an "adequate buffer." An "adequate buffer" is a native vegetation strip at least 35 feet landward from the shore. Most of the "inadequate" buffer areas were those with rock or seawall, hard structures, beach, active erosion or mowed laws. In a few instances, those with insufficient native vegetation at the shoreline to cover 35 feet landward from the water line were also called "inadequate."

Vegetated shoreland buffers help stabilize shoreline banks, thus reducing bank erosion. The plant roots give structure to the bank and also increase water infiltration and decrease runoff. A vegetated shore is especially important when shores are steep and soft, as are many of Arrowhead Lake shores. Figure 11 maps the adequate and inadequate buffers on Arrowhead Lake.

Figure 11: Arrowhead Lake Buffer Map (2004)



Lakeside buffers also serve as important habitat. Lake edges usually contain aquatic and wetland plants, grading into drier groundcover, then shrubs and trees as one moves inland towards drier land. Buffers provide habitat for many species of water-dependent wildlife, including furbearers, reptiles, birds and insects. Many wildlife species, including birds, small mammals, fish & turtles breed, nest, forage and/or perch in shore buffer areas. Further, 80% of the endangered and threatened species listed spend part of their life in this near-lake buffer area. (Wagner et al, 2006)

When the natural shoreline is replaced by traditional mowed turf-grass lawns, rock, wooden walls or similar installments, bird and animal life, land-based insects, and aquatic insects that hatch or winter on natural shore are negatively impacted. For example, on many Adams County lakes, the non-native aquatic plant, Eurasian Watermilfoil has invaded. There is a weevil native to Wisconsin that weakens Eurasian Watermilfoil by burrowing into and developing within its stems, but that weevil depends on a native-plant shore to overwinter. If the shore is instead covered by rock, seawall or traditional lawn, these weevils will be unavailable for the lake to use as Eurasian Watermilfoil control.

The filtering process and bank stabilization that buffers provide help improve a lake's water quality, including water clarity. Studies in Minnesota, Maine and Michigan have shown that waterfront property value increases for every foot the water clarity of a lake increases. (Krysel et al, 2003).

Figure 12: Example of Inadequate Vegetative Buffer

Figure 13: Example of Adequate Buffer

Natural shoreland buffers serve important cultural functions. They enhance the lake's aesthetics. Studies have shown that aesthetics rank high as one of the reasons people visit or live on lakes. Shore buffers can provide visual & audio privacy screens for homeowners from other neighbors and/or lake users.

Adequate buffers on Arrowhead Lake in some places could be easily installed on the inadequate areas by either letting the first 35 feet landward from the water just grow without mowing it, except for a path to the water, or by planting native seedlings sufficient to fill in the first 35 feet or using biologs to protect the shore that are vegetated. Where areas are deeply eroded, shaping, revegetating and protecting the shores will be necessary to prevent further erosion. Heavy armoring may be necessary to repair and protect the heavily-eroded points which are currently adding significant sediment to the lake.

WATER QUALITY

Between 2004 and 2006, Adams County Land & Water Conservation Department gathered water chemistry and other water quality information on Arrowhead Lake. Historic information about water testing on Arrowhead Lake was also obtained from the studies discussed earlier in this report.

Phosphorus

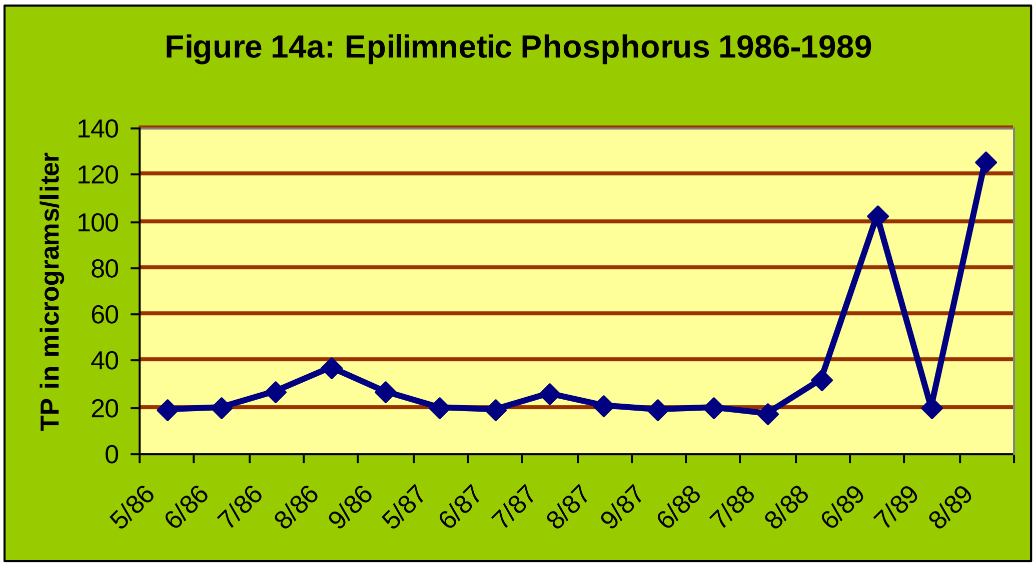
Most lakes in Wisconsin, including Arrowhead Lake, are phosphorus-limited lakes: of the pollutants that end up in the lake, the one that most affects the overall quality of the lake water is phosphorus. The amount of phosphorus especially affects the frequency and density of aquatic vegetation and the frequency and density of various kinds of algae, as well as water clarity and other quality aspects. One pound of phosphorus can produce as much as 500 pounds of algae.

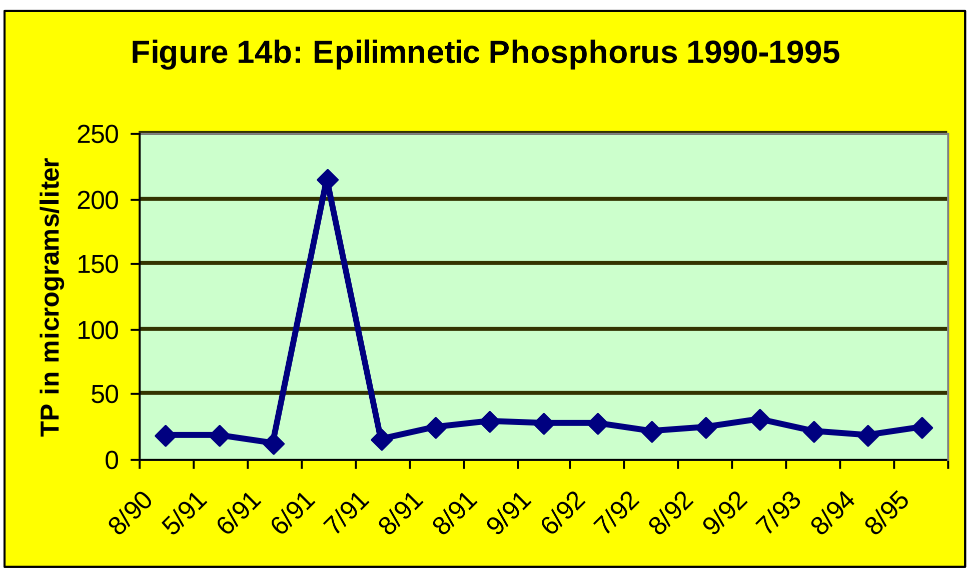
Phosphorus is not an element that occurs in high concentration naturally, so any lake that has significant phosphorus readings must have gotten that phosphorus from outside the lake or from internal loading. Some phosphorus is deposited onto the lake from atmospheric deposition, especially from soil or other particles in the air carrying phosphorus. A lake that includes a flooded wetland area may have a significant amount of phosphorus being released during the flushing of the wetland area. Phosphorus may accumulate in sediments from dying animals, dying aquatic plants and dying algae. If the bottom of the lake becomes anoxic (oxygen-depleted), chemical reactions may cause phosphorus to be released to the water column.

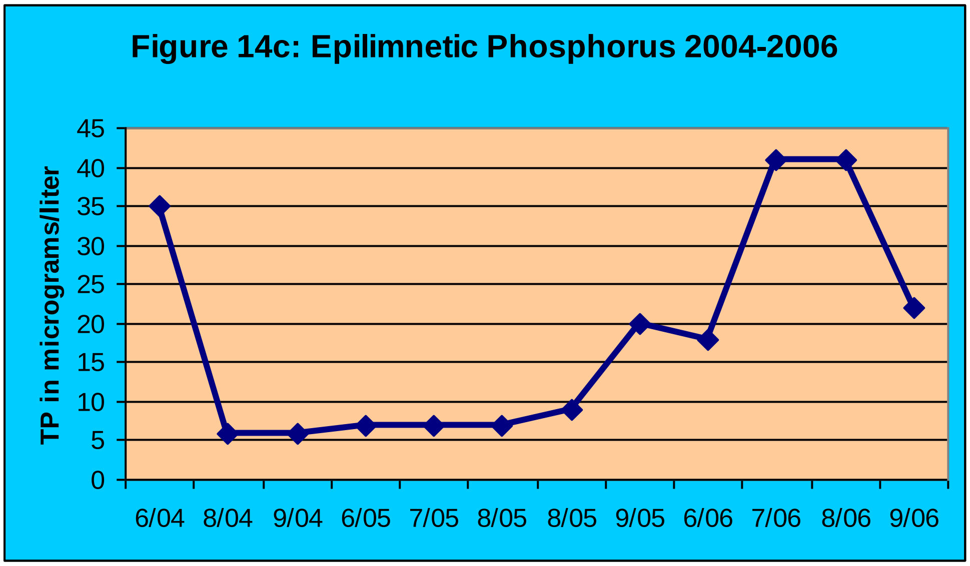
Although there are several forms of phosphorus in water, the total phosphorus (TP) concentration is considered a good indicator of a lake's nutrient status, since the TP concentration tends to be more stable than other types of phosphorus concentration. For an impoundment lake like Arrowhead Lake, a total phosphorus concentration below 30 micrograms/liter tends to prevent nuisance algal blooms. Arrowhead Lake's growing season (June 2004-September 2006) surface average total phosphorus level of 18.62 micrograms/liter, under the level at which nuisance algal blooms can be expected.

Since phosphorus is usually the limited factor, measuring the phosphorus in a lake system thus provides an indication of the nutrient level in a lake. Increased phosphorus in a lake will feed algal blooms and also may cause excess plant growth.

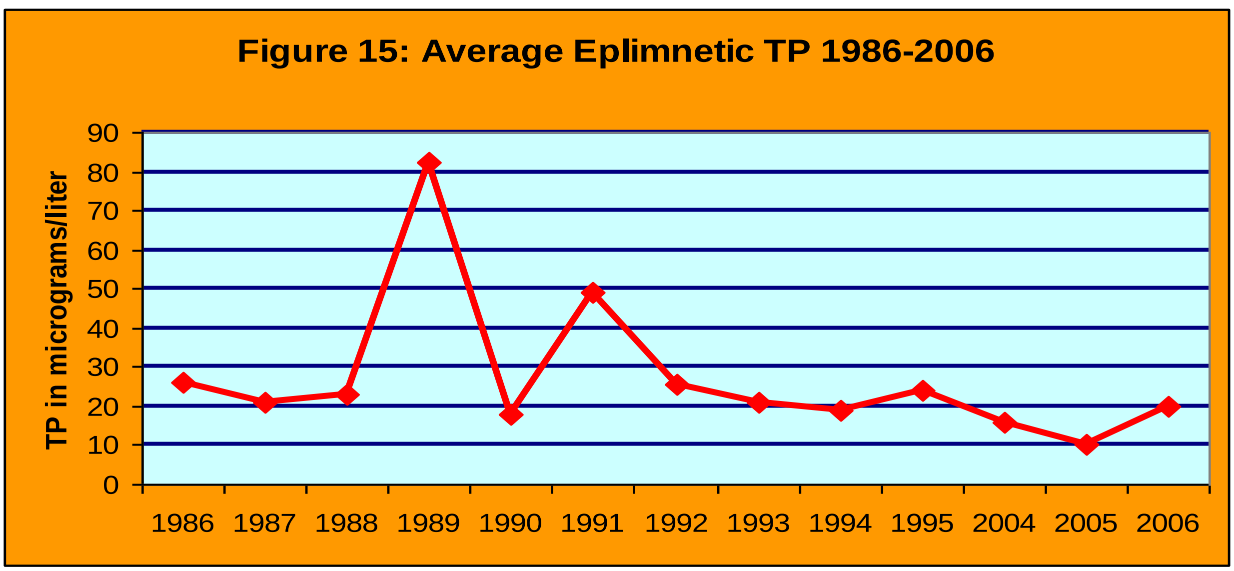
The 2004-2006 summer average phosphorus concentration in Arrowhead Lake of 18.62 micrograms/liter places Arrowhead Lake Lake in the "good" water quality section for impoundments. Figures 14a, 14b and 14c show the eplimnetic growing season readings on Arrowhead Lake since 1988.







The growing season total epilimnetic phosphorus level has been creeping down in Arrowhead Lake (see figure 15). In 1989, average eplimnetic growing season total phosphorus was 82.3 micrograms/liter. Since 1993, epilimnetic total phosphorus level during the growing season has averaged 18.3 micrograms/liter.



Although the growing season eplimnetic total phosphorus levels have stayed below the state impoundment average of 65 micrograms/liter. Considering the prior studies down on the Tri-Lakes and on Arrowhead Lake showing increasing phosphorus potential in the ground water, lake surface water phosphorus should continue to be monitored and steps should be taken to reduce the phosphorus levels in the lake.

Groundwater testing of various wells around Arrowhead Lake was done by Adams County LWCD and included a test one year for total phosphorus levels in the groundwater coming into the lake. The average TP level in the wells was 13.2 micrograms/liter, considerably lower than the lake surface water results. However, these figures don't negate the study results done earlier in the Arrowhead Lake area showing elevated phosphorus below septic fields.

Land use plays a major role in phosphorus loading. A key component of the computer models used is the phosphorus budget, that is, the estimated amount of phosphorus delivered to the lake from each land use type annually. The land uses that contribute the most phosphorus are non-irrigated agriculture and residences. Using the current land use data, as well as phosphorus readings from 2004 through 2006 water sampling, a phosphorus loading prediction model was run for Arrowhead Lake. The current results are shown in Figure 16.

Figure 16: Current Phosphorus Loading by Land Use

MOST LIKE ANNUAL PHOSPHORUS LOADING AMOUNTS		
LAND USE TYPE	**% Loading**	**LBS//Yr**
Pasture/Grassland	2.4%	22.00
Shoreland Residential	25.9%	226.60
Rural Residential	3.6%	30.80
Recreational	12.8%	112.20
Other Water	1.1%	8.80
Woodland	6.5%	41.93
Groundshed	24.5%	213.40
Commercial	1.1%	8.80
Lake Surface	5.4%	46.20
Septics	16.7%	145.20
total in pounds/year	100.0%	855.93

A review of the results of prior studies in the Tri-Lakes area suggest that overall phosphorus loading in the watershed is now less than it was in the early-1990s. This may be due to the installation of agricultural runoff practices in the upper watershed. However, land use distribution figures have also changed, including a significant increase in waterfront building around the lakes.

Currently, the most phosphorus loading is coming from human use in the surface watershed, including medium-density housing, septic systems and recreational uses. Although phosphorus deposits such as that from flooded wetlands or from atmospheric deposition cannot be controlled by humans, phosphorus loads from human activities such as agriculture, residential development, recreational and septic systems can be partly controlled by changes in human land use patterns. Practices such as agricultural buffers, nutrient management, shoreland buffer restoration; infiltrating stormwater runoff from roof tops, driveways and other impervious surfaces; using no phosphorus lawn fertilizers; and reducing phosphorus input to and properly managing septic systems will minimize phosphorus inputs into the lake. Circumstances such as increased impervious surface, lawns mowed to water's edge, disturbance of shore areas, improperly-functioning septic systems and removal of native vegetation can greatly increase the volume and content of runoff—and thus increase the volume of phosphorus entering the lake. Many of these practices can also increase the concentration of phosphorus entering the lake, by runoff or other methods of entry.

The models were run using not only the current known phosphorus readings in the lake, but also representing decreases or increases of human-controlled phosphorus input by 10%, 25%, and 50%. Just a 10% reduction of the human-impacted phosphorus would reduce the overall load by 72.82 pounds/year. This figure may not seem like much---until you calculate that one pound of phosphorus can result in up to 500 pounds of algae. A 10% reduction in these three areas could result in up to 36,410 pounds less of algae per year!

