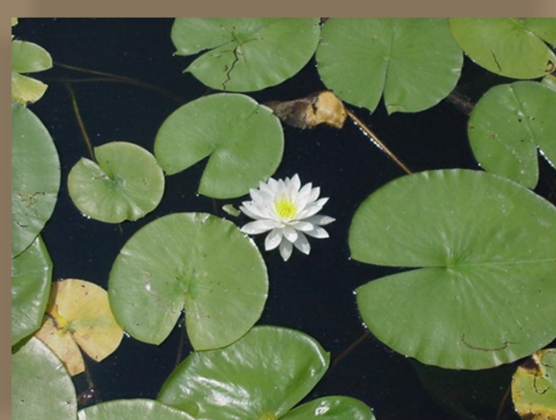
BIG MUSKEGO LAKE AND BASS BAY

MANAGEMENT PLAN





June 2004

CITY OF MUSKEGO
ELECTED OFFICIALS

2004

Mayor

Honorable Mark A. Slocomb

Common Council

Council President Nancy Salentine, District 4

Alderman Patrick Patterson, District 1

Alderman Chris Buckmaster, District 2

Alderman Neil Borgman, District 3

Alderman Bob Melcher, District 5

Alderman Eric Schroeder, District 6

Alderman Eileen Madden, District 7

Big Muskego Lake/Bass Bay
Protection and Rehabilitation District Commissioners
include Mayor as Chairman and body of 7 Aldermen

ACKNOWLEDGMENTS

BIG MUSKEGO LAKE/BASS BAY PROTECTION AND REHABILITATION DISTRICT DEPUTY COMMISSIONERS 2003-2004

Mr. Thomas Kies, Chairman

Mr. Gregory Burmeister   Mr. Lawrence Schweitzer

Mr. Leonard Pilak*   Mr. Steve Wojnowski

CITY OF MUSKEGO STAFF

Mr. Thomas Zagar, Conservation Coordinator

Ms. Marisa Pankowski, Conservation Intern 2002-2003

Mr. Jeff Muenkel, Planning Department Director

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Thanks also to Dr. Jeff Thornton of the Southeastern Wisconsin Regional Planning Commission, Bill Rose of United States Geological Survey, and all others who contributed to this document

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INTRODUCTION

OVERVIEW

The purpose of this document is to set a course for the management of Big Muskego Lake and Bass Bay. These connected waterbodies are located within the City of Muskego in southeastern Waukesha County in Wisconsin (Map 1). Big Muskego Lake is a large shallow water body covering 2,177 acres. Its name is derived from "Mus-kee-guac," the Potawatomi Native American word for sunfish. Bass Bay is a 109-acre connected waterbody named after the Bass (pronounced: "baas") family who resided on the bay's northern shore.

These waterbodies lie within the City of Muskego, a community encompassing 35.8 square miles with an estimated 2003 population of 22,054. Located within 12 miles of downtown Milwaukee, Muskego is considered a suburban community within the socio-economic influence of southeastern Wisconsin, including Milwaukee, Waukesha, Racine, Kenosha, and Walworth Counties. This area has an estimated 2003 population of 1,753,455.

With its proximity to Milwaukee, this waterway provides a convenient recreation venue for thousands of users each year. Continued development of lands within the watershed, invasive species, and effects of human activities are potential threats to the water quality, fishery, wildlife, and the quality of the recreational experience. Implementation of a sound lake management plan will ensure that Big Muskego Lake and Bass Bay remain a valuable resource to the area.

Between 1995 and 1997 a major lake restoration effort was undertaken on Big Muskego Lake and Bass Bay that resulted in improved water quality and enhanced fish and wildlife habitat. Prior to the project the lake was a turbid, carp-dominated, open expanse of shallow water. After a full year drawdown and eradication of rough fish, the lake shifted to a marsh/shallow lake complex with numerous islands of emergent vegetation (cattails, bulrushes). The clearer water supported a fishery that included large panfish and numerous Northern Pike. Nesting habitat for waterfowl improved and non-game species such as Forster's Terns, Yellow Headed Blackbirds, and Ospreys were more commonly seen in the enhanced conditions. Improved hunting, fishing, and wildlife viewing opportunities have increased the recreational use of the waterway.

Despite the successful restoration project, Big Muskego Lake/Bass Bay has never had a formally adopted comprehensive plan to guide its management efforts. This Management Plan uses long-term scientific data and lessons learned from the restoration project to develop a plan of action to protect and sustain what the restoration project was able to achieve. A major focus of this Plan is the management of issues unique to shallow lake/deep marsh aquatic systems.

After identifying goals, this Plan summarizes existing data on the physical characteristics, water quality, aquatic plants, fishery, wildlife, and human uses of Big Muskego Lake/Bass Bay. Specialized management concepts of shallow water systems are then presented and historical management activities are summarized. The Plan then identifies alternatives for future management and recommends particular courses of action to be implemented to achieve the stated goals.

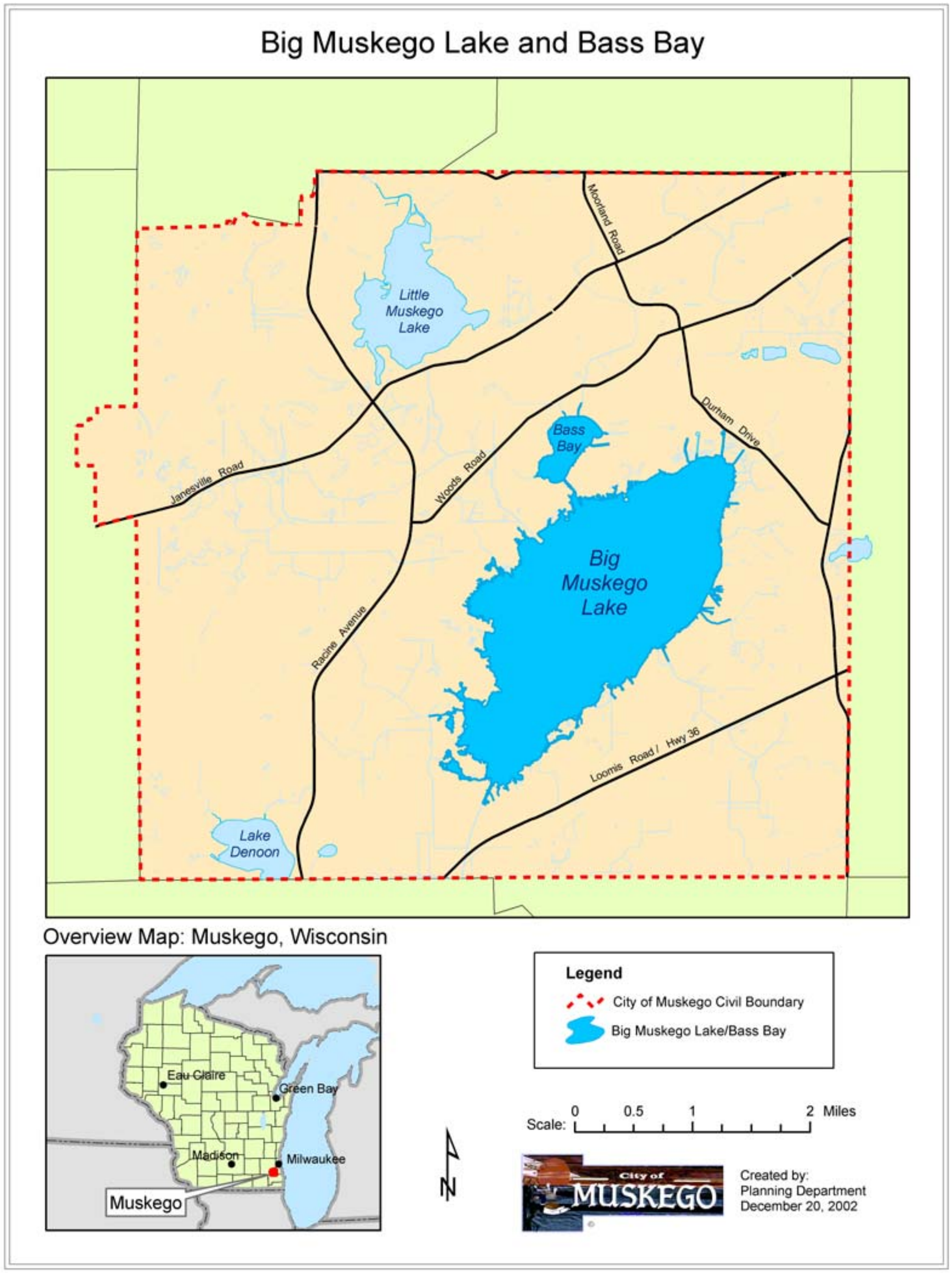
GOALS

The primary goals of this Plan include:

- Improving and maintaining water quality
- Improving and maintaining opportunities for water-based recreational activities
- Maintaining a healthy assemblage of fish and providing quality angling opportunities
- Providing quality waterfowl hunting opportunities
- Providing habitat for a diversity of wildlife including endangered, threatened, and rare species
- Managing aquatic plants to reduce nuisance and invasive species while maintaining the objectives above.

Unique goals of this Plan include:

- Surveying public opinion of lake condition and uses
- Maintaining a diverse assemblage of emergent and submergent vegetation for optimal wildlife and fish habitat
- Establishing and managing for an ideal coverage of emergent vegetation
- Planning a strategy to establish/maintain aquatic plants and reduce algae
- Identifying conditions and establishing thresholds of various parameters which would "trigger" the implementation of management actions
- Establishing a Common Carp population threshold that would dictate future chemical eradication (Rotenone) treatments
- Designing a settling basin for use during a lake drawdown that may be associated with future restoration projects
- Improving the knowledge base of public stakeholders and working with them to enable realistic expectations and outcomes.