Figure 17: Impact of Increase/Decrease on P Loading

MOST LIKE ANNUAL PHOSPHORUS LOADING AMOUNTS				
LAND USE TYPE	**LBS//Yr**	-10%	-25%	-50%
Pasture/Grassland	22.00	22.00	22.00	22.00
Shoreland Residential	226.60	203.94	169.95	113.3
Rural Residential	30.80	27.72	23.1	15.4
Recreational	112.20	100.98	84.15	56.1
Other Water	8.80	8.80	8.80	8.80
Woodland	41.93	41.93	41.93	41.93
Groundshed	213.40	192.06	160.05	106.7
Commercial	8.80	8.80	8.80	8.80
Lake Surface	46.20	46.20	46.20	46.20
Septics	145.20	130.68	108.9	72.6
total in pounds/year	855.93	783.11	673.88	491.83

Reducing the amount of input from the surface and ground watersheds results in less nutrient loading into the lake itself. Under the modeling predictions, reducing phosphorus inputs from human-based activities even 10% would improve Arrowhead Lake water quality by .6 to 4.1 micrograms/liter. A 25% reduction would save 1.5 to 10.25 micrograms/liter during the growing season. These predictions make it clear that reducing current phosphorus inputs to the lake are essential to maintain and protect Arrowhead Lake's health for future generations.

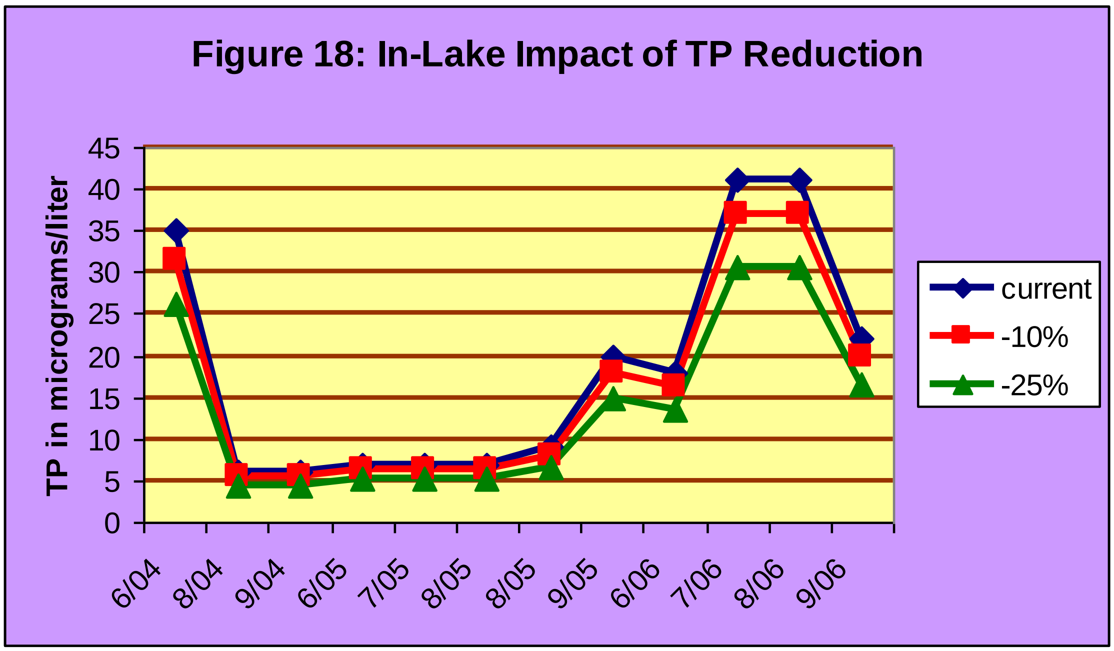
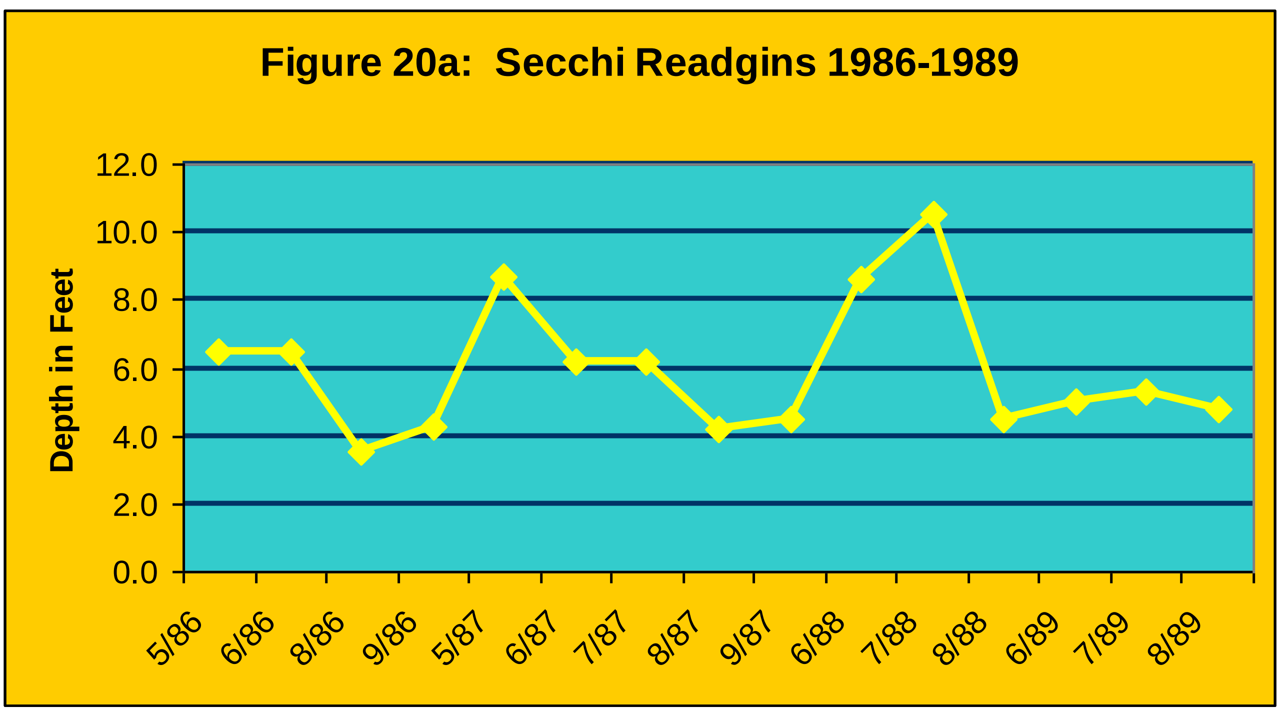


Figure 19: Photo of a Lake in Algal Bloom

Water Clarity

Water clarity is a critical factor for plants. If plants don't get more than 2% of the surface illumination, they won't survive. Water clarity can be reduced by turbidity (suspended materials such as algae and silt) and dissolved organic chemicals that color or cloud the water. Water clarity is measured with a Secchi disk. Average summer Secchi disk clarity in Arrowhead Lake in 2004-2006 was 5.99 feet. This is slightly more than the average for 1986-1992, when the Secchi disk average was 5.83'. Both these readings put Arrowhead Lake in the "fair" category of water clarity. These figures suggest that Arrowhead Lake's water clarity has stayed fairly steady for the last twenty years, i.e., it didn't decrease and it didn't substantially increase. Water clarity can be reduced by turbidity (suspended materials such as algae and silt) and dissolved organic chemicals that color or cloud the water. Water clarity often gets worse during the growing season due to increase in algae & other pollutants in the water, then clears up again by fall turnover. It is possible that some of Arrowhead Lake's water clarity can be attributed to the presence of zebra mussels, which were discovered in the lake in 2005, and are known to add to water clarity.



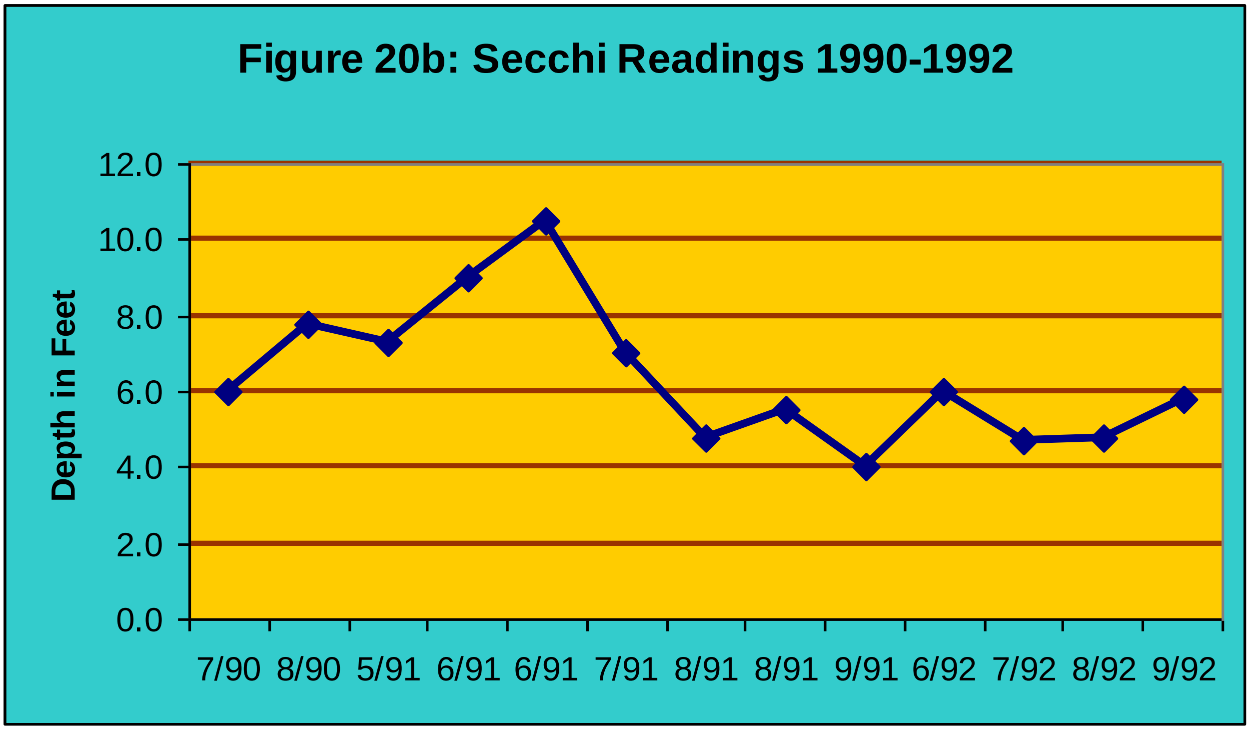


Figure 20b: Secchi Readings 1990-1992
Depth in Feet
12.0
10.0
8.0
6.0
4.0
2.0
0.0
7/90 8/90 5/91 6/91 6/91 7/91 8/91 8/91 9/91 6/92 7/92 8/92 9/92

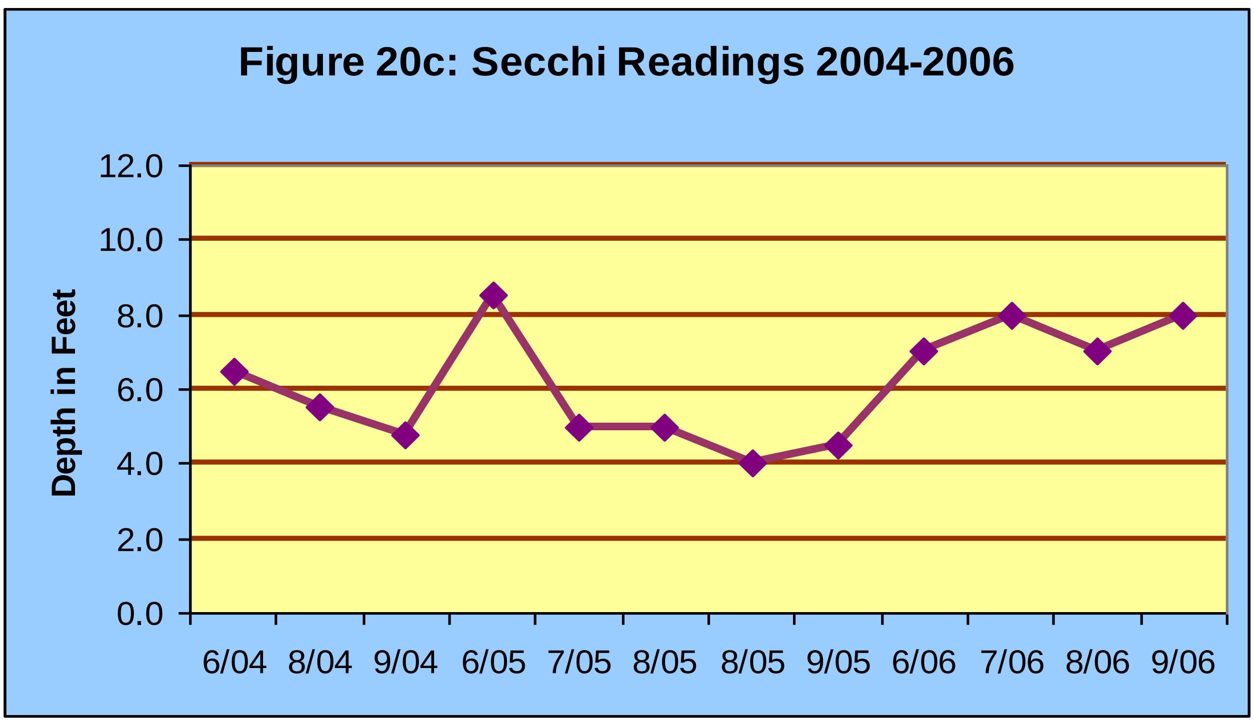


Figure 20c: Secchi Readings 2004-2006
Depth in Feet
12.0
10.0
8.0
6.0
4.0
2.0
0.0
6/04 8/04 9/04 6/05 7/05 8/05 8/05 9/05 6/06 7/06 8/06 9/06

Arrowhead Lake has a considerable history of Secchi disk readings in a number of years. A look at the average Secchi depth for the growing season in each year since 1986, Secchi disk depth readings on Arrowhead Lake have generally stayed about the same over the years (see figure 21). The overall average depth for the twenty years is 6.2 feet, only slightly above the growing season average of 5.99 feet for 2004-2006.

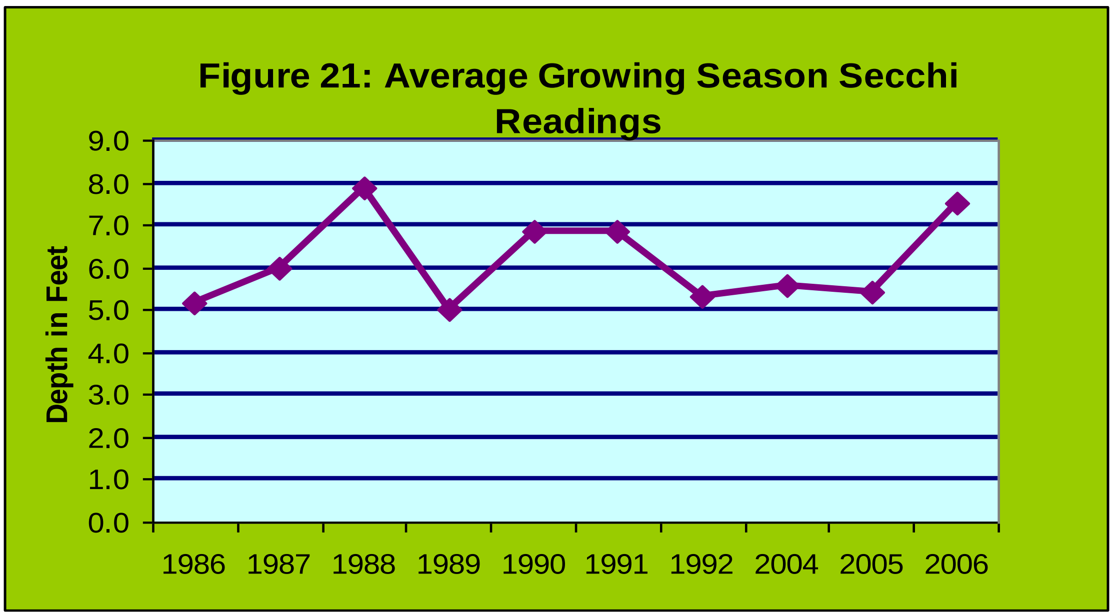


Figure 22: Photo of Testing Water Clarity with Secchi Disk

Chlorophyll a

Chlorophyll-a concentrations provide a measurement of the amount of algae in a lake's water. Algae are natural and essential in lakes, but high algal populations can increase water turbidity and reduce light available for plant growth, as well as result in unpleasing odor and appearance. Studies have shown that the amount of chlorophyll a in lake water depends greatly on the amount of algae present; therefore, chlorophyll-a levels are commonly used as a water quality indicator. The 2004-2006 growing season (June-September) average chlorophyll concentration in Arrowhead Lake was 9.55 micrograms/liter. Such an algae concentration places Arrowhead Lake at the "good" level for chlorophyll a results.

Figure 23: Chlorophyll a 1991-2006

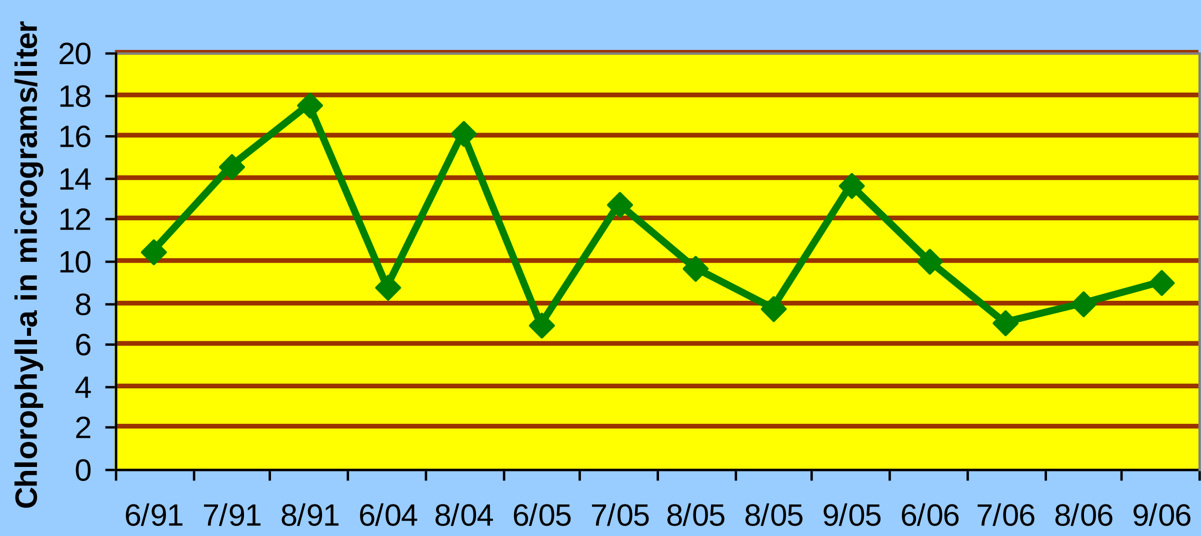
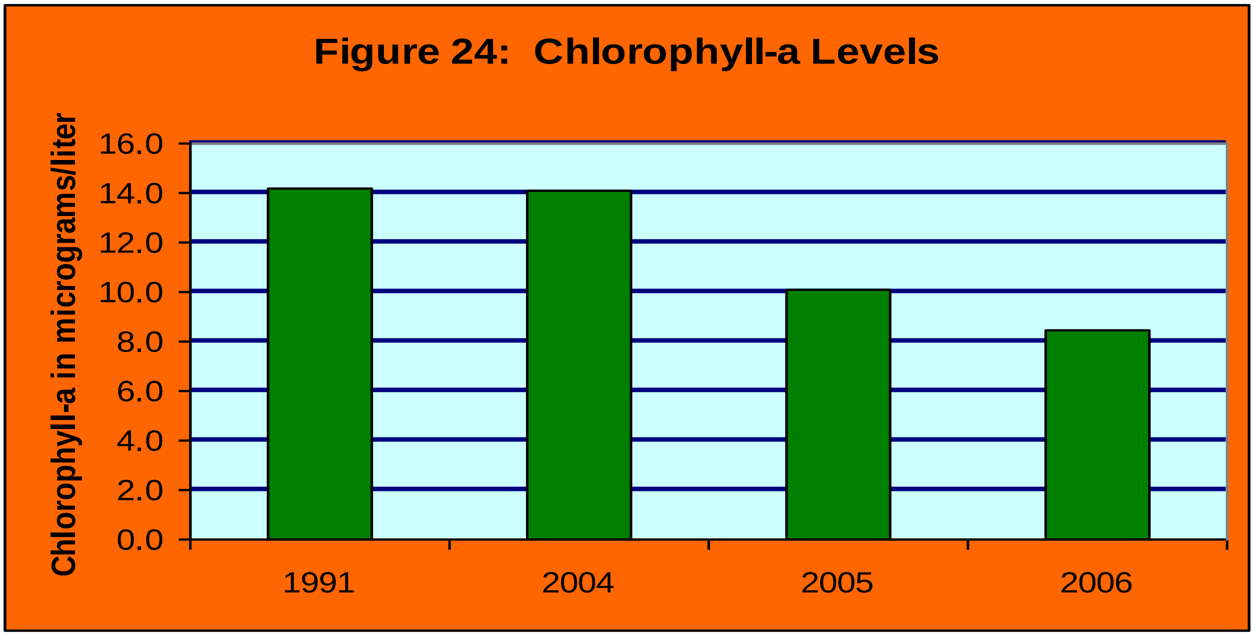


Figure 24 shows that summer chlorophyll-a averages have decreased somewhat from 1991 through through 2006, staying in the "good" category. It is possible that some of the reduced chlorophyll-a levels come from reduced algae due to the presence of zebra mussels. Continued monitoring of chlorophyll-a will need to occur to determine if these decreases are the result of zebra mussels or only a temporary decrease.



Dissolved Oxygen

Oxygen dissolved in the water is essential to all aerobic aquatic organisms. The oxygen in a lake comes from the atmosphere and from the process of photosynthesis. Aquatic plants and algae consume carbon dioxide and respirate oxygen back into the lake water. The distribution of oxygen within a lake is affected by many factors, including water circulation, water stratification, winds or storms, air temperature; water temperature, nutrient availability, and the density and location of algae and/or aquatic plants.

Prior studies of Arrowhead Lake have found anoxic (no oxygen) or hypoxic (low oxygen) in Arrowhead Lake near the dam (also the location of the deepest water in Arrowhead Lake). However, during the 2004-2006 study, no anoxia was found and hypoxia of just of 4.3 milligrams/liter occurred only in September 2004. Generally, dissolved oxygen levels didn't usually go below levels 5 milligrams/liter, the appropriate level for good fish survival. The charts (Figures 25) show the annual variations in dissolved oxygen levels in milligrams/liter, depth in feet and months of the years.

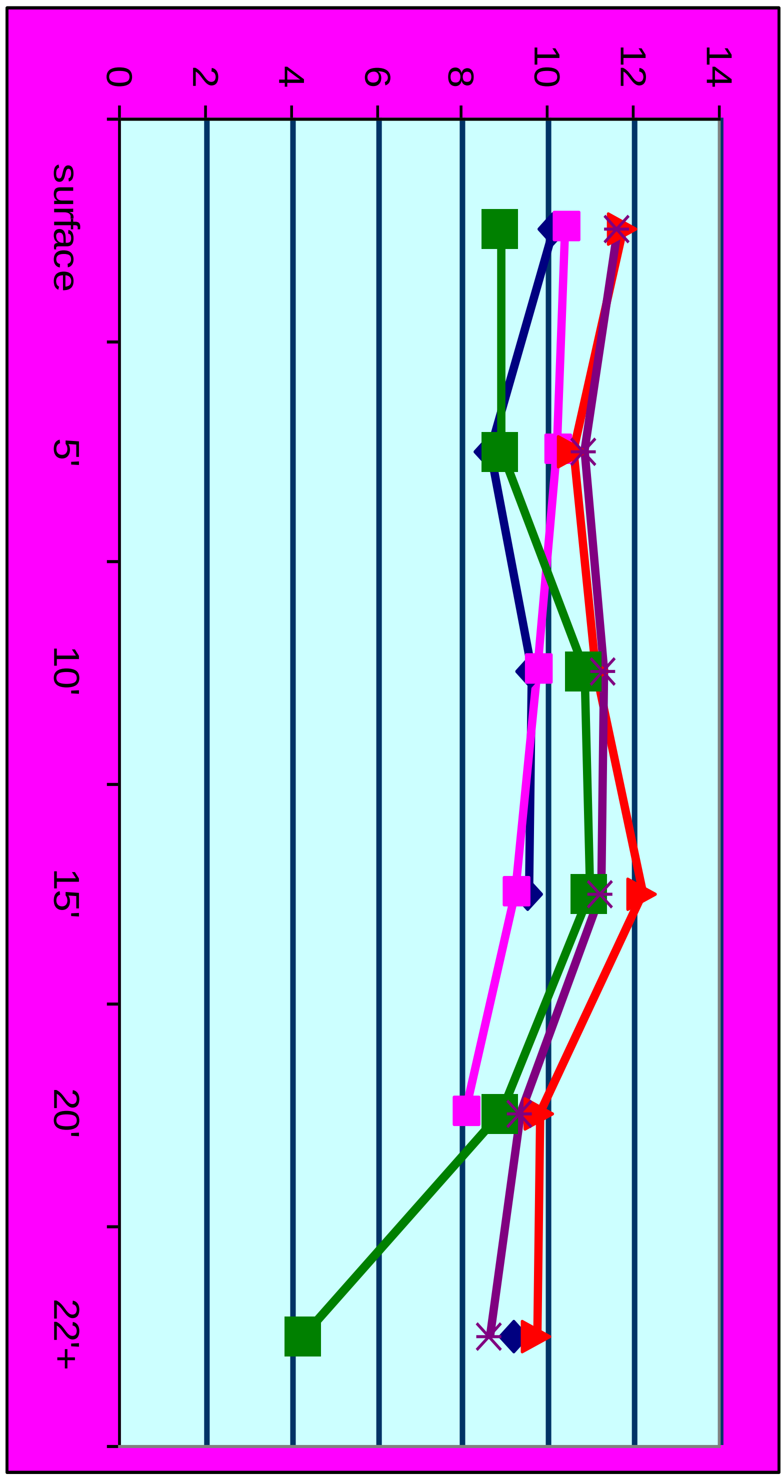
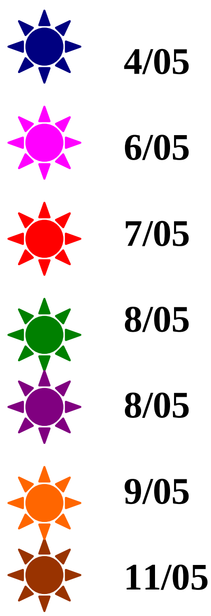
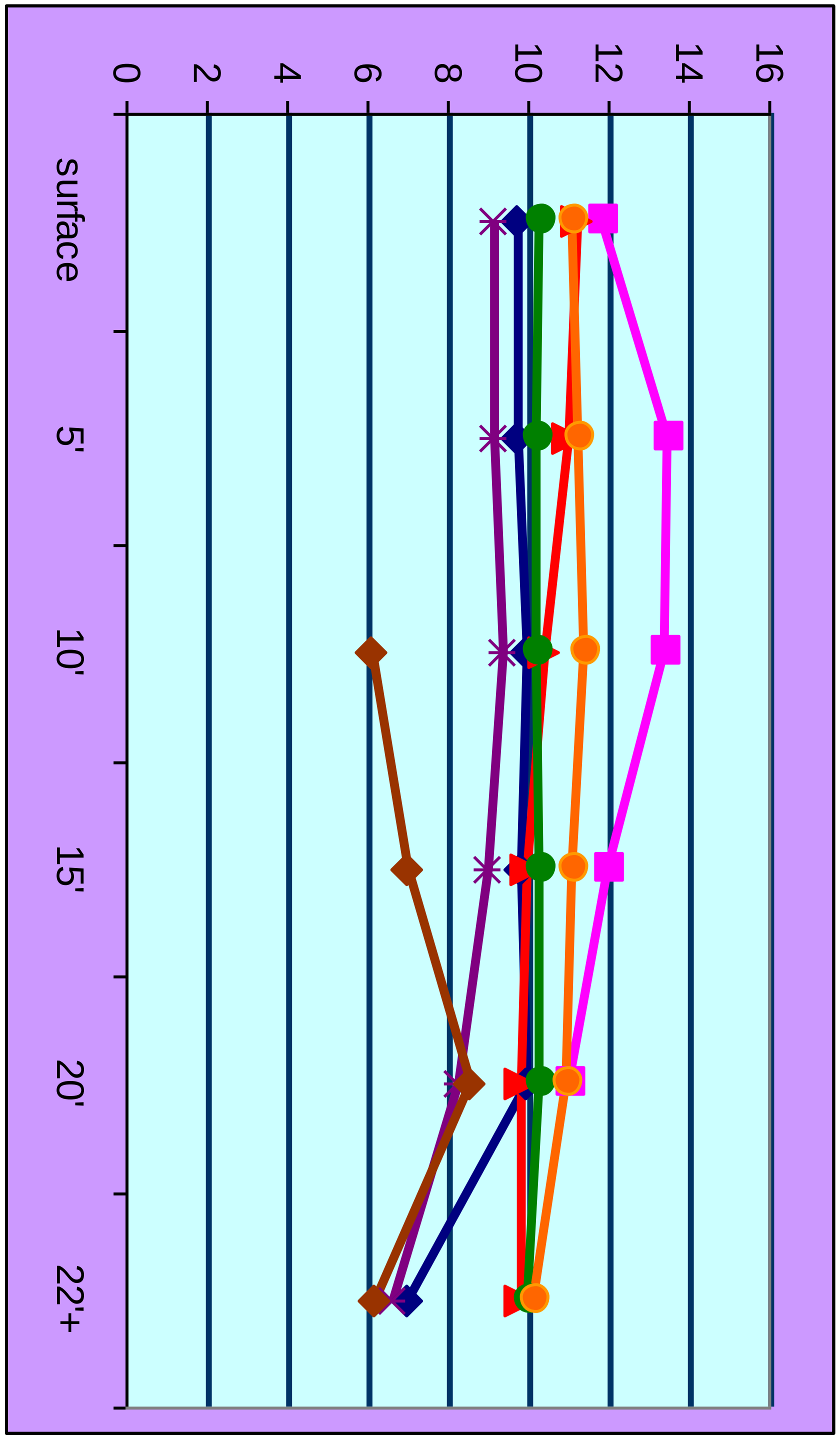


Figure 25a: Dissolved Oxygen Levels During 2004 Water Testing in milligrams/liter

Figure 25b: Dissolved Oxygen Levels During 2005 Water Testing in milligrams/liter