Map 1: Big Muskego Lake and Bass Bay

MANAGEMENT RESPONSIBILITIES OF BIG MUSKEGO LAKE/BASS BAY

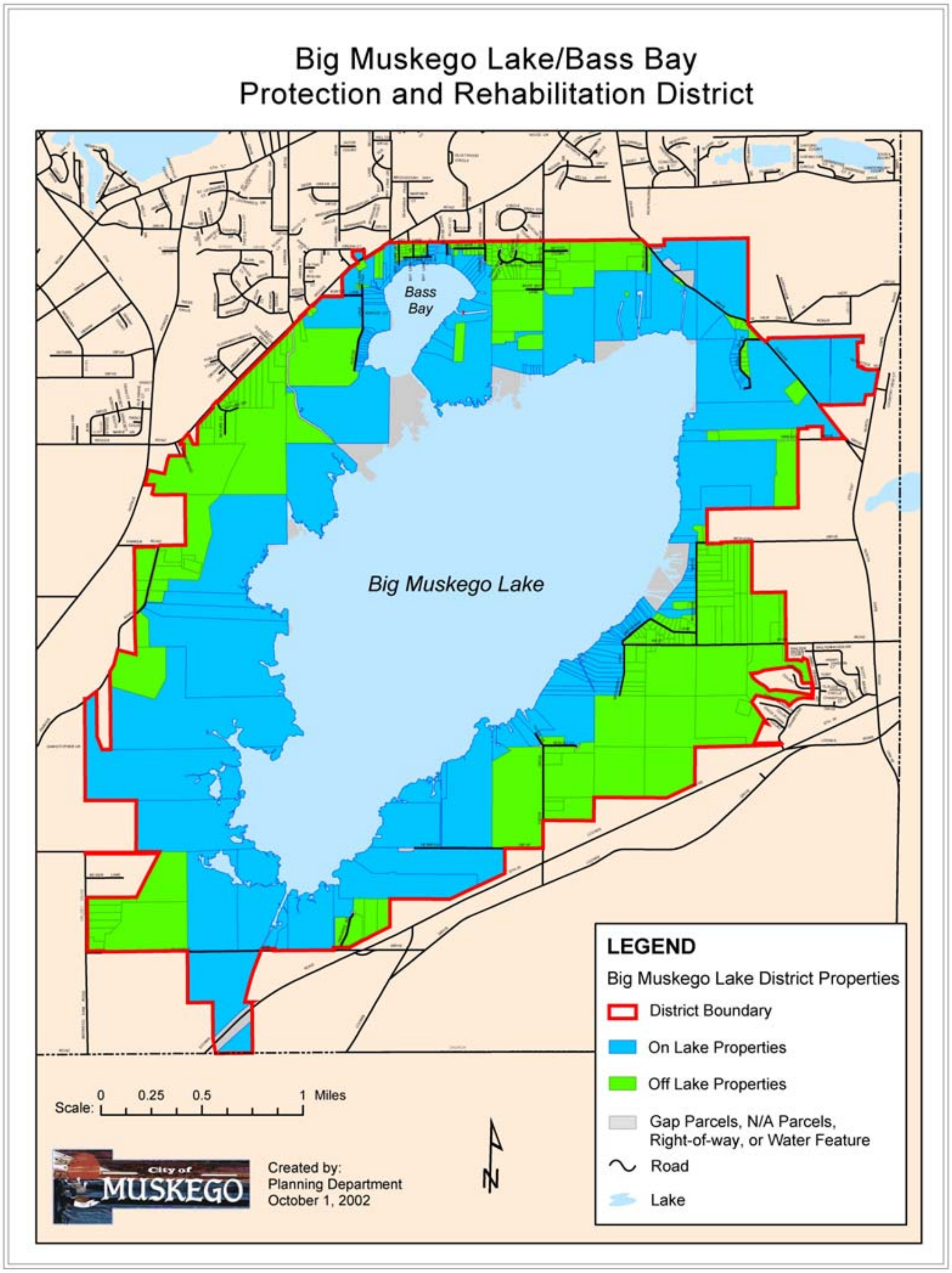
There are several governmental bodies and agencies responsible for the management of Big Muskego Lake and Bass Bay. Although there is some overlap, each entity has a particular role in the management of the resource. Cooperation between these entities is crucial in achieving the objectives of this lake management plan.

The State of Wisconsin is charged with the responsibility of protecting public waters for the public's use and enjoyment. The Public Trust Doctrine is a body of state constitutional, statutory, administrative and common law that protects the public rights to fish, swim, boat, hunt and enjoy the natural scenic beauty of Wisconsin's waterways. The Wisconsin Department of Natural Resources (DNR) is the specific state agency responsible for the enforcement of regulations concerning waterways including lakebed alterations, aquatic plant management, water quality, boating, fishing, and hunting. The Wisconsin DNR has jurisdiction over management of water levels through section 31.02 of the Wisconsin State Statutes.

The United States federal government has several agencies that play a role in the management and protection of Big Muskego Lake and Bass Bay. The U.S. Army Corps of Engineers review applications and issues permits for alterations of waterways, and conduct studies. The United States Geological Survey (USGS) conduct water quality monitoring, operate water level gauging stations, and conduct studies. The U.S. Fish and Wildlife Service conduct fisheries and wildlife management studies and habitat improvement projects.

Several departments within the City of Muskego have management authority over activities that directly and indirectly affect Big Muskego Lake/Bass Bay. The Planning Department administers shoreland zoning that establishes the type and size of structures, setbacks and permissible uses of properties. A Conservation Coordinator within the Planning Department is responsible for many aspects of local lake management for Muskego's four major water bodies (Big Muskego Lake, Bass Bay, Little Muskego Lake, and Lake Denoon) and serves as staff liaison to the local lake districts and associations. The Building & Engineering Department enforces ordinances concerning erosion control and storm water management. The Parks and Recreation Department operates public access facilities on Big Muskego Lake/Bass Bay. The Public Works Department operates the Big Muskego Lake outlet dam as well as the dam on Little Muskego Lake that drains to Big Muskego Lake.

In 1974, the Wisconsin Legislature enacted laws enabling lake residents and others to form inland lake protection and rehabilitation districts. Big Muskego Lake/Bass Bay Protection and Rehabilitation District was formed in 1978. District boundaries were drawn to include riparians (landowners with lake frontage) and other landowners within a certain proximity to the lake (Map 2). These property owners are assessed a special charge to finance lake management projects. A Board of Commissioners makes decisions regarding lake management. The Big Muskego Lake/Bass Bay Commissioners include the Mayor, who acts as Chairman and the body of seven Muskego Common Council members. A group of five Deputy Commissioners is elected annually by Lake District members to provide recommendations to the Commissioners and execute the projects of the District. A listing of the Commissioners and Deputy Commissioners can be found in the front of this document.



Map 2: Big Muskego Lake/Bass Bay Protection and Rehabilitation District

Chapter 2
LAKE CHARACTERISTICS

PHYSICAL CHARACTERISTICS

Big Muskego Lake is a shallow 2,177-acre flow-through lake fringed with cattail-dominated wetlands, and encompassing islands of emergent plant growth (cattail islands). Most of Big Muskego Lake is less than four feet deep with generally a muck bottom. Sediments have high moisture content, low sediment density and a high content of organic matter. The lake basin was formed from the glacial activity of the late Pleistocene Epoch. The present (2004) lake level and surface area is actually lower than its original historic level due to draining projects in the early 1890's (further discussed in Chapter 4).

Bass Bay is a 109-acre embayment connected to Big Muskego Lake that has a basin reaching a depth of 23 feet and a bottom substrate predominantly of muck with some isolated sandy shoreline areas (Map 3). A few undeveloped areas of shoreline on Bass Bay are fringed with cattail marsh. The basin of Bass Bay is a typical kettle lake formed in the void left from a large chunk of glacial ice.