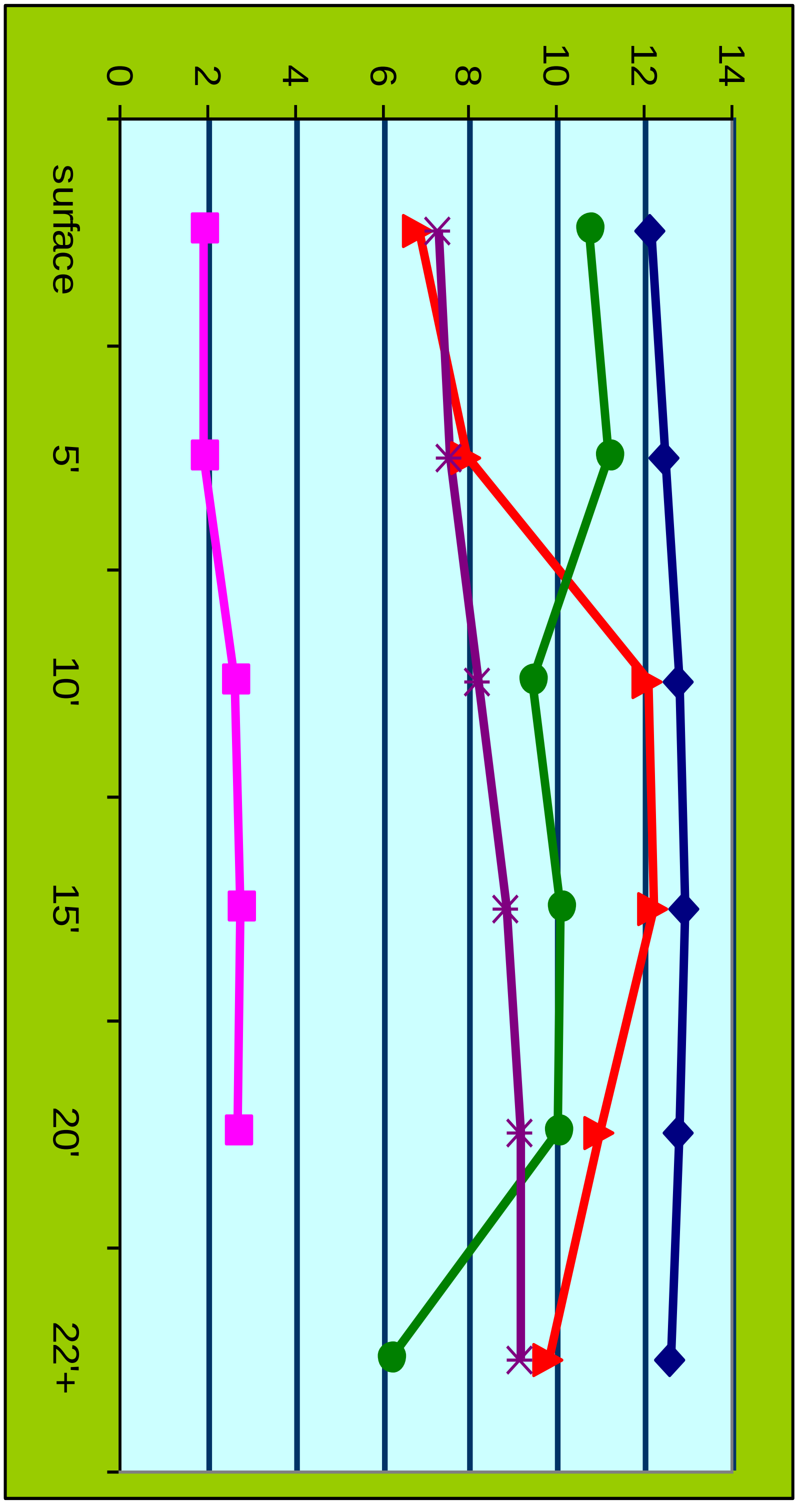


Figure 25c: Dissolved Oxygen Levels During 2006Water Testing in milligrams/liter

4/06

6/06

7/06

8/06

9/06

In deeper lakes, when the surface waters have cooled in autumn and water density throughout the water column is the same, the water column mixes vertically, a process known as “fall turnover.” Most of Arrowhead Lake is shallow and does not stratify. However, the east end of the lake, where depths exceed 27 feet deep, does stratify and turns over in the spring or fall.

Further, since flowing stream goes through the lake from east to west through Arrowhead Lake, some open water is common throughout the winter on part of the lake. This probably allows oxygen levels to stay elevated—even the winter, most of the dissolved oxygen readings over the amount needed by fish (over 5 milligrams/liter).

Figure 26a: One of the abundant fish in Arrowhead Lake—Bluegill (*Lepomis macrochirus)*

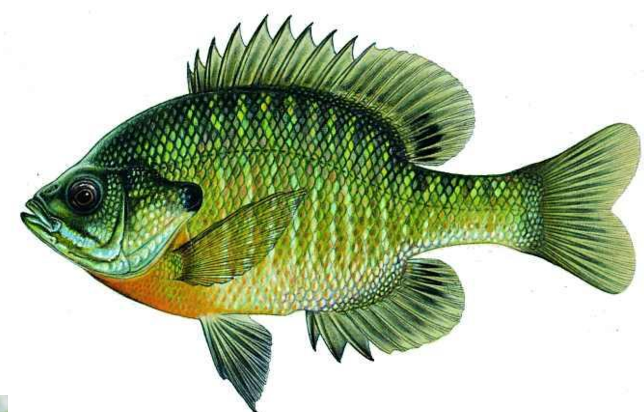


Figure 26b: One of the common Fish in Arrowhead Lake—Largemouth Bass (*Micropterus salmoides)*

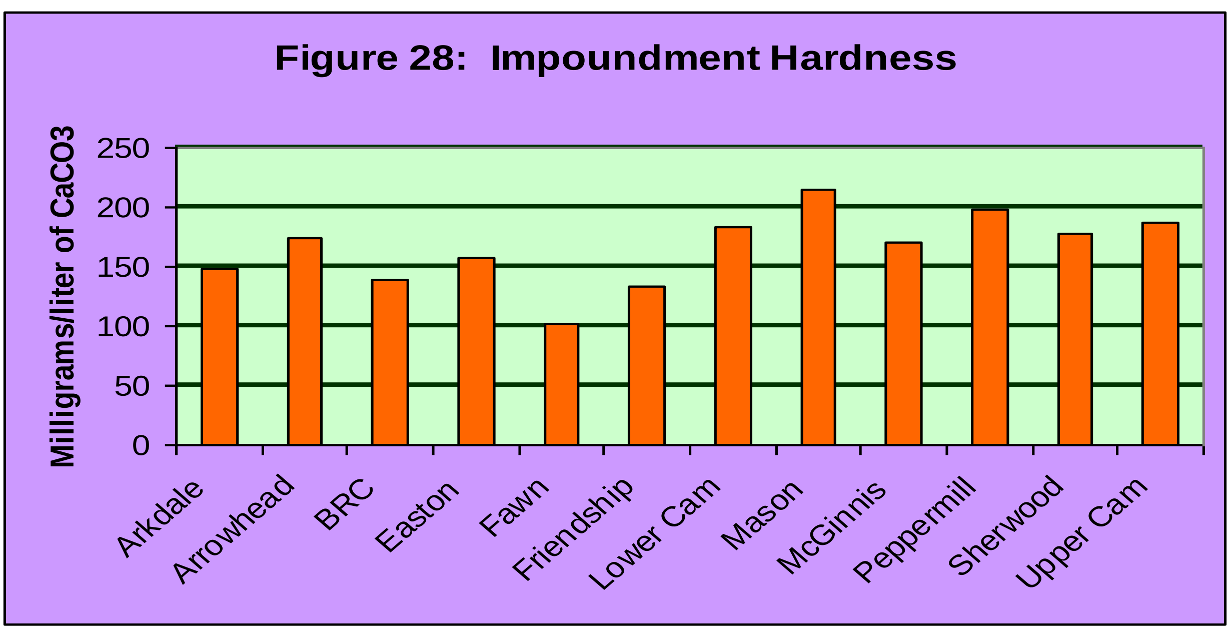
Water Hardness, Alkalinity and pH

Testing done by Adams County LWCD on Arrowhead Lake included annual testing for water alkalinity and water hardness. Hardness and alkalinity levels in a lake are affected by the soil minerals, bedrock type in the watershed, and frequency of contact between lake water & these materials.

Level of Hardness	Milligrams/liter CaCO3
SOFT	0-60
MODERATELY HARD	61-120
HARD	121-180
VERY HARD	>180

Figure 27: Hardness Table

One method of evaluating hardness is to test the water for the amount of calcium carbonate ($CaCO_3$) it contains. The surface water of all of the public access lakes in Adams County have water that is moderately hard to very hard, whether they are impoundments (man-made lakes) or natural lakes. In 2005 and 2006, random samples were also taken of wells around Arrowhead Lake to measure the hardness of the water coming into the lake through groundwater. Hardness in the groundwater ranged from 116 (moderately hard) to 204 (very hard), with an average of 152 milligrams/liter. Surface water hardness averaged 156.8 milligrams/liter, slightly higher than the groundwater hardness, but lower than the surface water hardness in the 1990s, which average 163.5 milligrams/liter. The hardness in both surface and groundwater is likely due to the underlying bedrock in Adams County, which is mostly sandstone with pockets of dolomite and shale.



As the graph (Figure 28) shows, Arrowhead Lake surface water testing results showed "hard" water (average 152 milligrams/liter CaCO3), slightly less than the overall hardness average impoundments in Adams County of 166 milligrams/liter of Calcium Carbonate. Hard water lakes tend to produce more fish and aquatic plants than soft water lakes because they are often located in watersheds with soils that load phosphorus into the lake water.

Alkalinity is important in a lake to buffer the effects of acidification from the atmosphere. "Acid rain" has long been a problem with lakes that had low alkalinity level and high potential sources of acid deposition.

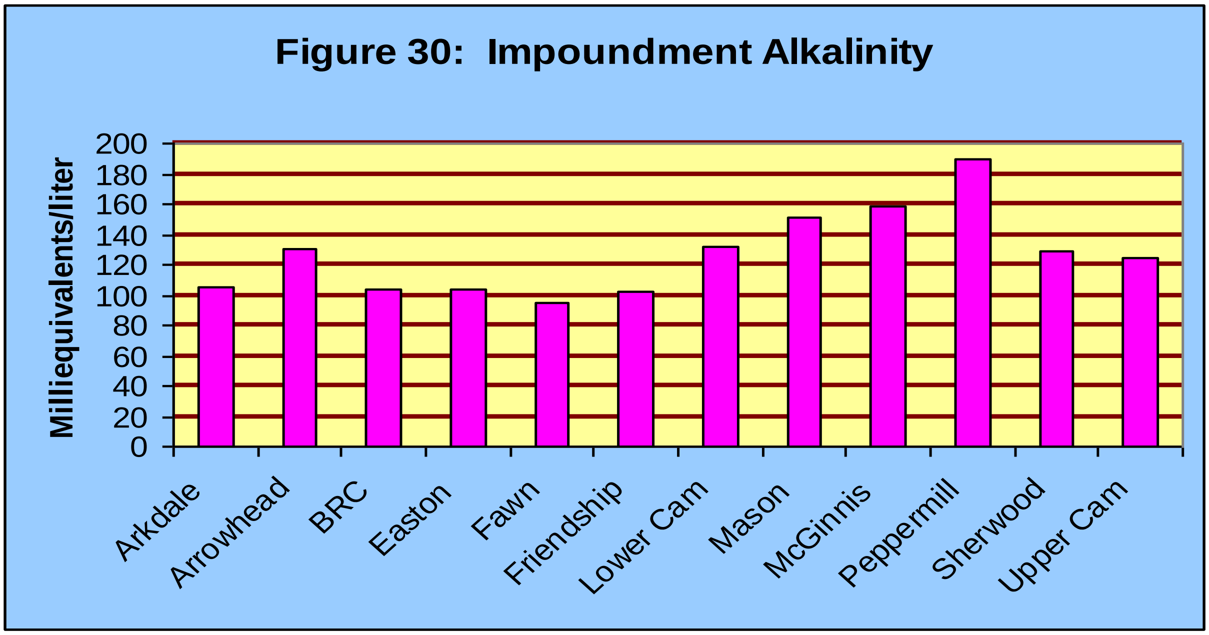
Acid Rain Sensitivity	ueq/l CaCO3
High	0-39
Moderate	49-199
Low	200-499
Not Sensitive	>500

Figure 29: Acid Rain Sensitivity

Well water alkalinity testing results average 152 milliequivalents/liter. This is higher than the surface water average of 130.7 milliequivalents/liter. Arrowhead Lake's potential sensitivity to acid rain is moderate, but luckily for Adams County, the acid deposition rate is very low, probably due to the little industrialization in the county.

Alkalinity also affects the pH level of lake water. The acidity level of a lake's water regulates the solubility of many minerals. A pH level of 7 is neutral. The pH level in Wisconsin lakes ranges from 4.5 in acid bog lakes to 8.4 in hard water, marl lakes.

Some of the minerals that become available under low pH, especially the metals aluminum, zinc and mercury, can inhibit fish reproduction and/or survival. Even what seems like a small variance in pH can have large effects because the pH scale is set up so that every 1.0 unit change increases acidity tenfold, i.e., water with a pH of 7 is 10 times more acid than water with pH of 8. Mercury and aluminum are not only toxic to many kinds of wildlife; they can also be toxic to humans, especially those that eat tainted fish.



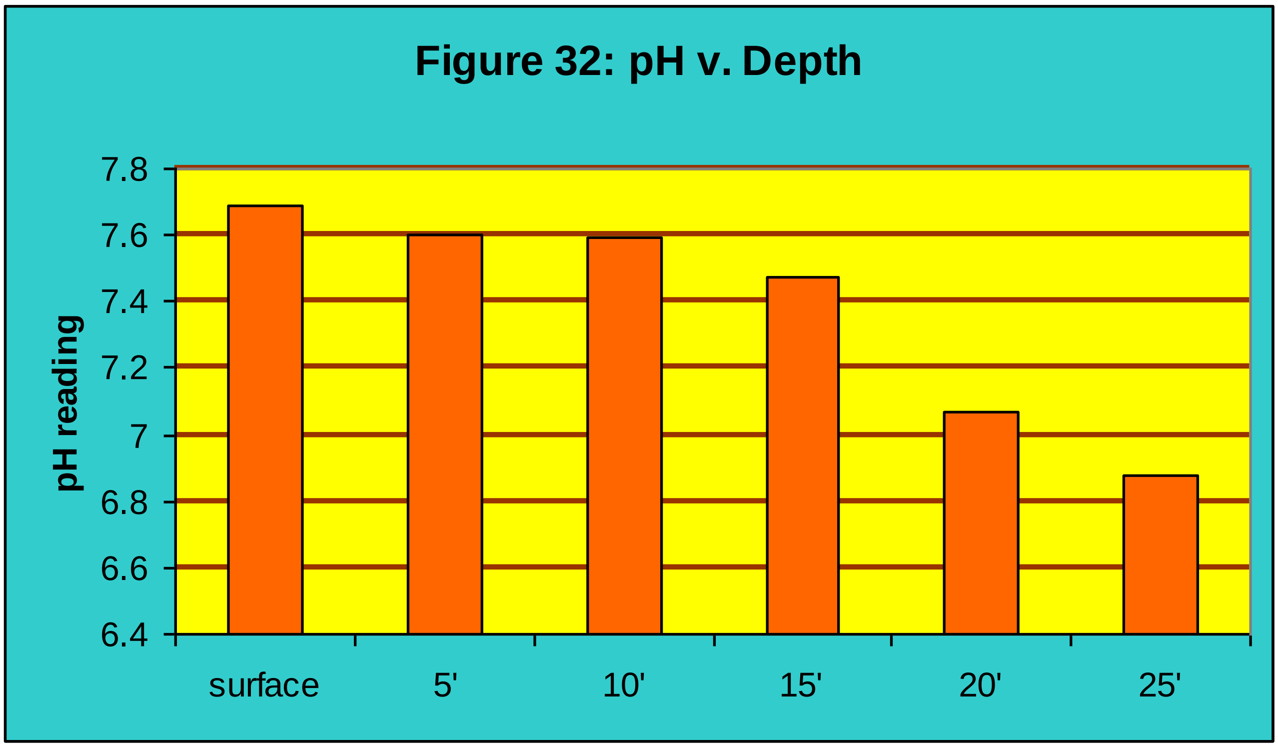
The testing occurring from 2004-2006 also included regular monitoring of the pH at several depths in Arrowhead Lake. As is common in the lakes in Adams County, Arrowhead Lake has pH levels starting at just under neutral (6.88) at over 22 feet depth and increasing in alkalinity as the depth gets less to 7.69 at the surface. A lake's pH level is important for the release of potentially harmful substances and also affects plant growth, fish reproduction and survival. Most plants grow best at pH levels between 5.5 and 8.

More importantly for many lakes, fish reproduction and survival are very sensitive to pH levels. The chart below indicates the effect of pH levels under 6.5 on fish (Figure 31):

Figure 31: Effects of pH Levels on Fish

Water pH	Effects
6.5	walleye spawning inhibited
5.8	lake trout spawning inhibited
5.5	smallmouth bass disappear
5.2	walleye & lake trout disappear
5	spawning inhibited in most fish
4.7	Northern pike, sucker, bullhead, pumpkinseed, sunfish & rock bass disappear
4.5	perch spawning inhibited
3.5	perch disappear
3	toxic to all fish

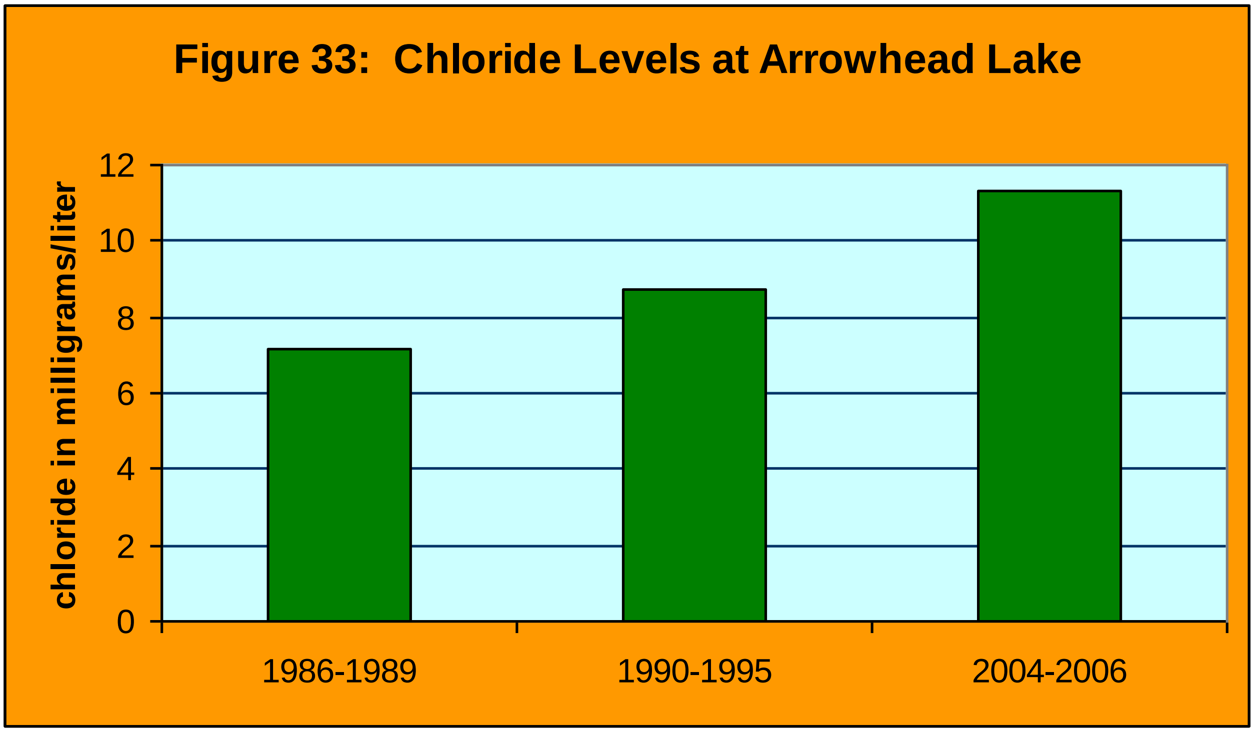
No pH levels taken in Arrowhead Lake between 2004-2006 fell below the pH level that inhibits walleye reproduction. A lake with a neutral or slightly alkaline pH like Arrowhead Lake is a good lake for fish and plant survival. Natural rainfall in Wisconsin averages a pH of 5.6. This means that if the rain falls on a lake without sufficient alkalinity to buffer that acid water coming in by rainfall, the lake's fish cannot reproduce. That is not a problem at Arrowhead Lake.



Other Water Quality Testing Results

CHLORIDE: Chloride does not affect plant and algae growth and is not known to be harmful to humans. It isn't common in most Wisconsin soils and rocks, so is usually found only in very low levels in Wisconsin lakes. However, the presence of a significant amount of chloride over a period of time indicates there may be negative human impacts on the water quality present from septic system failure, the presence of fertilizer and/or waste, deposition of road-salt, and other nutrients. An increased chloride level is thus an indication that too many nutrients are entering the lake, although the level has to be evaluated compared to the natural background data for chloride. The average chloride level found in Arrowhead Lake during the 2004-2006 testing period was 11.33 milligrams/liter, elevated substantially above the natural level of 3 milligrams/liter for chloride in this area of Wisconsin.

Prior studies also found elevated chloride levels in Arrowhead Lake. In fact, substantially elevated chloride levels have been found at Arrowhead Lake since records were kept (1985). Further investigation needs to be performed as to the causes of such continued chloride elevations.



NITROGEN: Nitrogen is necessary for plant and algae growth. A lake receives nitrogen in various forms, including nitrate, nitrite, organic, and ammonium. In Wisconsin, the amount of nitrogen in a lake's water often corresponds to the local land use. Although some nitrogen will enter a lake through rainfall from the atmosphere, that coming from land use tends to be in higher concentrations in larger amounts, coming from fertilizers, animal and human wastes, decomposing organic matter, and surface runoff. For example, the growth level of the exotic aquatic plant, Eurasian Watermilfoil (*Myriophyllum spicatum*) has been correlated with fertilization of lake sediment by nitrogen-rich spring runoff.

Nitrogen levels can affect other aspects of water quality. The sum of water testing results for nitrate, nitrite and ammonium levels of over .3 milligrams/liter in the spring can be used to project the likelihood of an algal bloom in the summer (assuming sufficient phosphorus is also present). Arrowhead Lake combination spring levels from 2004 to 2006 averaged .88 milligrams/liter, above the .3 milligrams/liter predictive level for nitrogen-related algal blooms. These elevations suggest that some of the algal blooms on Arrowhead Lake may be at least partly nitrogen-related.

CALCIUM and MAGNESIUM: Calcium is required by all higher plants and some microscopic lifeforms. Magnesium is needed by chlorophyllic plants and by algae, fungi and bacteria. Both calcium and magnesium are important contributors to the hardness of a lake's waters. Magnesium elevated about 125 milligrams/liter may have a laxative effect on some humans. Otherwise, no health hazards to humans and wildlife are known from calcium and magnesium. The average Calcium level in Arrowhead Lake's water during the testing period was 42.37 milligrams/liter (near the 41.96 milligrams/liter figure of 1986 to 1989). The average Magnesium level was 18.04 milligrams/liter. Both of these are low-level readings.

SODIUM AND POTASSIUM: These elements occur naturally only in low levels in Wisconsin waters and soils. Their presence may indicate human-caused pollution. Sodium is found with chloride in many road salts and fertilizers and is also found in human and animal waste. Potassium is found in many fertilizers and also found in animal waste. The level of these two is generally not useful as a specific pollution indicator, but increasing levels or one or both of these elements can indicate possible contamination from damaging pollutants. High levels of sodium have also been found to influence the development of a large population of cyanobacteria, some of which can be toxic to animals and humans. Some health professionals have suggested that sodium levels over 20 milligrams/liter may be harmful to heart and kidney patients if ingested. From 2004-2006, the average sodium level was 3.6 milligrams/liter. Prior sodium levels, taken in the mid-1980's, were slightly lower at 2.1 milligrams/liter. The sodium level average from 1985 to 2006 was 2.08 milligrams/liter. The average potassium reading from 2004 to 2006 was 2.22 milligrams/liter. This is slightly higher than the potassium levels from the mid-1980s, which averaged 1.36 milligrams/liter. However, both of these reading remain low on the overall scale of potential problems.

SULFATE: In low-oxygen waters (hypoxic), sulfate can combine with hydrogen and becomes the gas hydrogen sulfate, which smells like rotten eggs and is toxic to most aquatic organisms. Sulfate levels can also affect the metal ions in the lake, especially iron and mercury, by binding them up, thus removing them from the water column. To prevent the formation of hydrogen sulfate, levels of 10 milligrams/liter are best. A health advisory kicks in at 30 milligrams/liter. Arrowhead Lake sulfate levels averaged 27.44 milligrams/liter during the testing period, above the level for hydrogen sulfate formation, but still slightly below the health advisory level. The overall average for the years in which sulfate testing was done is 26.63, still below the health advisory level but considerably higher than the recommended 10 milligrams/liter.

TURBIDITY: Turbidity reflects water clarity. The term refers to suspended solids in the water column—solids that may include clay, silt, sand, plankton, waste, sewage and other pollutants. Turbid water may mask the presence of bacteria or other pollutants because the water looks murky or muddy. In general, turbidity readings of less than 5 NTU are best. Very turbid waters may not only smell, but also tend to be aesthetically displeasing, thus curtailing recreational uses of the water. Turbidity levels for Arrowhead Lake's waters were all below the 5 NTU level: 3.35 NTU for 2004; 3.71 NTU for 2005; and 4.74 NTU for 2006.

Figure 34: Examples of Very Turbid Water

HYDROLOGIC BUDGET

According to a recently-completed bathymetric (depth) map, Arrowhead Lake has 298.7 surface acres, and the volume of the lake is 3235.9 acre-feet. At that time, 9.5% of the lake was less than 3 feet deep and5.2% was over 20 feet deep. The maximum depth was 25.2 feet.

A "hydrologic budget" is an accounting of the inflow to, outflow from and storage in a hydrological unit (such as a lake). "Residence time" is the average length of time particular water stays within a lake before leaving it. This can range from several days to years, depending on the type of lake, amount of rainfall, and other factors. "Flushing rate" is the time it takes a lake's volume to be replaced. "Annual runoff volume", as used in WiLMS, is the total water yield from the drainage area reaching the lake. The "drainage area" is the amount of area (in acres) contributing surface water runoff and nutrients to the lake. The "areal water load" is the total annual flow volume reaching the lake divided by the surface area of the lake. "Hydraulic loading" is the total annual volume of all water sources (including precipitation, non-point sources & point sources) loading into the lake.

Using the data gathered from historical testing and that done by the Adams County LWCD from 2004-2006, the WiLMS model calculated the tributary drainage area for Arrowhead Lake as 8749 acres. The average unit runoff for Adams County in the Arrowhead Lake area is 9.4 inches. WiLMS determined the expected annual runoff volume as 6853.4 acre-feet/year. Anticipated annual hydraulic loading is 7512.9 acre-feet/year. Areal water load is 21.5 feet/year. In an impoundment lake like Arrowhead Lake, a significant portion of the water and its nutrient load running through it from the impounded creek tend to flush through the lake and continue downstream—in Arrowhead Lake's case, modeling estimates a water residence of 0.46 year. The calculated lake flushing rate is 1.89 1/year. Water and its load flow through Arrowhead Lake fairly quickly.

Figure 35: Example of Hydrologic Budget

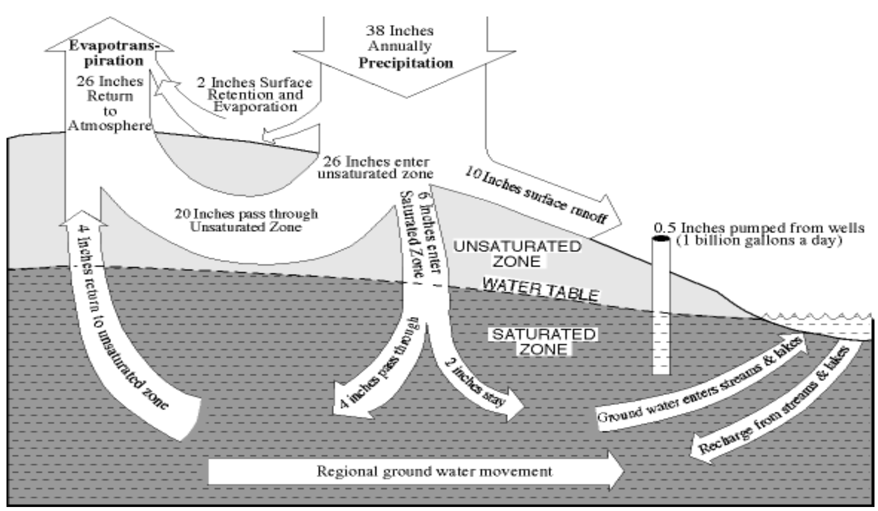
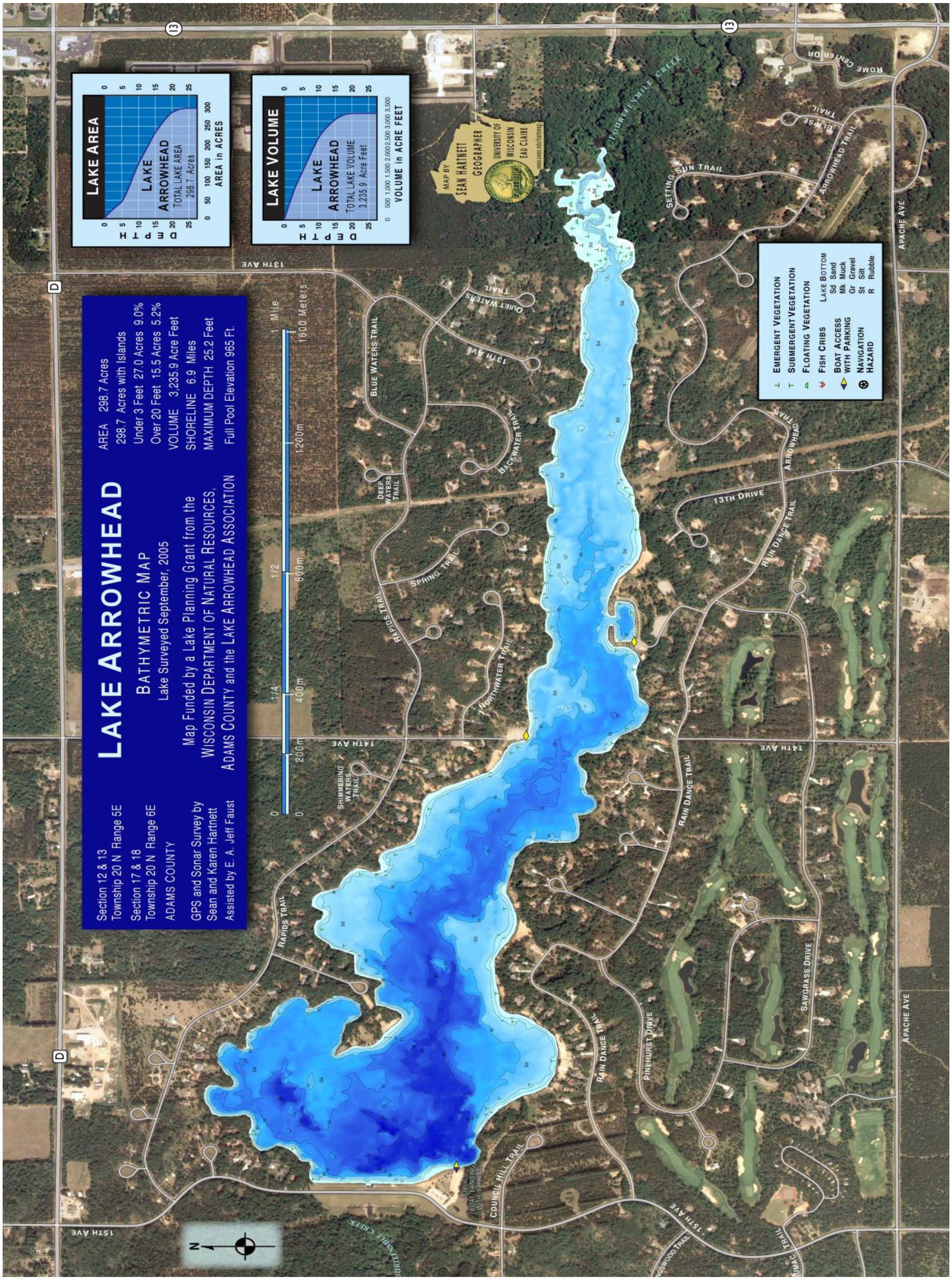


Figure 36: Arrowhead Lake Bathymetric Map



TROPHIC STATE

The trophic state of a lake is one measure of water quality, basically defining the lake's biological production status (see Figure 37). **Eutrophic lakes** are very productive, with high nutrient levels, frequent algal blooms and/or abundant aquatic plant growth. **Oligotrophic lakes** are those low in nutrients with limited plant growth and small populations of fish. **Mesotrophic lakes** are those in between, i.e., those which have increased production over oligotrophic lakes, but less than eutrophic lakes; those with more biomass than oligotrophic lakes, but less than eutrophic lakes; often with a more varied fishery than either the eutrophic or oligotrophic lakes. In comparing water quality testing results with the prediction from the computer modeling of this modeling with the actual figures outlined above, the actual Trophic State of Arrowhead Lake is what was predicted from the modeling. Modeling results predicted that the overall TSI for Arrowhead Lake would be **50**. This score places Arrowhead Lake's overall TSI at above average for impoundment lakes in Adams County (52.83). In the instance of the TSI, the lower the score, the better the water quality is likely to be. Thus, the surface water quality of Arrowhead Lake is slightly better than the average surface water quality for impoundments in Adams County.