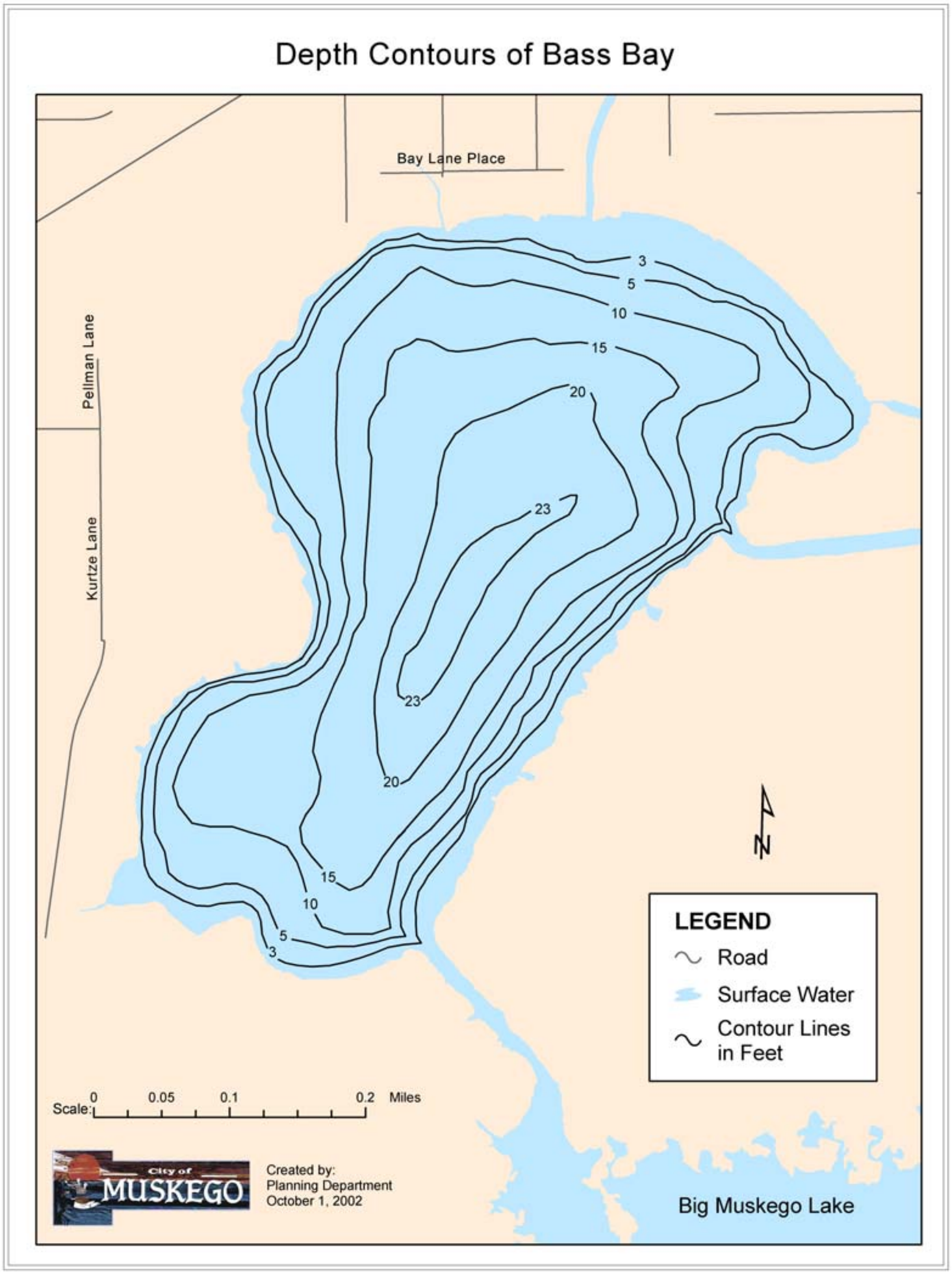
WATERSHED AND LAND USES

The total watershed area of Big Muskego Lake and Bass Bay covers 28 square miles (Map 4). The direct drainage area of Big Muskego Lake and Bass Bay covers 16.5 square miles. A considerable portion of the water in Big Muskego Lake is derived from Muskego Creek (locally known as Pilak Creek), which is the outlet of Little Muskego Lake. Water from Big Muskego Lake and Bass Bay ultimately drains into the Gulf of Mexico via the Muskego Canal, Wind Lake, Wind Lake Canal, Fox River, Illinois River, and Mississippi River.

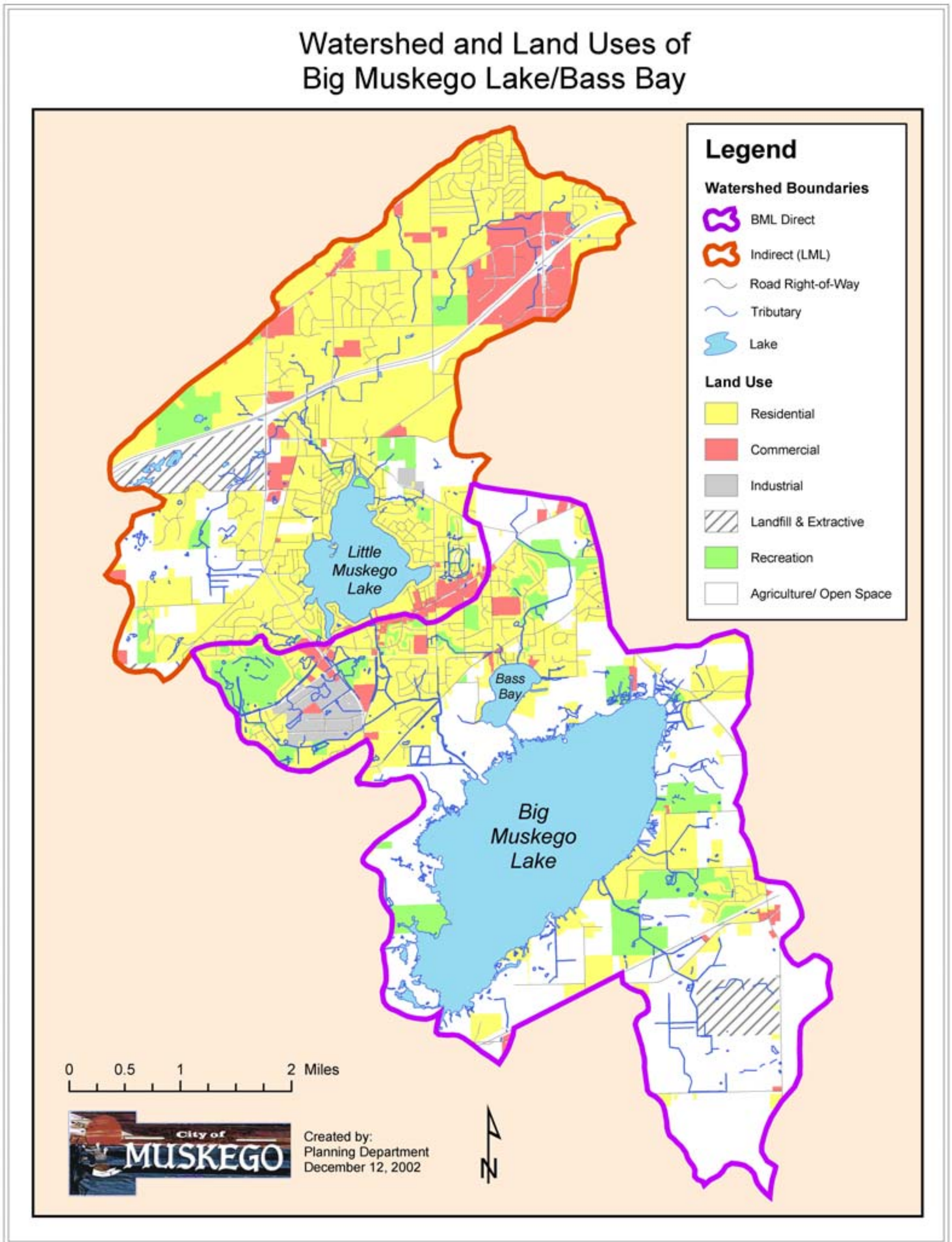
Land uses within the watershed are identified in Table 1. Residential uses comprise the greatest percentage, followed by agriculture/open space. The impacts of particular land uses on surface water quality are discussed in the section entitled "Land Uses and Nonpoint Source Pollutant Loading" presented near the end of this chapter.

Land Use	Acres	Percentage
Residential	5851	33
Commercial	905	5
Industrial	206	1
Landfill and Extractive	602	3
Recreation	1206	7
Agriculture/Open Space	4646	25
Surface Water and Undesignated*	4516	26
Total	17,932	100

Table 1: Land Uses within Big Muskego Lake/Bass Bay Watershed
* Undesignated includes road rights-of-way and non-platted shoreline areas



Map 3: Bass Bay Depth Contours



Map 4: Watershed and Land Uses of Big Muskego Lake and Bass Bay

WATER QUALITY

The quality of water within a waterway affects the quality of the entire lake ecosystem. Poor water quality results in a lower diversity of plant and animal life and in turn results in a diminished value to humans. A major objective of lake management is to improve and maintain water quality. Therefore it is important to monitor water quality on an ongoing basis to determine if goals are being achieved.

The United States Geological Survey (USGS) has conducted yearly water quality monitoring on Bass Bay and Big Muskego Lake on a continual basis from 1988 to 2002. An extensive array of physical and chemical water quality parameters (29) were measured each spring following lake turnover. During three to four other sampling dates throughout the year, USGS monitored a more limited set of parameters. Samples were taken in the middle of Bass Bay over the deepest area (~23 ft.) and taken near the south end of Big Muskego Lake over the deepest natural area (~6 feet). Samples were taken both ½-meter below the water's surface, and ½-meter above the lake bottom.

USGS also operates a gauging station at the outlet dam that continuously monitors the lake's stage (water level) and discharge. Until 2002, this station also ran an automated sampling device that collected water samples at various times including periods of higher discharge following precipitation events. Combined with stage information, these water quality data were used to estimate loadings of sediments and nutrients discharged from the lake.

In 2003, the City of Muskego began conducting all of the same routine in-lake monitoring that USGS had previously done. The City and Lake District continue to contract with USGS to operate the gauging station at the lake outlet.

Table 2 lists water quality parameters and the frequency in which they are sampled. A brief description of some of the common measurements of water quality follows.

Parameter*	Sampling Frequency		Frequency
Lake Stage (ft.)	Continuous	Color (Pt.-Co. scale)	Spring turnover
Secchi Depth (m)	4-5 times/yr.	Turbidity (NTU)	Spring turnover
Chlorophyll a (*u*g/L)	4-5 times/yr.	Hardness (as $CaCO_3$)	Spring turnover
Sample Depth (m)	4-5 times/yr.	Calcium, dissolved (Ca)	Spring turnover
Water Temperature (°C)	4-5 times/yr	Magnesium, diss. (Mg)	Spring turnover
Specific Conductance (*u*S/cm)	4-5 times/yr	Sodium, dissolved (Na)	Spring turnover
pH (units)	4-5 times/yr	Potassium, dissolved (K)	Spring turnover
Dissolved Oxygen (mg/L)	4-5 times/yr	Alkalinity (as $CaCO_3$)	Spring turnover
Phosphorus, total (as P)	4-5 times/yr	Sulfate, dissolved (SO_4)	Spring turnover
Phosphorus, ortho, dissolved (as P)	Spring turnover	Chloride, dissolved (Cl)	Spring turnover
Nitrogen, NO_2+NO_3, diss. (as N)	Spring turnover	Silica, dissolved (SiO_2)	Spring turnover
Nitrogen, ammonia, dissolved (as N)	Spring turnover	Solids, dissolved, at 180°C	Spring turnover
Nitrogen, amm. + organic, total (as N)	Spring turnover	Iron, dissolved (Fe) *u*g/L	Spring turnover
Nitrogen, total (as N)	Spring turnover	Manganese, dissolved (Mn) *u*g/L	Spring turnover

Table 2: Water Quality Parameters Measured on Big Muskego Lake/Bass Bay from 1988 to 2002

* Concentrations in mg/L unless indicated otherwise.

Water Temperature and Stratification

Many chemical reactions and life processes of aquatic organisms are dependent upon water temperature in lakes. The density difference of water due to temperature variations causes lakes to stratify. The density of water increases with decreasing temperature until reaching 4° C, then decreases with decreasing temperature between 4° C and freezing (0° C). As surface waters warm in spring a layer of water forms that is less dense than the cooler water below. This density differential can become so pronounced that it resists the mixing action of wind. By early summer a stratification of water forms that includes the *epilimnion* (warmer, less dense surface water) and the *hypolimnion* (the cooler, denser water found below). The depth at which a sharp temperature gradient exists between these two layers is termed the *thermocline* or *metalimnion*. In fall, when the cooling of surface water lessens the density gradient, wind energy can once again mix these layers. This phenomenon is commonly known as "fall turnover." Stratification also develops in winter as ice (0° C water) is found at the surface and the densest water (4° C) is found at the bottom.

Stratification of lakes has implications for water quality parameters and the distribution of aquatic organisms. For example, the oxygen concentration within the hypolimnion declines over time due to the oxygen-demanding processes of decomposition and respiration and this layer can become completely devoid of oxygen (anoxic). As a result of diminishing oxygen in the hypolimnion, many species of fish will seek the higher oxygen levels found above the thermocline.

Big Muskego Lake generally does not sustain any thermal stratification in the summer due to the mixing force of wind acting on its shallow depth. However, the deeper basin of Bass Bay stratifies in both winter and summer.

Specific Conductance

Specific conductance is a measure of the ability of water to conduct an electrical current and is an indicator of the concentration of dissolved solids in water. As the concentration of dissolved solids increases, specific conductance increases. Specific conductance can vary throughout the water column depending on physical and chemical processes occurring within the lake strata. During both winter and summer stratification, concentrations of dissolved constituents increases within the hypolimnion due to the decomposition of materials settling to the bottom and release of dissolved materials (e.g. iron, manganese, and phosphorus) from the bottom sediments during anoxic periods (USGS, 2001).

Water Clarity – Secchi Disk

Light penetration into the water column affects the level of photosynthetic activity that can occur. A Secchi disk is a black and white colored circular 20 cm object that is lowered into the water to a point at which it is no longer visible from the surface. It is then raised to a point at which it becomes visible and this depth is referred to as the Secchi depth. Phytoplankton, zooplankton, dissolved substances and suspended solids all affect water clarity. Water clarity in turn affects the depth at which aquatic plants can grow.

Phosphorus

Phosphorus is one of the essential nutrients for the growth of plants. Of the three essential nutrients necessary for plant growth (nitrogen, phosphorus, and potassium), phosphorus is usually the limiting nutrient. That is, phosphorus is in the shortest supply and any addition of this nutrient will cause an increase in plant growth. High inputs of phosphorus can cause profuse and nuisance growths of algae and aquatic plants.

Phosphorus is internally cycled through lakes in various forms. Phosphorus may be utilized by aquatic plants and animals and stored within the tissue of these organisms. After death and decomposition, phosphorus is returned to the water and sediments. Anoxia that frequently occurs within the hypolimnion makes phosphorus more soluble and releases it from the sediments into the water column. After spring and fall turnover, this phosphorus is distributed into the upper portion of the water column where photosynthetic activity occurs (trophogenic zone) and becomes available for a new cycle of plant growth.

Chlorophyll *a*

Chlorophyll *a* is a photosynthetic pigment found in algae and other green plants. Its concentration is used as a measure of the density of the algal population in a lake. Populations of algae are critical to the ecological health of a lake as they serve as food for zooplankton and some fishes. However, excessive populations, or algal blooms, can limit sunlight penetration and cause taste and odor problems. Blooms of blue-green algae can produce levels of toxins that can cause illness or death to animals that ingest the water.

Water Quality of Big Muskego Lake and Bass Bay - Trophic State Index

Trophic states describe the relative amount of nutrient loading and organic production of a water body. Lakes that are classified as oligotrophic have low nutrient inputs and low organic production. Oligotrophic lakes typically have deeper, clear water and fewer aquatic plants. Eutrophic lakes have relatively high inputs of nutrients and high organic production. They are usually shallower and have prolific growth of plants and/or algae. Mesotrophic lakes are categorized in the middle.

The Wisconsin DNR established a classification scheme that uses Secchi disk readings, and concentrations of chlorophyll *a* and total phosphorus to categorize the trophic state of lakes (Lillie et al, 1993). The values of each parameter are used in a log formula to establish a “trophic state index” (TSI). TSI can be calculated using the following equations:

$TSI_{Secchi} = 60.0 – 32.2 (\log_{10} \text{Secchi depth})$
$TSI_{Chlorophyll\ a} = 32.82 + (17.41)(\log_{10} \text{Chorophyll } a \text{ concentration})$
$TSI_{Total\ Phosphorus} = 28.24 + (17.81)(\log_{10} \text{Total Phosphorus Concentration})(1000)$

Data from the last sixteen years have shown Secchi disk readings and concentrations of total phosphorus and chlorophyll *a* that place Bass Bay into the slightly eutrophic category (Figure 1). Big Muskego Lake has typically had quite shallow Secchi disk readings and high concentrations of total phosphorus and chlorophyll *a*, placing it well into the eutrophic range (Figure 2) (USGS, 2001). However, because many of the Secchi depth readings on Big Muskego Lake were often taken while the disk rested on the bottom and was still visible, the Secchi TSI values are likely over estimates.

Trophic State Index of Bass Bay

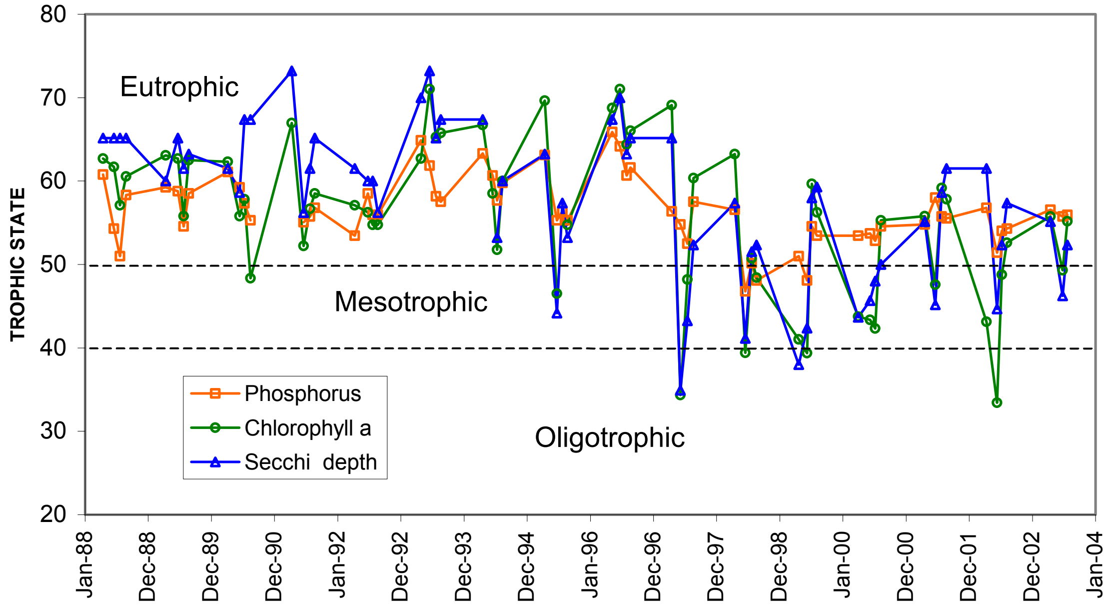


Figure 1: Trophic State Index of Bass Bay

Trophic State Index of Big Muskego Lake

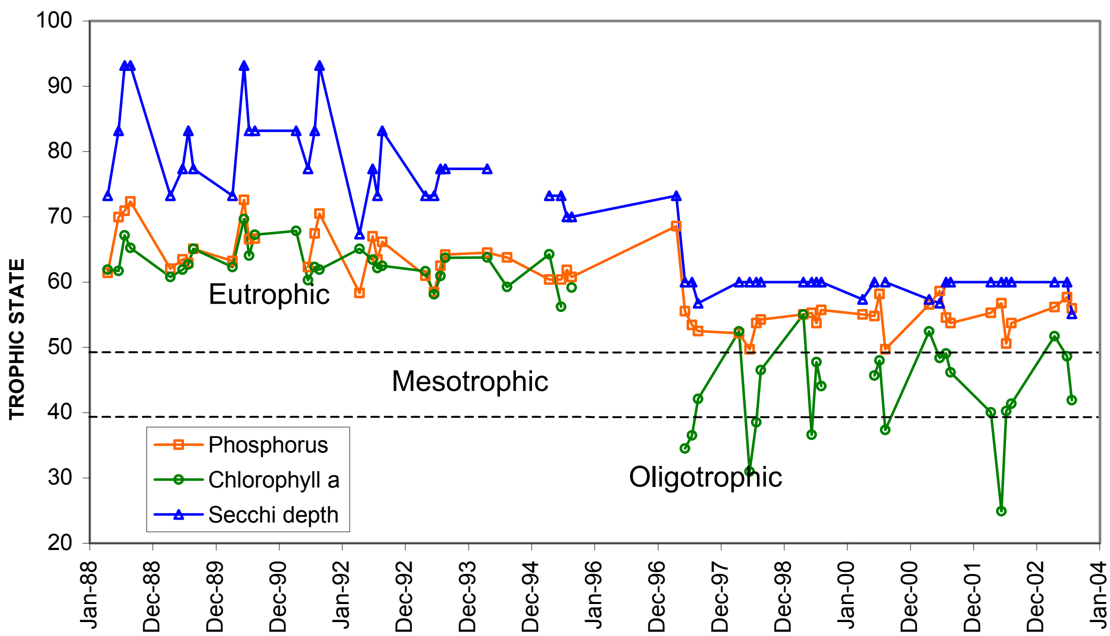


Figure 2: Trophic State Index of Big Muskego Lake

Since the 1995-96 drawdown and rough fish removal, and 1998 alum treatment (discussed in Chapter 4), some Bass Bay TSI values for total phosphorus and chlorophyll *a* have fallen into the mesotrophic range and even into the oligotrophic range. In Big Muskego Lake, $TSI_{Chlorophyll\ a}$ values measured since the restoration have generally been in the mesotrophic range. Total phosphorus and Secchi disk values for Big Muskego Lake since the restoration project, while still eutrophic, have moved closer to the mesotrophic category.