Figure 37: Trophic Status Table

Score	TSI Level Description
30-40	**Oligotrophic:** clear, deep water; possible oxygen depletion in lower depths; few aquatic plants or algal blooms; low in nutrients; large game fish usual fishery
40-50	**Mesotrophic:** moderately clear water; mixed fishery, esp. panfish; moderate aquatic plant growth and occasional algal blooms; may have low oxygen levels near bottom in summer
50-60	**Mildly Eutrophic:** decreased water clarity; anoxic near bottom; may have heavy algal bloom and plant growth; high in nutrients; shallow eutrophic lakes may have winterkill of fish; rough fish common
60-70	**Eutrophic:** dominated by blue-green algae; algae scums common; prolific aquatic plant growth; high nutrient levels; rough fish common; susceptible to oxygen depletion and winter fishkill
70-80	**Hypereutrophic:** heavy algal blooms through most of summer; dense aquatic plant growth; poor water clarity; high nutrient levels

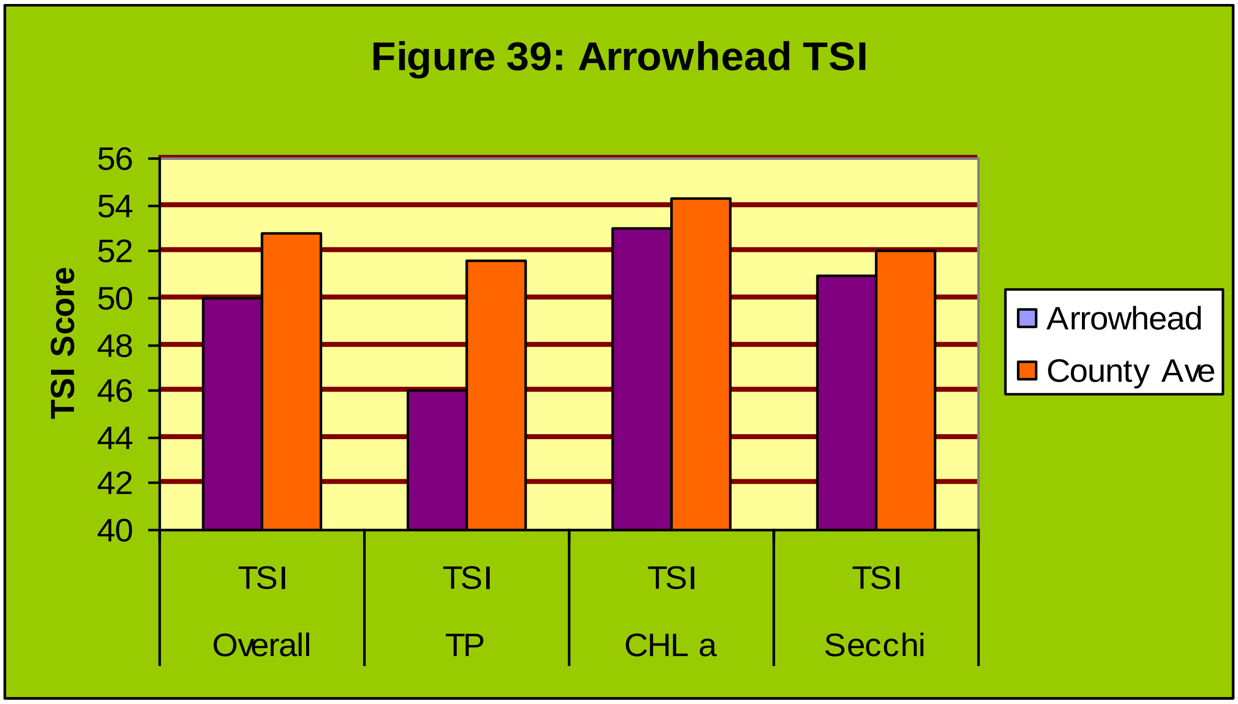
Arrowhead Lake = 50

Phosphorus concentration, chlorophyll-a concentration and water clarity data are collected and combined to determine a trophic state. As discussed earlier, the average growing season epilimnetic total phosphorus for Arrowhead Lake was 18.62 micrograms/liter. The average growing season chlorophyll-a concentration was 9.55 micrograms/liter. Growing season water clarity averaged a depth of 5.99 feet. Figure 39 shows where each of these measurements from Arrowhead Lake falls in trophic level.

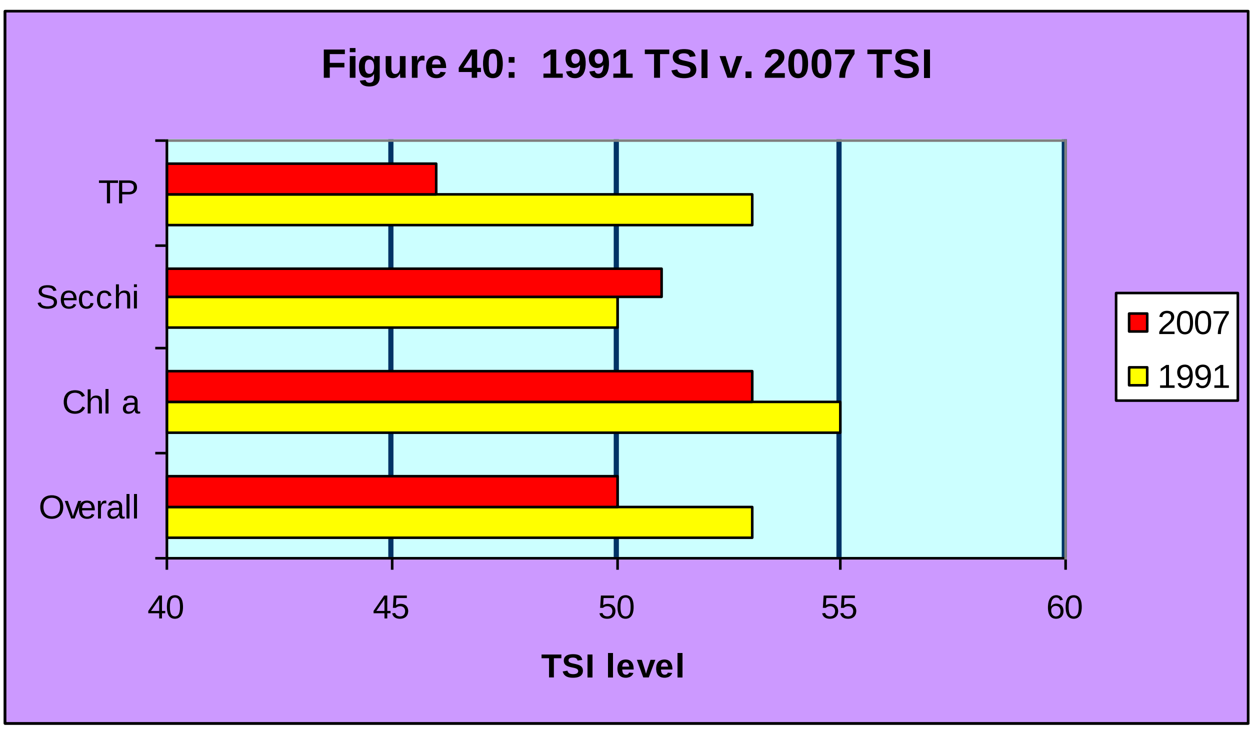
Figure 38: Arrowhead Lake Trophic Status Overview

Trophic State	**Quality Index**	**Phosphorus**	**Chlorophyll a**	**Sechhi Disk**
		(ug/l)	**(ug/l)**	**(ft)**
Oligotrophic	Excellent	<1	<1	>19
	Very Good	1 to 10	1 to 5	8 to 19
Mesotrophic	Good	**10 to 30**	**5 to 10**	6 to 8
	Fair	30 to 50	10 to 15	**5 to 6**
Eutrophic	Poor	50 to 150	15 to 30	3 to 4
Arrowhead Lake		**18.62**	**9.55**	**5.99**

These figures show that Arrowhead Lake has fair to good levels overall for the three parameters often used to describe water quality: Secchi disk depths; average TP for the growing season; and chlorophyll a levels. It is normal for all of these values to fluctuate during a growing season. However, they can be affected by human use of the lake, by summer temperature variations, by algae growth & turbidity, and by rain or wind events.



During the 1991 study, water chemistry samples were taken and TSI levels were calculated. Figure 40, which compares the current TSI levels to those from 1991, shows that all the parameters for TSI calculations have decreased, indicating that the lake nutrient levels have decreased.



IN-LAKE HABITAT

Aquatic Plants

A healthy aquatic plant community plays a vital role within the lake community. This is due to the role plants play in improving water quality, providing valuable habitat resources for fish and wildlife, resisting invasions of non-native species and checking excessive growth of the most tolerant species.

An aquatic plant survey was performed in 2006 by staff from the Adams County Land & Water Conservation Department and a Tri-Lakes property owner. The Simpson's Diversity Index in 2006 for Arrowhead Lake was .91, showing good species diversity. This was up slightly from the 2000 index of .89. A rating of 1.0 would mean that each plant in the lake was a different species (the most diversity achievable). This places it in the upper quartile for Simpson's Diversity Index readings for both North Central Hardwood Forest and all Wisconsin lakes. The AMCI for Arrowhead Lake is 56, placing it in the average range for North Central Wisconsin Lakes and all Wisconsin Lakes. The AMCI in 2000 was also 56. In 2000, there were fewer species and fewer sensitive plants, but more submergent plants.

Native herbaceous vegetation was the shoreline cover with highest percent of frequency (56.67%), but wooded vegetation had the highest coverage amount (30.00%), although cultivated lawn was close behind with 29% coverage. Some type of native vegetated shoreline covered 48.00% of the lake shoreline. But disturbed sites, such as those with traditional lawn, rock/riprap, hard structures and pavement, were also frequent, covering over 40.34% of the shoreline. Bare unprotected or eroded soil was found (11.66% coverage). Overall, 52.00% of Arrowhead Lake's shore has some kind of disturbed situation. These conditions offer little protection for water quality and have significant potential to negatively impact Arrowhead Lake's water by increased runoff (including lawn fertilizers, pet waste, pesticides) and shore erosion.

Of the 28 species found in Arrowhead Lake, 25 were native and 3 were exotic invasives. In the native plant category, 9 were emergent, 3 were free-floating plants, and 13 were submergent species. Three exotic invasives, *Myriophyllum spicatum* (Eurasian Watermilfoil), *Phalaris arundinacea* (Reed Canarygrass) and *Potamogeton crispus* (Curly-Leaf Pondweed) were found. Filamentous algae were found at 22.88% of the sample sites in 2006 and found at 15.6% of the sites in 2000.

Potamogeton pectinatus was the most frequently-occurring plant in Arrowhead Lake in 2006 (58.46% frequency). No other species reached a frequency of 50% or greater. Next closest in frequency of occurrence were *Chara* spp (40.00%), *Potamogeton* *zosteriformis* (38.46%), and *Najas flexilis* (36.92%). In 2000, no species reached a frequency of 50% of greater in the lake overall, although *Chara* spp had an overall occurrence frequency of 44.95%.

Potamogeton pectinatus was also the densest plant in Arrowhead Lake, with a mean density of 1.43 (on a scale of 1 to 4). In the lake overall, none of the aquatic vegetation had a mean density of over 2.0, meaning none occurred at more than average. There were no species at more than average density in any of the depth zones either.

However, when looking at the mean density where present, several plants had a more than average density of occurrence: *Ceratophyllum demersum; Chara* spp*; Elodea canadensis; Lemna minor; Najas flexilis; Onoclea sensibilis; Potamogeton pectinatus; Potamogeten zosteriformis; Ranunculus longirostris; Spirodela polyrhiza; Vallisneria americana; Wolffia columbiana;* and *Zosterella dubia.* 2 of these plants are emergent; 3 are free-floating; and 8 are submergent plants. These figures indicate several species in the lake have higher than average growth form density that can interfere with fish habitat and recreational use.

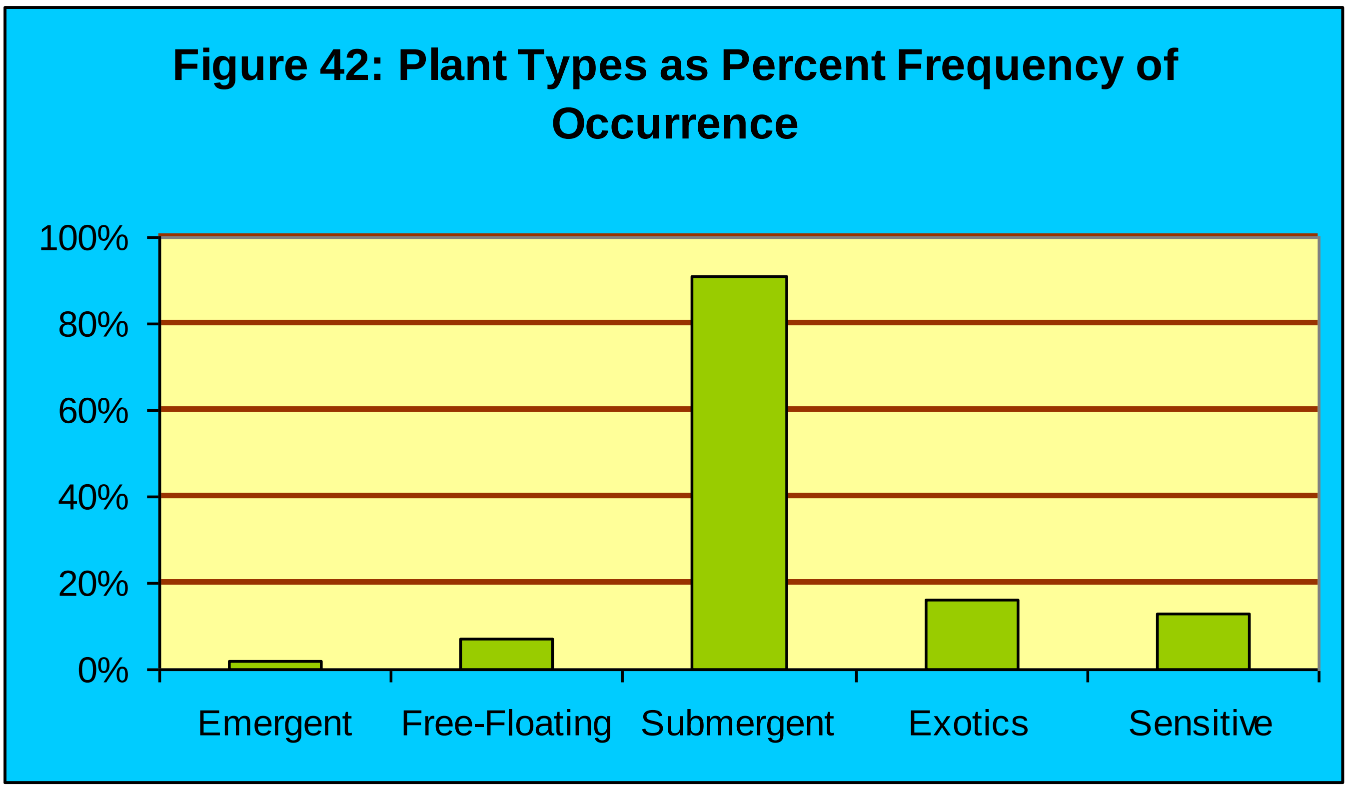
The 2000 figures show, as did the 2006 figures, that many of the plants have more than average density at the sites at which they occur. In other words, where aquatic plants are present, they often occur at higher than desired densities. In 2000, those included *Ceratophyllum demersum*, *Chara* spp, *Elodea canadensis*, *Lemna minor*, *Phalaris arundinacea*, *Potamogeton foliosus*, *Potamogeton pectinatus*, *Ranunculus longirostris*, *Spirodela polyrhiza*, *Vallisneria americana* and *Wolffia columbiana.* There were two more species at higher than average density where present in 2006 than in 2000. Many of the same species—*Ceratophyllum demersum, Chara* spp.*, Elodea canadensis, Lemna minor, Potamoeton pectinatus, Spirodela polyrhiza, Vallisneria americana,* and *Wolffia columbiana*—occurred at high densities where present in both years.

Based on dominance value, *Potamogeton pectinatus* was the dominant aquatic “plant” species in Arrowhead Lake. Sub-dominant were *Najas flexilis* and *Chara* spp,.and *Potamogeton zosteriformis.* *Myriophyllum spicatum*, *Phalaris arundinacea* and *Potamogeton crispus*, the exotics found Arrowhead Lake, were not present in high frequency, high density or high dominance.