Water Level and Dam Operation

A gauging station located at the outlet dam measures the stage, or water level, of Big Muskego Lake. Lake stage is affected by the amount of precipitation and runoff in the watershed and manipulation of Big Muskego Lake's dam gate. Groundwater levels and operation of the dam on Little Muskego Lake also affect stage.

The crest of the dam is located at 11.52 feet above vertical datum. Datum of gauge is 760.00 ft above National Geodetic Vertical Datum of 1929 (mean sea level). Figure 3 summarizes the average monthly stage of Big Muskego Lake since 1988. The yellow line represents the dam crest.

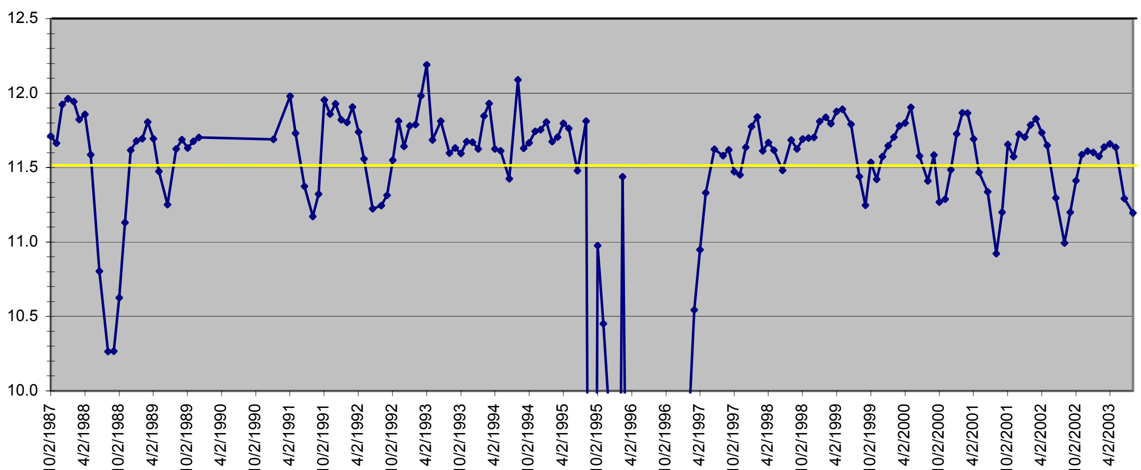


Figure 3: Monthly Mean Water Level of Big Muskego Lake

The Wisconsin Railroad Commission (now called the Public Services Commission) established the current operation of the Big Muskego Lake dam. The following text is the findings excerpt from Volume 18: pages 363-381 of Railroad Commission of Wisconsin Reports, published in 1916. The October 4, 1916 decision is *IN RE* Application of John Schaffer and other riparian owners on Muskego Lake, Waukesha County, Wisconsin, for an Order Fixing the Level of Said Lake. This remains the current water level order, now under the jurisdiction of the Department of Natural Resources. The 11.40' ordinary and 11.60' maximum levels reported correspond to 771.46' and 771.66' mean sea level respectively.

Findings:

Upon all the record and files herein and upon all the evidence and testimony had, the Railroad Commission of Wisconsin hereby finds:
First. That the lawful ordinary level of Muskego Lake is 11.40, when referred to Commission's bench mark No. 14, the top of which has been given an assumed elevation of 15.45; that in order to maintain this level the maximum level should not exceed an elevation of 11.60, when referred to the top of said bench mark, and the dam now being used to maintain the level of Muskego Lake should be altered or changed and operated as in the second finding determined.

Second. Said dam should be altered in either of two ways: (a) By the lowering of the entire crest of said dam to an elevation of 10.60 and constructing thereon flash boards, the top of which shall have an elevation not to exceed 11.40; or, (b) There should be constructed in said spillway a gate having a width of twenty-five feet and a depth reaching to the level 9.0 when referred to the top of Commission's bench mark, said gate to be of a construction to be easily operated by hand. Whether flash boards are used or a gate constructed in said dam, said flash boards or gate, as the case may be, should be so operated at all times that the level of the water is kept as near as may be at an elevation of 11.40 and should not exceed a maximum level of 11.60. Plans for changes in dam should be submitted to the Commission for approval as provided by statute.

AQUATIC PLANT COMMUNITY

Aquatic plants include larger plants, or macrophytes, and microscopic algae, or phytoplankton. Macrophytes that are rooted in the lake bottom with leaves growing mostly beneath the water's surface are termed "submergent." Pondweeds and coontail are examples of submergent aquatic plants. Aquatic macrophytes with leaves extending above the surface such as cattails and bulrushes are called "emergent" plants.

Aquatic plants constitute an integral part of the food web in aquatic systems by converting inorganic nutrients in the water and sediments into organic compounds that are directly available as food to other aquatic organisms. Through photosynthesis they process carbon dioxide and produce atmospheric and dissolved oxygen. Aquatic plants also provide habitat for fish, wildlife, and aquatic organisms. At times, however, certain aquatic plants can become invasive, reaching densities where they adversely impact the quality of fish and wildlife habitat and human recreational uses.

Chapter 3 describes two stable states in which the aquatic plant makeup of a shallow lake can be dominated by either phytoplankton (algae) or macrophytes (plants). For water quality and habitat value, it is more desirable to have an aquatic plant community dominated by macrophytes. Appendix A describes aquatic plant species found in Big Muskego Lake/Bass Bay and describes their value to fish and wildlife.

Aquatic Plant Surveys

The United States Army Corps of Engineers (ACOE) sampled the aquatic plant community of Big Muskego Lake as an evaluation of the effects of the lake drawdown of 1996 (Madsen, 1997). Frequency of occurrence of aquatic plants was recorded at 214 sampling points in August 1995 before the lake was drawn down. Following the refill of the lake, 209 of these points were sampled in August 1997. Bass Bay was not included in the study. City of Muskego and DNR staff sampled a subset of the ACOE sampling sites (44 sites) in 2002. Sampling points were located with GPS equipment and all species present within a square meter transect were noted. Table 3 summarizes these findings. Data is presented as "percent occurrence," identifying the percentage of sites found to contain each particular species.

Table 4 compares the average numbers of plant species found at sampling sites in each year the survey was conducted. This table shows mean number of species observed, number of native species observed during aquatic plant surveys conducted in August. The table also shows the total number of species observed for each year, including additional species observed outside of the sampling transects. Although plant diversity had greatly increased the year following the drawdown, it appears that in the ensuing years, the plant community has become somewhat less diverse.

Floristic Quality

Table 4 also compares the floristic quality of each sampling year. A Floristic Quality metric has been established for plant communities of Wisconsin lakes to evaluate the closeness of their flora to undisturbed conditions (Nichols, 1999). This value is derived by multiplying the average "coefficient of conservatism" times the square root of the number of species observed. A coefficient of conservatism has been developed for each plant species with the value representing the estimated probability that the plant would occur in pre-settlement conditions. Those plants intolerant to disturbances have higher values. The floristic quality of Big Muskego Lake compares favorably to other lakes in the southeastern Wisconsin region. The floristic quality of Big Muskego Lake has ranged from 23.8 to 29.1 compared to a median of 20.9 in the region. Number of species observed in Big Muskego Lake has ranged between 18 and 21 compared to a median of 14 in the region.

Scientific Name	Common Name	Percent Occurrence 1995	Percent Occurrence 1997	Percent Occurrence 2002
Carex spp.	Sedge	0.9	0	6.8
Ceratophyllum demersum	Coontail	4.2	2.9	25
Ceratophyllum echinatum	Smooth Coontail	0	0.5	0
Chara spp.	Muskgrass, Chara	0	67	65.9
Elodea Canadensis	Elodea	0	1	0
Lemna Minor	Lesser Duckweed	0	53	38.6
Lemna trisulca	Star Duckweed	0	0.5	22.7
Lythrum salicaria	Purple Loosestrife	9.4	12	4.5
Myriophyllum sibiricum	Northern Water Milfoil	5.6	4.3	9.1
Myriophyllum spicatum	Eurasian Water Milfoil	89.7	35.9	15.9
Najas flexilis	Northern Naiad	0.5	0.5	0
Najas marina	Spiny Naiad	1.9	18.2	43.2
Nuphar luteum	Yellow Pond Lily	6.1	0.3	2.3
Nymphaea alba	White Water Lily	5.2	12	2.3
Potamogeton amplifolius	Large-leaf Pondweed	3.3	0.5	0
Potamogeton crispus	Curlyleaf Pondweed	0.3	7.2	0
Potamogeton foliosous	Leafy Pondweed	0	0	2.3
Potamogeton illinoensis	Illinois Pondweed	0	5.7	4.5
Potamogeton nodosus	American Pondweed	0	0.5	0
Potamogeton pectinatus	Sago Pondweed	2.4	51.7	38.6
Potamogeton pusillus	Narrowleaf Pondweed	0.5	0.5	6.8
Ranunculus longirostris	Water Crowfoot	0.9	16.3	0
Sagittaria latifolia	Arrowhead	0	0.5	0
Scirpus spp.	Bulrush	0.5	61.7	0
Typha latifolia	Cattail	9.9	78.5	15.9
Utricularia vulgaris	Common Bladderwort	2.9	1.4	18.2
Zizania aquatica	Wild Rice	0	0.5	0
Zosterella dubia	Water Stargrass	0.9	0	2.3

Table 3: Aquatic Plant Frequency of Occurrence

Year	1995	1997	2002
Number of Species Observed/Sample site	1.45	4.37	3.2
Number of Native Species Observed/Site	0.43	3.82	2.97
Total Number of Species Observed in Lake	18	25	21
Floristic Quality Index	23.8	29.1	25.1

Table 4: Numbers of Aquatic Plant Species Observed in Big Muskego Lake and Floristic Quality

Nuisance Aquatic Plant Species

Eurasian Water Milfoil

Eurasian Water Milfoil (*Myriophyllum spicatum*) is an invasive nonnative submergent aquatic plant that has reached nuisance proportions in some areas of Bass Bay and Big Muskego Lake (Figure 4). Like native milfoils, Eurasian Water Milfoil (EWM) has slender stems whorled with feather-like leaves. Northern Water Milfoil (*Myriophyllum sibiricum*), a native milfoil that is also known as Spiked Water Milfoil, is very similar but has fewer leaflets per leaf (7-11 pairs, versus 9-21 pairs). EWM is an opportunistic species, establishing rapidly in early spring. Stolons, lower stems and roots persist over winter and store carbohydrates that enable EWM to begin growing earlier than native plants. They “top out” on the surface and form a canopy that shades out native aquatic plants. Monotypic stands of EWM lower the habitat value by reducing the quantity of beneficial native plant species which native wildlife have evolved to depend upon. Beds can become so dense that they fence out larger fish species and affect predator-prey relationships. Recreational uses, such as swimming, boating, and fishing, are also inhibited.

Most noteworthy of the changes in comparing pre- and post-drawdown aquatic plant data (Table 3, above) is the decrease in Eurasian Water Milfoil. These data support the implementation of a lake drawdown as a viable control option in the management of this nuisance plant.

Figure 4: Eurasian Water Milfoil

Purple Loosestrife

Purple Loosestrife (*Lythrum salicaria*) is a nonnative emergent plant that grows in wetlands, along shorelines and adjacent uplands. This plant displaces native wetland plants and forms monotypic stands that are of little use to native wildlife. Chapter 4 details management strategies that have been used to control this invasive plant.

Cattails

Most of the cattails that grow around Big Muskego are the Broad-leaved Cattail (*Typha latifolia*). Although this is a native plant species, it can become invasive and forms monotypic stands because they easily propagate both asexually and by seed. When hybridized with another native cattail, Narrow-leaved Cattail (*Typha angustifolia*), the hybrid plant (*Typha x glauca*) is extremely aggressive and out competes its parents and other native species when established.

However, cattails have many positive qualities and should not be regarded in the same light as nonnative invasive plants. Stands of cattails are desirable to reduce the "fetch" or unbroken stretch of open water of a lake. This reduces wind generated wave action and the resulting re-suspension of sediments. Emergent plants such as cattails create habitat for a variety of organisms. These plants are a critical component in the life cycle of damselflies and dragonflies. The nymph stages of these insects utilize emergent plants to crawl out of the water, pupate and hatch into adults. Dragonflies and damselflies are important natural control agents for mosquitoes, feeding voraciously upon mosquito larvae as nymphs and adult mosquitoes as free-flying adults. Muskrats and many species of waterfowl are also dependent on cattails for both food and shelter. Management of cattails growth is discussed in Chapter 3.

Phragmites

Phragmites australis, or common reed, is a wetland plant that is widely distributed throughout the world. However, nonnative genotypes have been introduced to North America and have become problematic invaders. Phragmites can grow over 12 feet high in dense stands and is long-lived. Phragmites is capable of reproduction by seeds, but primarily reproduces asexually by means of rhizomes.

WILDLIFE

Big Muskego Lake and associated marsh provide habitat for a great diversity of wildlife. The Southeastern Wisconsin Regional Planning Commission classifies the area as a natural area of local significance. Many species of waterfowl and shorebirds utilize the area for summer nesting and as a stopover along their migration route to more northern latitudes.

Endangered, Threatened, and Rare Species

Endangered wildlife resources of Big Muskego Lake and surrounding marsh include the Forster's Tern and Common Tern (both endangered), the Great Egret and Osprey (both threatened), and the Black Tern (rare).

Big Muskego Lake is one of the few places in Wisconsin to have nesting colonies of the endangered Forster's Tern (*Sterna forsteri*) (Figure 5). These small gull-like birds feed primarily on small fish by diving head first into the water. They migrate from their wintering area of the Gulf Coast to isolated areas of suitable marsh habitats such as Big Muskego Lake to establish nesting colonies. They begin nesting in May on floating mats of vegetation, old muskrat houses, or mud bars. They usually hatch three eggs and defend their young by dive-bombing intruders.

Figure 5: Forsters tern

The Common tern (*Sterna hirundo*), listed as endangered in Wisconsin, is similar to the Forster's Tern but can be distinguished by its darker primary wing feathers. Fewer Common Terns are sighted around Big Muskego Lake than Forster's Terns. They winter in southern US coastal areas and in the southern hemisphere and migrate to temperate northern hemisphere areas for breeding. These colony-nesting birds are declining in many areas due to predation from gulls.

Black Terns (*Chilidonias niger*) are listed as rare in Wisconsin and are the only species of tern to have solid black summer plumage on its head. They often catch small fish and other food items by picking them from the water's surface rather than diving head first like other species of terns. Black Terns are semi-colonial nesters and migrate to South America for winter. Big Muskego Lake supports a large summer population of Black Terns.

The Great Egret (*Casmerodius albus*) is a large, white, graceful wading bird listed as a state threatened species. They stalk fish, frogs, and other aquatic life in marshes and shore areas. While some are year round residents of coastal areas of the southern US and Central America, some migrate to more northern latitudes for the breeding season. They lay and incubate a clutch of three or four eggs in nests constructed of sticks/twigs in trees above water.

Osprey (*Pandion haliaetus*), a threatened species, is sometimes confused with bald eagles. However, these "fish hawks" can be distinguished by their smaller size, dark cheek patch, and narrower, angled-back wings. These raptors hover over water and plunge feet first to catch fish with their sharp talons. Discontinued use of organochlorine pesticides, like DDT, is thought to be responsible for the Osprey's comeback from endangered status in 1972 to threatened in 1989. Reintroduction of Ospreys to Big Muskego Lake is discussed in Chapter 4.

FISH

The fertile waters of Big Muskego Lake and Bass Bay support a fishery that includes Northern Pike (*Esox lucius*), Largemouth Bass (*Micropterus salmoides*), Yellow Perch (*Perca flavescens*), Black Crappie (*Pomoxis nigromaculatus*), White Crappie (*Pomoxis annularis*), Bluegill (*Lepomis macrochirus*), Pumpkinseed (*Lepomis gibbosus*), Warmouth (*Lepomis gulosus*), and Green Sunfish (*Lepomis cyanellus*). A diverse assemblage of forage fish species also inhabits the waters - including Golden Shiner (*Notemigonus crysoleucas*), Fathead Minnow (*Pimephales promelas*), and Darter species (*Etheostoma spp.*). Fish growth rates and angling success was very good in the years immediately following the lake rehabilitation project. The Lake Chubsucker (*Erimyzon sucetta*), designated as a state species of special concern, is a soft-bodied forage fish that was successfully introduced to the lake as part of this restocking.

The Wisconsin DNR conducted a comprehensive fisheries survey on Big Muskego Lake and Bass Bay in spring 1999 and 2000 to evaluate the success of post-chemical treatment restocking and restrictive size and bag limits on the developing fishery. These results are summarized in Chapter 4 and the full report can be found in Appendix B.

Winter Fish Kills

With its shallow depth and high content of organic matter, Big Muskego Lake is susceptible to winter fish kills resulting from oxygen depletion. The oxygen within the limited volume of water between the ice layer and lake bottom can be readily consumed through the respiration of organisms and the decomposition of organic matter. Furthermore, little oxygen is produced in years of deep snow cover due to reduced light penetration and photosynthesis. Because of its deeper basin, Bass Bay provides a habitat less susceptible to winter fish kills and serves as a refuge during winterkill conditions on Big Muskego Lake.

LAND USES AND NONPOINT SOURCE POLLUTANT LOADING

Nonpoint sources of pollution are those that cannot easily be traced to a single source such as a discharge pipe. Nonpoint source pollutants are carried off in storm water runoff from farm fields, streets, parking lots, barnyards, construction sites, and other sources. Principal pollutants of concern include sediment, nutrients, bacteria, oils and grease, and heavy metals. Loads of these materials carried by runoff from rainwater and snow melt affect the water quality in lakes and streams.

Land uses within the watershed affect the nonpoint source pollutant loading of Big Muskego Lake and Bass Bay. These land uses are depicted on Map 4. The City of Muskego Comprehensive Stormwater Management Plan Phase 2 identified loadings of pollutants from various land uses within a study area that includes most of the direct watershed to Big Muskego Lake. For established land uses, agricultural use was responsible for 93% of the sediment loading and 80% of the phosphorus loading in 1996. The stormwater plan estimates that 80% of the sediment load and 52% of the phosphorus load will be derived from agricultural uses in 2010.

However, when considering all of the nonpoint sources, construction site erosion accounts for 63% of sediment loading, compared to 32% from agricultural use (City of Muskego Comprehensive Stormwater Management Plan Phase 2). Although it can be expected that sediment loading will diminish once development has stabilized, the *process* of developing lands into other uses is the biggest nonpoint pollution source of sediment for the waters of Big Muskego Lake and Bass Bay.

Non-agricultural land uses are expected to account for roughly half of the phosphorus loading in 2010. The greatest percentage of non-agricultural phosphorus loading is expected to come from residential development. Studies show that lawn fertilization is a significant source of phosphorus pollution. A correlation exists between phosphorus concentrations in lawn runoff to phosphorus concentrations found in lawn soils. Median dissolved phosphorus concentration in runoff from fertilized lawns is twice that of unfertilized lawns (USGS, 2002).