Figure 41. Arrowhead Lake Aquatic Plant Species, 2006

Scientific Name	Common Name	Type	Found in 2000
Ceratophyllum demersum	Coontail	Submergent	x
Chara spp	Muskgrass	Submergent	x
Decodon vertticillatus	Swamp Loosestrife	Emergent	
Eleocharis acicularis	Needle Spikerush	Emergent	
Elodea canadensis	Waterweed	Submergent	x
Iris versicolor	Blue-Flag Iris	Emergent	
Lemna minor	Lesser Duckweed	Free-Floating	x
Myriophyllum sibiricum	Northern Milfoil	Submergent	x
Myriophyllum spicatum	Eurasian Watermilfoil	Submergent	x
Najas flexilis	Bushy Pondweed	Submergent	x
Onoclea sensibilis	Sensitive Fern	Emergent	
Phalaris arundinacea	Reed Canarygrass	Emergent	x
Potamogeton crispus	Curly-Leaf Pondweed	Submergent	x
Potamogeton foliosus	Leafy Pondweed	Submergent	x
Potamogeton illinoensis	Illinois Pondweed	Submergent	
Potamogeton nodusus	Long-Leaf Pondweed	Submergent	
Potamogeton pectinatus	Sage Pondweed	Submergent	x
Potamogeton pusillus	Small Pondweed	Submergent	x
Potamogeton zosteriformis	Flat-Stem Pondweed	Submergent	x
Ranunculus longirostris	Water Buttercup	Emergent	x
Sagittaria spp	Arrowhead	Emergent	
Salix spp	Willow	Emergent	x
Scirpus validus	Soft-Stem Bulrush	Emergent	
Spirodela polyrhiza	Greater Duckweed	Free-Floating	x
Typha angustifolia	Narrow-Leaf Cattail	Emergent	x
Vallisneria americana	Water Celery	Submergent	x
Wolffia columbiana	Watermeal	Free-Floating	x
Zosterella dubia	Water Stargrass	Submergent	x

Aquatic plants occurred at 90.8% of the sample sites in Arrowhead Lake to a maximum rooting depth of 16 feet in 2006. In 2000, aquatic plant occurred at 80.7% of the sample sites, with a maximum rooting depth of 15 feet. Free-floating plants were found in three depth zones in 2006; they were found only in the shallowest zone in 2000. Filamentous algae were found in all sampling zones in both years.



Both total occurrence and total density were substantially increased in 2006, compared to 2000. Similarly, species richness increased in 2006 compared to 2000. In each year, the 1.5 feet-5 feet depth zone (Zone 2) had the highest species richness, and the 10 feet-20 feet depth zone (Zone 4) had the lowest. In 2006, the shallowest depth zone had the next to highest species richness, with the 5 feet-10 feet depth zone having the next to lowest. Those were reversed in 2000.

	2006	2000
Zone 1	4	1.97
Zone 2	4.53	3.27
Zone 3	3.47	2.86
Zone 4	2.76	0.9
Overall	3.76	2.88

Figure 43: Species Richness— 2000 and 2006

Previously, a value was assigned to all plants known in Wisconsin to categorize their probability of occurring in an undisturbed habitat. This value is called the plant's Coefficient of Conservatism. A score of 0 indicates a native or alien opportunistic invasive plant. Plants with a value of 1 to 3 are widespread native plants. Values of 4 to 6 describe native plants found most commonly in early successional ecosystem. Plants scoring 6 to 8 are native plants found in stable climax conditions. Finally, plants with a value of 9 or 10 are native plants found in areas of high quality and are often endangered or threatened. In other words, the lower the numerical value a plant has, the more likely it is to be found in disturbed areas.

The Average Coefficient of Conservatism in Arrowhead Lake in 2006 was 4.58, similar to the 4.5 result from 2000. This puts Arrowhead Lake in the lowest quartile for Wisconsin Lakes (6.0) and for lakes in the North Central Hardwood Region (5.6). The aquatic plant community in Arrowhead Lake is in the category of those very tolerant of disturbance, probably due to selection by a series of past disturbances.

The Floristic Quality Index of the aquatic plant community in Arrowhead Lake of 23.34 is slightly above average for Wisconsin Lakes (22.2) and the North Central Hardwood Region (20.9). In 2000, it was 19.09, slightly below average, so the FQI has increased slightly since 2000. This suggests that the plant community in Arrowhead Lake is a little closer to an undisturbed condition than the average lake in Wisconsin overall and in the North Central Hardwood Region. Using either scale, the aquatic plant community in Arrowhead Lake has been impacted by at least an average amount of disturbance.

The Aquatic Macrophyte Community Index (AMCI) in 2006 for Arrowhead Lake is 56, placing it in the average range for North Central Wisconsin Lakes and all Wisconsin Lakes. The AMCI in 2000 was also 56. In 2000, there were fewer species and fewer sensitive plants, but more submergent plants.

Figure 44: Aquatic Macrophyte Community Index Comparisons

Aquatic Macrophyte Community Index			-	-
	2006	2006	2000	2000
	results	value	results	value
rooting depth	16'	9	15'	9
% littoral zone vegetated	90.80%	10	80.70%	10
% submersed plants	62%	6	73%	9
% sensitive plants	17%	7	12%	6
# taxa found	26	10	22	9
% exotic species	10%	5	9%	5
Simpson's Index	0.91	9	0.89	8
		56		56

The AMCI for both 2000 and 2006 is 56, but the Average Coefficient of Conservatism is lower than it was in 1979. Species Richness and the Floristic Quality Index went up between 2002 and 2006, as did the Simpson's Index of Diversity. But the Floristic Quality Index in 1979 was between the 2000 and 2006 scores. It appears, even using the limited information from 1979 and 1992, that increase in these figures may not necessarily indicate an ongoing increase in the quality of the aquatic plant community.

Further, when calculating the coefficient of similarity between the 2000 and 2006 surveys, they score as statistically dissimilar. Based on frequency of occurrence, the aquatic plant communities of the two years are only 53% similar. Based on relative frequency, they are 57% similar. Similarity percentages of 75% or more are considered statistically similar; obviously, Arrowhead Lake percentages are far from that.

Figure 45: Changes in the Aquatic Plant Community 2000 to 2006

	Changes in the Macrophyte Community			
Arrowhead	2000	2006	Change	%Change
Number of Species	18	26	8.00	**44.4%**
Maximum Rooting Depth	15.0	16.0	1.00	**6.7%**
% of Littoral Zone Unvegetated	19.30%	9.20%	-10.10	-52.33%
%Sites/Emergents	6.82%	5.93%	-0.01	-13.0%
%Sites/Free-floating	6.82%	11.86%	0.05	**73.9%**
%Sites/Submergents	100.00%	100.00%	0.00	0.0%
%Sites/Floating-leaf	0.00%	0.00%	0.00	
Simpson's Diversity Index	0.89	0.91	0.02	**2.2%**
Species Richness	2.88	3.86	0.98	**34.0%**
Floristic Quality	19.09	23.34	4.25	**22.3%**
Average Coefficient of Conservatism	4.5	4.58	0.08	**1.8%**
AMCI Index	56	56	0.00	**0.0%**

It is worth noting that the report on the 2000 aquatic plant surveys mentioned the absence of emergent plants in Arrowhead Lake. The 2006 survey shows that emergent plants seem to be "coming back", i.e., are re-establishing in Arrowhead Lake. However, the occurrence of filamentous algae has also increased since 2000, as had the total occurrence and total density of aquatic plant growth in all depth zones. Further, the increase in free-floating plants may be due to increased nutrient loading.

The chart below outlines the changes in specific plant species between 2000 and 2006. Plants such as *Ceratophyllum demersum* and *Potamogeton pectinatus* are among those most tolerant of disturbances and poor water clarity. The increase in those plants may be indicative of ongoing disturbance in the lake overall. There was 5% increase in the occurrence of sensitive species. Exotic species stayed about the same occurrence frequency overall (9% in 2000 vs. 10% in 2006). Arrowhead Lake did increase in emergent species, although that tended to be localized, but continues to be low in floating-leaf plants that provide habitat for fish and invertebrates.

The following aquatic species decreased between 2000 and 2006: *Carex* spp.; *Chara* spp*; Elodea canadensis; Potamogeton foliosus; Potamogeton pusillus; Typha latifolia; Zosterella dubia.* Two of these species are emergent plants; one is a macrophytic algae; the others are submergent aquatic plants. Other species increased: *Ceratophyllum demersum; Decodon verticillatus; Iris versicolor; Lemna minor; Myriophyllum sibiricum; Myriophyllum spicatum* (an invasive); *Najas flexilis; Onoclea sensibilis;; Phalaris arundinacea* (an invasive); *Potamogeton crispus* (an invasive); *Potamogeton nodosus*; *Potamogeton pectinatus; Potamogeton zosteriformis; Ranunclus longirostris; Sagittaria* spp; Spirodela *polyrhiza; Vallisneria americana; Wolffia Columbiana.* Five of these species are emergent aquatic plants; the rest are submergent plants.

Figure 46a: Emergent Plant Distribution in 2006

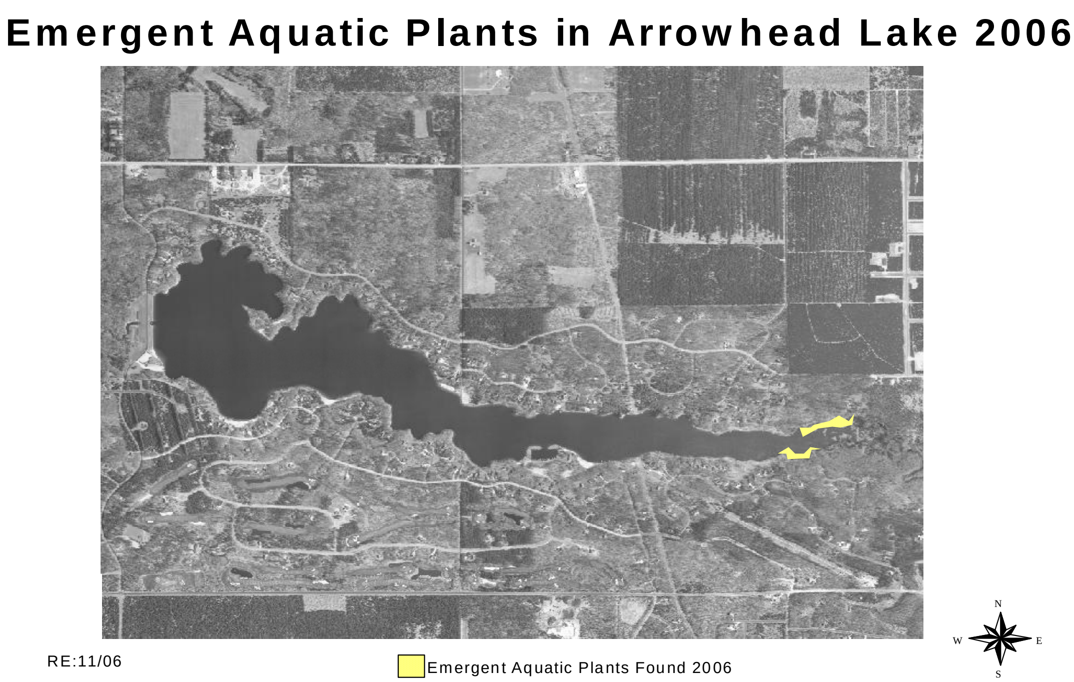


Figure 46b: Free-Floating Plant Distribution in 2006

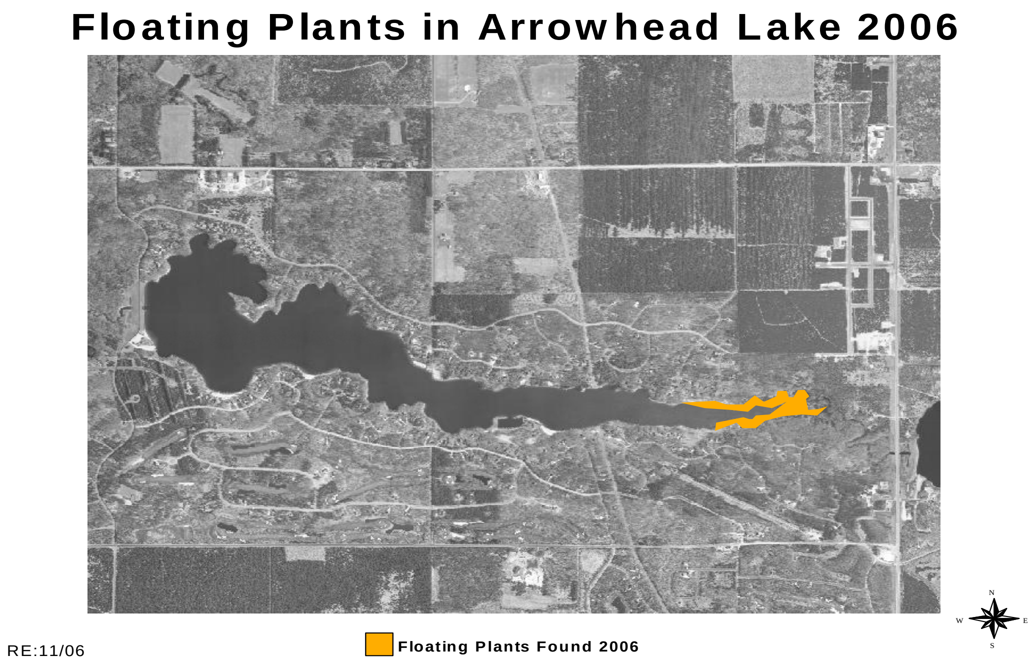
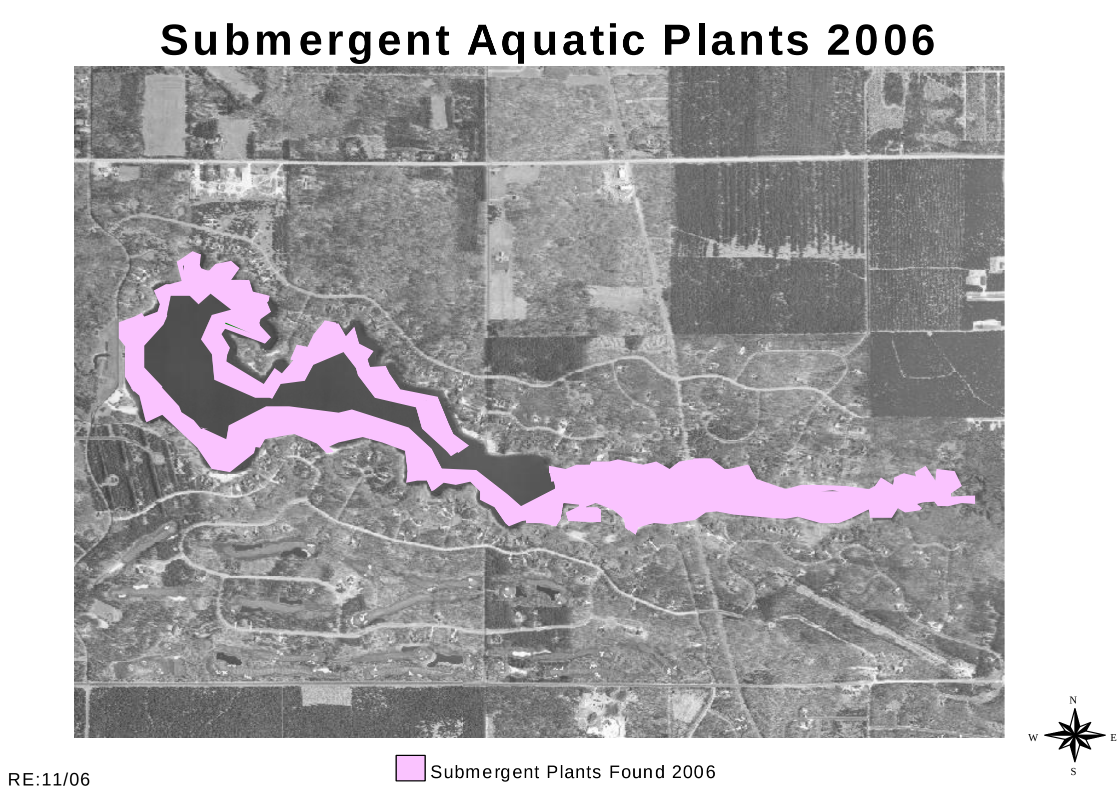


Figure 46c: Submergent Aquatic Plant Distribution in 2006



There was a long history of chemical use for treating aquatic plant growth and algae in Arrowhead Lake, 1970-2000. Some chemical products that are now banned because of their toxicity were used. Broad-spectrum chemicals were also used. Two chemicals that do not biodegrade, but build up in the sediment, resulting in toxic sediment were used.