HUMAN RECREATIONAL USES

Lakes attract people for a variety of reasons. As discussed above, Big Muskego Lake with its extensive marsh and islands of emergent plants provides habitat for a plethora of fish and wildlife. Before European settlement, Native Americans utilized the abundant fish and wildlife of the lake and marsh for sustenance. Waterfowl hunters harvested ducks on the lake for market until as recently as the early 1920's. Today hunting and fishing continues to draw people to the waterway as a recreational activity.

Although there is residential development along many portions of Big Muskego Lake, it is generally set back of the open water due to the extensive cattail fringe and wetlands. Slightly more than half of the shoreline on Bass Bay is developed with residential housing. Collectively there are 168 riparian landowners on Big Muskego Lake and Bass Bay as of June 2004.

The major recreational activities on Big Muskego Lake include fishing, hunting, and wildlife viewing. There are also three gun clubs located on the lake that offer trap shooting. Due to the shallow waters and muck bottom, the lake is not well suited for swimming, water skiing, and personal watercraft operation. The deeper basin on Bass Bay is more favorable for these recreational activities.

Most riparian owners have at least one watercraft to use for lake recreation. Most recreational lake users however do not live on the lake or bay. The City of Muskego provides a public boat launch on Durham Drive at the north end of Big Muskego Lake and operates the launch at Boxhorn Gun Club on Boxhorn Drive. Hunters Nest Resort on Durham Drive also facilitates the launching of boats.

Statistics for usage of City-operated launches are provided in Table 5. To calculate overall lake usage it is assumed that privately operated launches and on-lake users would collectively equal the number of launches from the public access sites. Under this assumption, there are approximately 7,000 watercraft launched annually on Big Muskego Lake/Bass Bay. Assuming 1.5 persons/craft, it is estimated that 10,500 persons use Big Muskego Lake and Bass Bay during the open water season. Assuming a nine-month open water season, an average of 38 persons per day use Big Muskego Lake and Bass Bay.

Year	Daily Launches	Annual Pass Launches (est.)	Total
1998	1,559	1,428	2,987
1999	3,221	1,351	4,572
2000	3,162	2,020	5,182
2001	571	484	1,055
2002	1,848	2,011	3,859
5-yr. Total	10,361	7,294	17,655
Average	2,072	1,459	3,531

Table 5: Public Boat Launch Usage on Big Muskego Lake

Lake District Survey

As part of this Plan, a survey was sent to all residents of the Big Muskego Lake/Bass Bay Protection and Rehabilitation District to inventory how people use the lake and gather public opinion on the lake's condition. Of 362 surveys sent, there were 177 respondents (49%), which is considered an excellent return rate for a mail survey. The complete survey analysis and summary are found in Appendix C.

Fishing was the activity cited by most people as the primary reason that they use Big Muskego Lake and Bass Bay. The next most popular reasons, in order, were: enjoying the view, observing wildlife, motorized boating, hunting, and entertaining friends and relatives. However, responses varied depending upon where respondents lived. For Bass Bay residents, observing the view was the most popular use cited.

The high ranking of enjoyment of the view is an important consideration in managing the waterway for human uses. Although water-based recreational activities come to mind when thinking of lake uses, consideration should be given to how these activities impact passive uses such as simply viewing the lake.

Recognition of the Natural Resource Value

Big Muskego Lake and the surrounding marsh have long been recognized as an outstanding natural resource. Aldo Leopold even mentions the marsh in his most famous writing, *A Sand County Almanac*. The Southeastern Wisconsin Regional Planning Commission classifies Big Muskego Lake Marsh as a natural area of local significance.

The Wisconsin Department of Natural Resources recently led a two-year effort to identify Wisconsin's natural resource "gems." The culmination of this effort is *Wisconsin's Land Legacy Report*, which sought to identify the places believed to be most important to meeting Wisconsin's conservation and recreation needs over the next fifty years. The Legacy Report identified 228 places statewide and collectively they are the special places that "make Wisconsin Wisconsin." Big Muskego Lake, with its wetland fringe and adjacent uplands is one of those 228 places. Moreover, the report identifies Big Muskego Lake as one of only 10 legacy places identified within the South Lake Michigan Coastal Ecological Landscape.

Chapter 3
SHALLOW LAKE MANAGEMENT CONCEPTS

INTRODUCTION

The ecology of shallow lakes is quite different from that of deep lakes. Shallow lakes tend to have higher nutrient concentrations, resulting in greater productivity and biodiversity. Shallow lakes are also more easily affected by fluctuations in water level. They do not develop thermal stratification in summer and mixing readily cycles phosphorus and other nutrients from the sediment. Restoration efforts that have been successful on deep lakes - reversing eutrophication through phosphorus reduction - have often failed on shallow lakes. Therefore shallow lakes require a specialized management approach.

ALTERNATIVE STABLE STATES MODEL

Researchers have found that shallow lakes tend to be in one of two stable states. Over a wide range of nutrient concentrations, both plant-dominated and algal-dominated states can exist as alternatives (Scheffer, 1990, and 1998; Moss, 1998). The preferred plant-dominated condition is typified by seasonal windows of clear water where algae are grazed to low levels, macrophytes (rooted aquatic plants) dominate, and gamefish like Bluegill, Pumpkinseed, Northern Pike, and Largemouth Bass are dominant. The alternative algal-dominated state is typified by high available phosphorus levels, turbid water, dominance of algae, a relative absence of macrophytes, and is dominance by benthivorous fish (bottom feeding fish like carp and bullhead). Turbid water puts sight-feeding gamefish at a disadvantage, and often results in slower growth rates and size. Figure 6 graphically illustrates the two stable states.

Shallow lakes can shift or “switch” between these states, although the reasons are often difficult to pinpoint. Lake researchers have identified conditions that resist a switch and have termed these “buffers.” They have also identified conditions that will likely induce a switch between the two states.

Figure 7 illustrates the relative stability of each state under various nutrient conditions (Scheffer, 1993). The “marbles” in the valleys of the landscape diagram correspond to stable ecological conditions. In the oligotrophic (nutrient poor) situation in the top diagram the plant-dominated, clear state is the only stable condition. Likewise in the hypereutrophic (extremely nutrient rich) condition on the bottom diagram the algal-dominated, turbid state is the only stable condition. The middle three diagrams show how the marble may rest within two alternative valleys, but how nutrient enrichment affects which state within which the marble is more likely to rest. Continued nutrient enrichment gradually causes the stability of the clear state to shrink to nil, where the lake is more vulnerable to perturbations that would shift the equilibrium to the turbid state.