The problems with the herbicides that were used included the following:

1) The broad-spectrum chemical Diquat was used. This killed all plant species and inadvertently opened up areas for the introduction of exotic and invasive species. Over 113 gal of Diquat compounds were used over the 30-year span.
2) The Hydrothol formulation is toxic to young fish.
3) Cutrine and CuSO4 are copper products that were used to kill algae and reduce swimmer's itch. Since copper is an element, it does not biodegrade further, building up the sediments. The drawbacks of copper treatments are: (a) the very short effective time; (b) the toxicity of copper to aquatic insects, an important part of the food chain in a lake; (c) the build up of copper in the sediments, resulting in sediments that are toxic to mollusks that are the natural consumers of algae in a lake.

Figure 47: Chemical Aquatic Plant Treatments in Arrowhead Lake

		Aquatic Herbicicides Applied to Arrowhead Lake				
Year	**Copper (lbs)**	**Cutrine (gal)**	**Aquathol (gal)**	**Hydrothol (gal)**	**Diquat (gal)**	**Rodeo (gal)**
1981	1400					
1982	125					
1983	150		7		6	
1984	75		14	52		
1985	300		41.5		15	
1986	610		30		10	
1987	350		5		5	
1988	375		22		10	
1989	1050					
1990	200				3	0.75
1991	475		5		3	
1992	300		10		10	
1993			10		20	
1994	785		6.25		3.75	
1995	725		24		9	
1996		55	11			11
1997		65				
1999			5		5	
2000			15		15	
Total	6920 lbs	121 gal	205.75 gal	52 gal	113.75 gal	11.75 gal

Mechanical harvesting of aquatic plants in Arrowhead Lake started in 1995 and has continued through 2006. The chart below shows the pounds of aquatic plant removed through mechanical harvesting through 2006. For 2005 and 2006, plant samples were taken to a laboratory to be tested for the amount of phosphorus in milligrams per kilogram of aquatic plants. This is also shown on the chart on the next page.

Figure 48: Mechanical Harvesting from Arrowhead Lake

Year	Pounds Harvested	Phosphorus Removed in Pounds
1995	37,000	NA
1996	98,000	NA
1997	85,000	NA
1998	214,000	NA
1999	221,100	NA
2000	274,000	NA
2001	328,000	NA
2002	54,600	NA
2003	313,000	NA
2004	296,000	NA
2005	55,000	281.88
2006	4,188,000	1261.38
total	6,163,700	1543.26

Figure 49: Most common Native Aquatic Species in Arrowhead Lake

Potamogeton pectinatus
(Sago Pondweed)

***Chara* spp**
(Muskgrass)

MANAGEMENT RECOMMENDATIONS

(1) Because the plant cover in the littoral zone of Arrowhead Lake is over the ideal (25%-85%) coverage for balanced fishery and there are some areas with more than average plant density, continued harvesting to open fishing lanes should occur in some areas. Removal should occur by hand in the shallower areas to be sure that entire plants are removed and to minimize the amount of disturbance to the sediment.

(2) Natural shoreline restoration and erosion control in several areas is needed, especially on some bare steep banks. If trees fall at these eroded sites due to continued erosion, large portions of the banks will fall with them.

(3) To protect water quality, a buffer area of native plants needs to be restored on those many sites that now have seawalls or have traditional lawns mowed to the water's edge.

(4) The Tri-Lakes Management District and the Arrowhead Lake Association should continue to cooperate with the WDNR to monitor and, if possible, control the zebra mussel infestation in the lake to protect the aquatic plant community.

(5) Stormwater management of the many impervious surfaces around the lake is essential to maintain the current quality of the lake water and prevent further degradation.

(6) No lawn chemicals should be used on properties around the lake. If they must be used, they should be used no closer than 50' to the shore.

(7) The aquatic plant management plan should be reviewed annually. Mechanical harvesting plans should continue target harvesting for Eurasian Watermilfoil (EWM) and include target harvesting for Curly-Lead Pondweed to prevent further spread.

(8) The Arrowhead Lake Association may want to continue to apply for grants from the Wisconsin Department of Natural Resources to help defray the cost of aquatic plant management.

(9) No broad-scale chemical treatments of aquatic plant growth are recommended due to the undesirable side-effects of such treatments, including increased nutrients from decaying plant material and decreased dissolved oxygen and opening up more areas to the invasion of EWM.

(10) Fallen trees should be left at the shoreline or in the water.

(11) The Tri-Lakes Management District conducted water quality monitoring for several years, but has decreased its involvement during 2004-2006 when Adams Land & Water Conservation Department was doing more intense monitoring as part of a Lake Classification Grant. Monitoring by the Lake District or through the DNR Self-Help Monitoring Program should be restarted.

(12) Arrowhead Lake residents should identify, cooperate with and participate in watershed programs that will reduce nutrient and sediment inputs. Nutrients appear to have increased within the lake district, so residents must take steps to reduce their nutrient inputs.

(13) No drawdowns of water level except for DNR-approved purposes should occur. Drawdowns in the past have increased nutrient inputs to the lake through ground water; these increased nutrients are feeding the algae growth.

(14) The few sites where there is undisturbed shore, mostly in designated conservancy areas, should be maintained and left undisturbed.

(15) The Tri-Lakes Management District should make sure that its lake management plan takes into account all inputs from both the Arrowhead Lake surface ground watershed and inputs from Camelot & Arrowhead Lakes, and addresses the concerns of this larger lake community.

(16) Cooperation with the Adams County Parks Department in keeping the boat ramp and swimming beach in safe condition should help reduce any negative impacts caused by the heavy use of these public areas.

(17) Pursue installation of sewage system around the lake to reduce nutrient input from the lakeshores. Reduction of nutrient inputs by residents needs to occur before asking watershed residents to reduce theirs.

Aquatic Invasives--Plants

Arrowhead Lake has three known invasive aquatic plant species: Curly-Leaf Pondweed (submergent); Eurasian Watermilfoil (submergent); and Reed Canarygrass (emergent). The lake gets a significant amount of transient boat traffic due to its location with beach and large public boat ramp. The Tri-Lakes Management District has a lake management plan that includes management of aquatic invasives. The lake has been using targeted harvesting for Eurasian Watermilfoil, emphasizing the harvesting of that plant in May and September, while harvesting the summer months for navigation, rather than control of Eurasian Watermilfoil. In 2008, some lake citizens were trained to monitor the aquatic invasives and participate in the Clean Boats, Clean Waters boater education program.

Figure 50: Distribution of Exotic Aquatic Plants in Arrowhead Lake

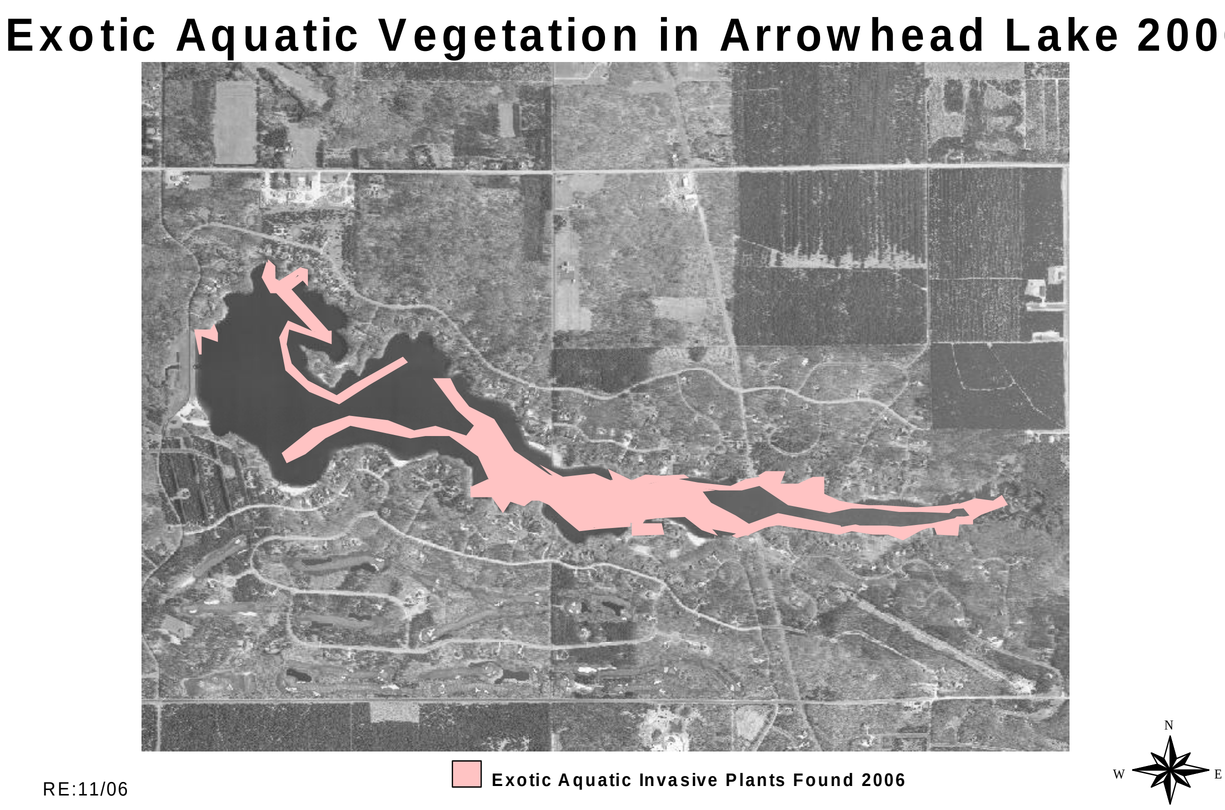
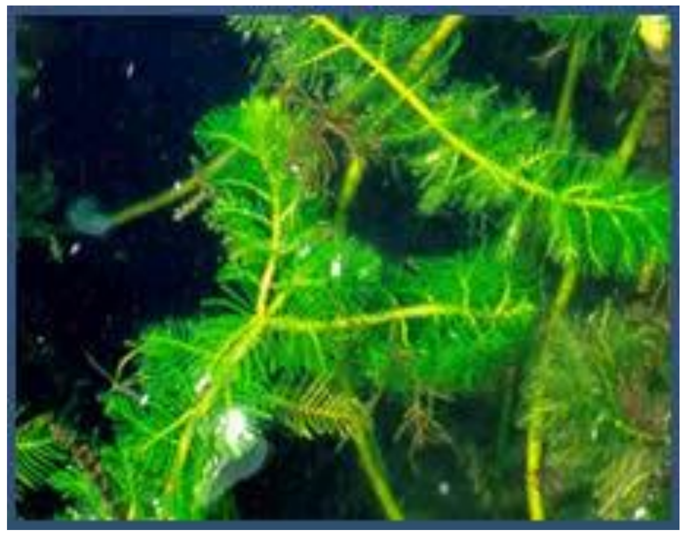


Figure 51: Invasive Aquatic Plants in Known at Arrowhead Lake

Curly-Leaf Pondweed

Eurasian Watermilfoil



Reed Canarygrass

Aquatic Invasive—Animals

Arrowhead Lake is currently the only in-land lake in Adams County known to have zebra mussels. They are also found in the Wisconsin River and in both Castle Rock and Petenwell Lakes on the western edge of Adams County.

The WDNR has been monitoring Arrowhead Lake since the zebra mussels were discovered and works with the Tri-Lakes Management District to try to manage the mussels. Because of the presence of these mussels, participation in the Clean Boats, Clean Waters program is especially urgent.

Figure 52: Zebra Mussels

Rusty Crayfish are also known to be in the Tri-Lakes system in all three lakes, but do not appear to have reached a level to cause any significant impact at this time. They should be monitored, so that if they appear to be increasing in presence, action can be taken to manage them. Unchecked, rusty crayfish can seriously damage a lake's ecosystem, destroying many of the aquatic plants on which fish & their prey depend, and ultimately negatively affecting the fish population.

Figure 53: Rusty Crayfish

FISHERY/WILDLIFE/ENDANGERED RESOURCES

The most recent fishery survey of Arrowhead Lake was done in October 2004. That inventory found that walleye and largemouth bass were abundant. Bluegill and white suckers were common. Both yellow perch and northern pike were scarce.

Muskrat are known to use Arrowhead Lake shores for cover, reproduction and feeding, mostly in the conservancy areas. Seen during the field survey were various types of waterfowl, and songbirds. Frogs and salamanders are known, using the lake shores for shelter/cover, nesting and feeding. Turtles and snakes also use this area for cover or shelter in this area, as well as nested and fed in this area. Upland wildlife feed and nest here as well.

Arrowhead watersheds contain a number of endangered natural communities, plants and animals. Natural communities in these watersheds include Alder Thicket, Northern Sedge Meadow, Northern Wet Forest, Pine Barrens and Shrub-Carr. Red-shouldered hawk, also in jeopardy, is known here. Plants of concern include Crossleaf Milkwort, Grassleaf Rush and Yellow Screwstem. The area is also good habitat for Karner Blue Butterflies.

KARNER BLUE BUTTERFLY

YELLOW SCREWSTEM

Figure 54: Photos of some of the species of concern in Arrowhead Lake Watersheds*

*information courtesy of Wisconsin Department of Natural Resources

RESOURCES

Bell, R.A. 2000. Phytoplankton Community Composition and Distribution in the Tri-Lakes Area. UW-Stevens Point.

Bryan, B., B. Charry. 2006. Conserving Wildlife in Maine's Shoreland Habitats. Maine Audobon Society.

Carlson, R.E. 1977. A Trophic State Index for Lakes. Limnology and Oceanography 22:361-369.

Comas, S.R. 1993. Tri-Lakes, Adams County, Wisconsin Lakes & Watershed Characterization. Blue Water Science, St. Paul, Minnesota.

Dennison, W., R. Orth, K. Moore, J. Stevenson, V. Carter, S. Kollar, P. Bergstrom, R. Batuik. 1993. Assessing Water Quality with Submersed Vegetation. Bioscience 43(2):86-94.

Engel, S. 1985. Aquatic Community Interactions of Submerged Macrophytes. Wisconsin Department of Natural Resources Bulletion #156.

Frankenberg, J. Land Use and Water Quality. Purdue Extension Publication ID-230.

James, T. 1992. A Guidebook for Lake Associations. The International Coalition for Land and Water Stewardship in the Red River Basin, Minnesota.

James, W.F., J. Barko & H. Eaken. 2002. Limnological Investigations of Camelot, Sherwood, & Arrowhead Lakes, WI. U.S. Army Corps of Engineers, Spring Valley, WI.

Kibler, D.F., ed. 1982. Urban Stormwater Hydrology. Water Resources Monograph 7. American Geophysical Union.

Krysel, C, E.M. Boyer, C. Parson, P. Welle. 2003. Lakeshore Property Values and Water Quality: Evidence from Property Sales in the Mississippi Headwaters Region. Report to the Legislative Commission on Minnesota Resources.

Lillie, R.A., J.W. Mason. 1983. Limnological Characteristics of Wisconsin Lakes. Department of Natural Resources Bulletin No. 138.

MSA Professional Services. 1999. Septic Study of Tri-Lakes.

Nichols, S. 1998. Floristic Quality Assessment of Wisconsin Lake Plant Communities with Example Applications. Journal of Lake and Reservoir Management 15(2):133-141.

Nichols, S., S. Weber, B. Shaw. 2000. A Proposed Aquatic Plant Community Biotic Index for Wisconsin Lakes. Environmental Management 26(5): 491-562.

Shaw, B., C. Sparacio, J. Stelzer, N. Turyk. 2001. Assessment of Shallow Groundwater Flow Chemistry & Interstitial Water Sediment, Aquatic Macrophyte Chemistry for Tri-Lakes, Adams County, WI. UW-Stevens Point.

Shaw, B., C. Mechanich, L. Klessing. Understanding Lake Data. UW-Extension Publication SR-02/2002-1M-525, 2000.

Terrell, C., P. Perfetti. 1989. Water Quality Indicators Guide: Surface Waters. United States Department of Agriculture Publication SCS-TP-161.

University of Wisconsin-Madison Water Resources Management Program. 1978. Fourteen Mile Creek Watershed: A Water Management Study. UW-Madison.

Wagner, C., J. Haack, R. Korth. Protecting Our Living Shores. 2003. Shoreland Stewardship Series #3 WDNR Publication WT-764-2003. UW-Extension, Wis. Lakes Partnership, WDNR, Wisconsin Association of Lake & River Alliance of Wisconsin.

Figure 55: One of the Marinas for Lake Arrowhead Property Owners