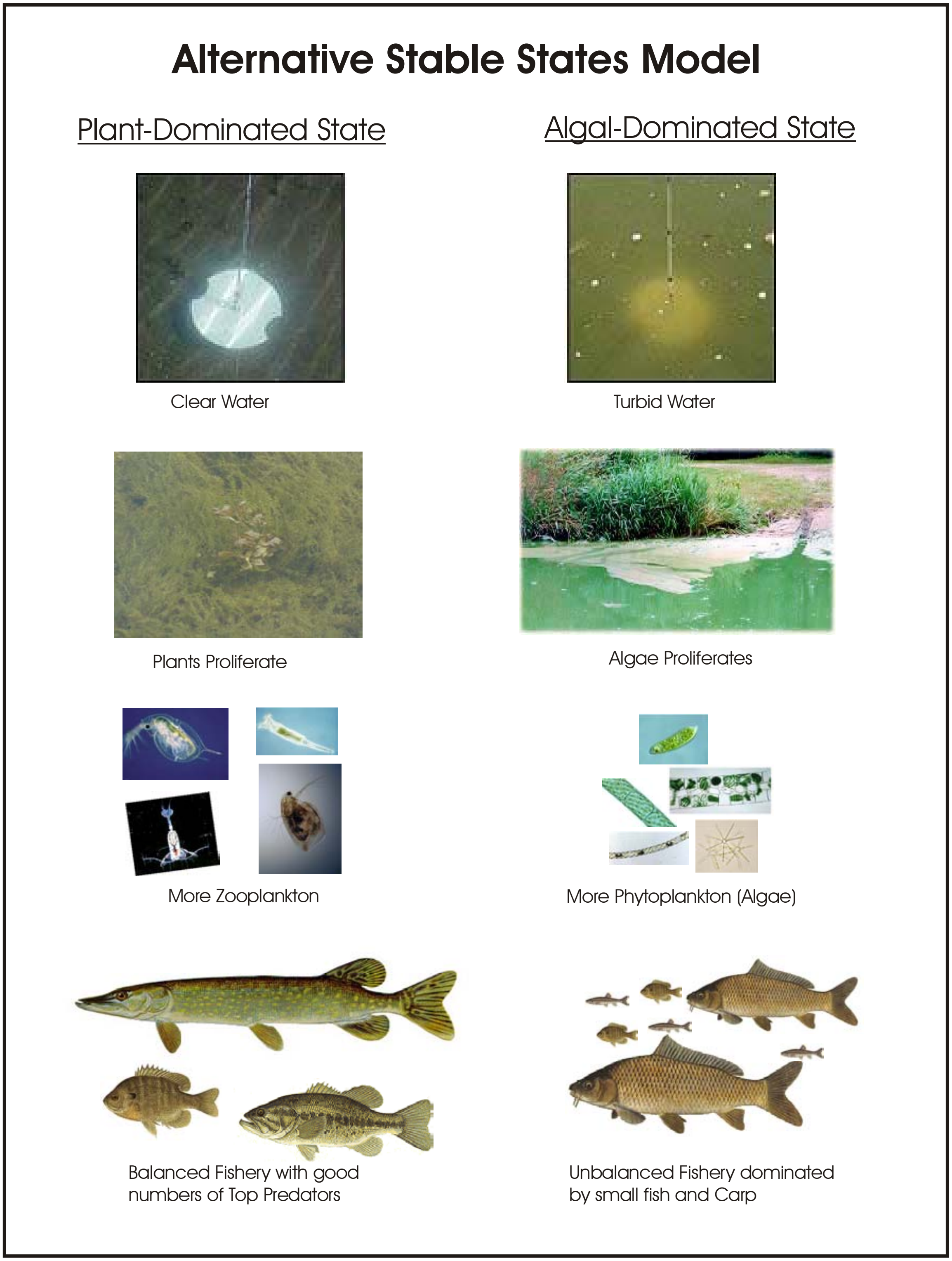


Figure 6: Alternative Stable States Model

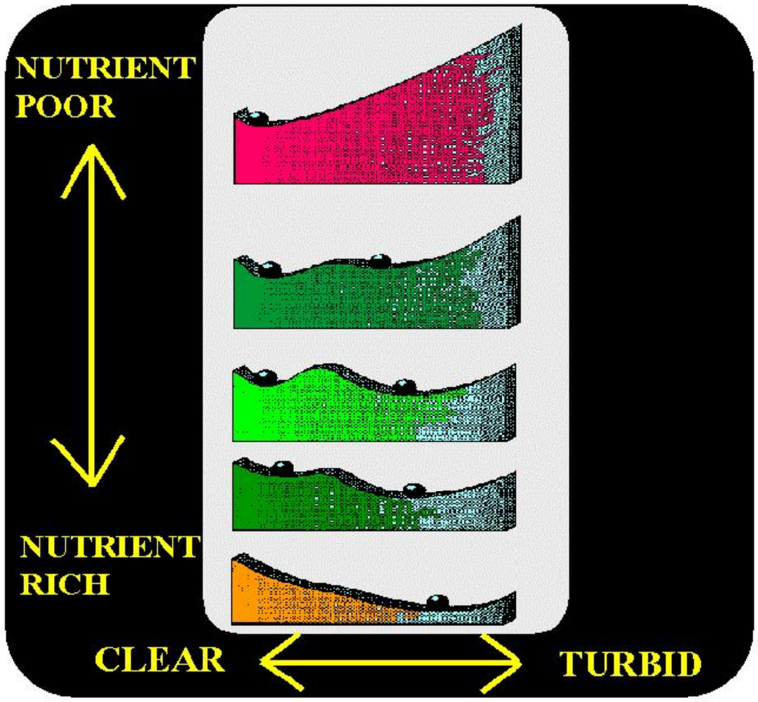


Figure 7: Stability of Each Alternative State

Buffers for the Plant-dominated (Clear-Water) State

Moss (1998) identifies particular sets of buffer mechanisms that can stabilize each of the alternative states. The plant-dominated state is buffered by the following factors:

1. Suppression of wave action or eddy currents. Stands of rooted emergent plants reduce open fetch areas, which in turn lessen the likelihood of submergent plants becoming uprooted. Beds of submergent plants also absorb wave energy, reducing the re-suspension of sediments and resulting turbidity. This turbidity could in turn, block sunlight to the plants causing their decline.
2. Uptake of nutrients by plants. Plants take up large amounts of both nitrogen and phosphorus (luxury consumption) compared to their immediate growth needs.
3. Structural refuges for zooplankton. Plant photosynthesis changes the chemistry of water located near it. Through inorganic carbon equilibria, carbon dioxide and bicarbonate are withdrawn and pH values can rise above 9. This appears to inhibit fish activity and thus a refuge from fish predation is created for zooplankton within the bed of aquatic plants (Beklioglu and Moss, 1996).
4. Allellopathy and provision of habitat for grazers of periphyton. Periphyton algae can pose a threat to aquatic plants by forming a fur of growth on their surface and compete for sunlight, nutrients and carbon dioxide. Laboratory experiments show that plants secrete substances that inhibit the growth of algal cultures (Forsberg, et. al., 1990). In addition to this allelopathy, plants provide habitat for periphyton grazers such as snails, mayfly nymphs, and chironomid larvae.
5. Production of structured sediment suitable for plant germination. At the end of the growing season, plants lay down coarse material that stabilizes sediments and provides a good rooting medium for the following year.

Buffers of the Algal–Dominated (Turbid-Water) State

1. Maintenance of open habitat conducive to wind mixing. Greater fetches of open water can produce larger waves with greater energy to stir sediments that block sunlight and inhibit the establishment of rooted plants. Phytoplankton also rely on eddy currents to keep them suspended and re-supply nutrients.
2. Early algal growth competing with plants for sunlight and carbon dioxide. Algae grow rapidly because they have shorter diffusion pathways for the uptake of dissolved substances.
3. Maintenance of structureless habitat with no refuge for large zooplankton against fish predation. In shallow open water, lacking of structure and deep dark layers to provide refuges for zooplankton, fish easily remove large, efficient grazers such as water fleas (Cladocera). With grazing intensity reduced, phytoplankton flourish.
4. Production of small algal species with high capacity for light absorption. Small algal species are easily moved through the water column and can photosynthesize toward the surface. Their greater surface area to size ratio also makes them more efficient photosynthesizers.
5. Production of amorphous, high water-content sediment unsuitable for plant regeneration. Dead material from phytoplankton is more fluid and amorphous than that from plants. This creates an unstable rooting medium and is also vulnerable to resuspension resulting in turbidity that reduces light for plant development.
6. Maintenance of fish communities with high numbers of small fish. Structureless habitat favors large populations of small fish because their predators, such as Northern Pike and Largemouth Bass, need cover from which to ambush their prey.

Switches

The events or manipulations to a shallow lake system that cause a change between plant-dominated and algal-dominated states are known as a switch (Moss, 1998). A change from plant dominance to algal dominance is referred to as a forward switch. Reverse switches cause a change from algal dominance to a plant-dominated system and are often associated with intentional human efforts to restore a shallow water system.

Forward Switches

Two types of forward switches occur in shallow lakes: those that directly destroy the plant structure, and those that indirectly affect the plant structure by preventing buffer mechanisms from operating. The direct type includes mechanical harvesting of plants, the application of herbicides, or damage done by boating. It can also include natural damage from wind, storms, ducks, and geese (Moss 1998, Sondergaard et al 1996). Examples of indirect forward switches include the leakage of pesticides and other toxins that kill zooplankton, the addition of nutrients from surface run-off, and introduction of Common Carp. There is a strong correlation between the presence of pesticides in sediment and zooplankton mortality (Stansfield et al 1989). With populations of zooplankton reduced, lakes become susceptible to algal domination.

Water level in a lake is an important control variable with respect to aquatic macrophyte dominance. Vegetation can withstand turbid water more easily if a lake is shallower. A small shift in critical turbidity resulting from a higher water level can cause a loss of macrophyte coverage and a forward switch to the algal-dominated state (Scheffer, 1998).

Biomanipulation - Reverse Switches

Biomanipulation is an ecological management approach that manipulates the biomass of a particular level of the food web to have an effect on the biomass of another. The term originally encompassed a range of techniques applied to terrestrial and aquatic ecosystems. In aquatic systems it typically refers to top-down manipulation of fish communities, i.e. enhancement of piscivorous (fish-eating) fish populations and reduction of zooplanktivores and/or benthivores (Perrow et al, 1997). In one of the earliest published reports, Caird (1945) hypothesized that stocking of Largemouth Bass was responsible for reductions in phytoplankton through food chain interactions. Several researchers (Hrbacek et al, 1961; Brooks and Dodson, 1965; Hurlbert et al, 1971) found that planktivorous (plankton-eating) fish can severely reduce or eliminate *Daphnia*, the largest, most efficient grazers of phytoplankton. These results suggested that lowered planktivorous fish densities would maintain greater densities of *Daphnia*, and thus control algal biomass.

A reverse switch involves biomanipulating the fish community to reinstate the plant buffers and destroy the buffers of algal-dominance. An abundance of small, zooplanktivorous fish can quickly reduce the population of *Daphnia* that efficiently graze algae. Biomanipulation seeks to replenish the zooplankton population by reducing the population of their predators. To decrease populations of small zooplanktivorous fish, top predators, such as pike, are added to the system. As a biomanipulation strategy in Big Muskego Lake, the Wisconsin DNR stocks Northern Pike and panfish are managed for larger size. At larger sizes, panfish become more piscivorous in their feeding habits and help reduce the numbers of small, zooplanktivorous fish. Lower predation pressure allows the zooplankton community to thrive and prey on planktonic algae. Biomanipulation is graphically depicted in Figure 8.

Biomanipulation to attain a plant-dominated state can also involve eliminating Common Carp from the system, not just because of their zooplanktivorous habits, but more importantly, their behavior of stirring sediments and the resultant turbidity that inhibits plant growth. Because it is impractical to selectively remove carp while maintaining desirable fish species, total fish eradication is often performed for a biomanipulation project. The lake is then restocked with healthier balance of fish including more “top predator” piscivorous fish. In Big Muskego Lake, Northern Pike (*Esox lucious*) occupy the role as top predator. Other piscivorous fish include Largemouth Bass, Bluegill, and Yellow Perch. These fish keep the population of zooplanktivorous fish under control by preying on eggs and juvenile fish so that large zooplankton such as *Daphnia* are allowed to flourish and consume phytoplankton (algae). As a result, the water becomes clearer, allowing sunlight penetration and the proliferation of the submergent aquatic plant community. The established aquatic plant community utilizes the nutrients (i.e. nitrogen and phosphorus) that were the main food source of the algae, and the algae diminish. Overall, biomanipulation can be extremely successful, but often only for short periods of time. In order for it to be successful in the long term, the piscivore and zooplanktivore populations in the lakes must be closely monitored to prevent a forward switch.

Special fishing regulations on Big Muskego Lake serve as a biomanipulation strategy. The eight-inch size limit and 15 fish bag limit result in a panfish population with a larger size structure. At larger sizes panfish become more piscivorous in their feeding habits. Similarly, the 18-inch size limit for largemouth bass also maintains a population of larger sized bass.

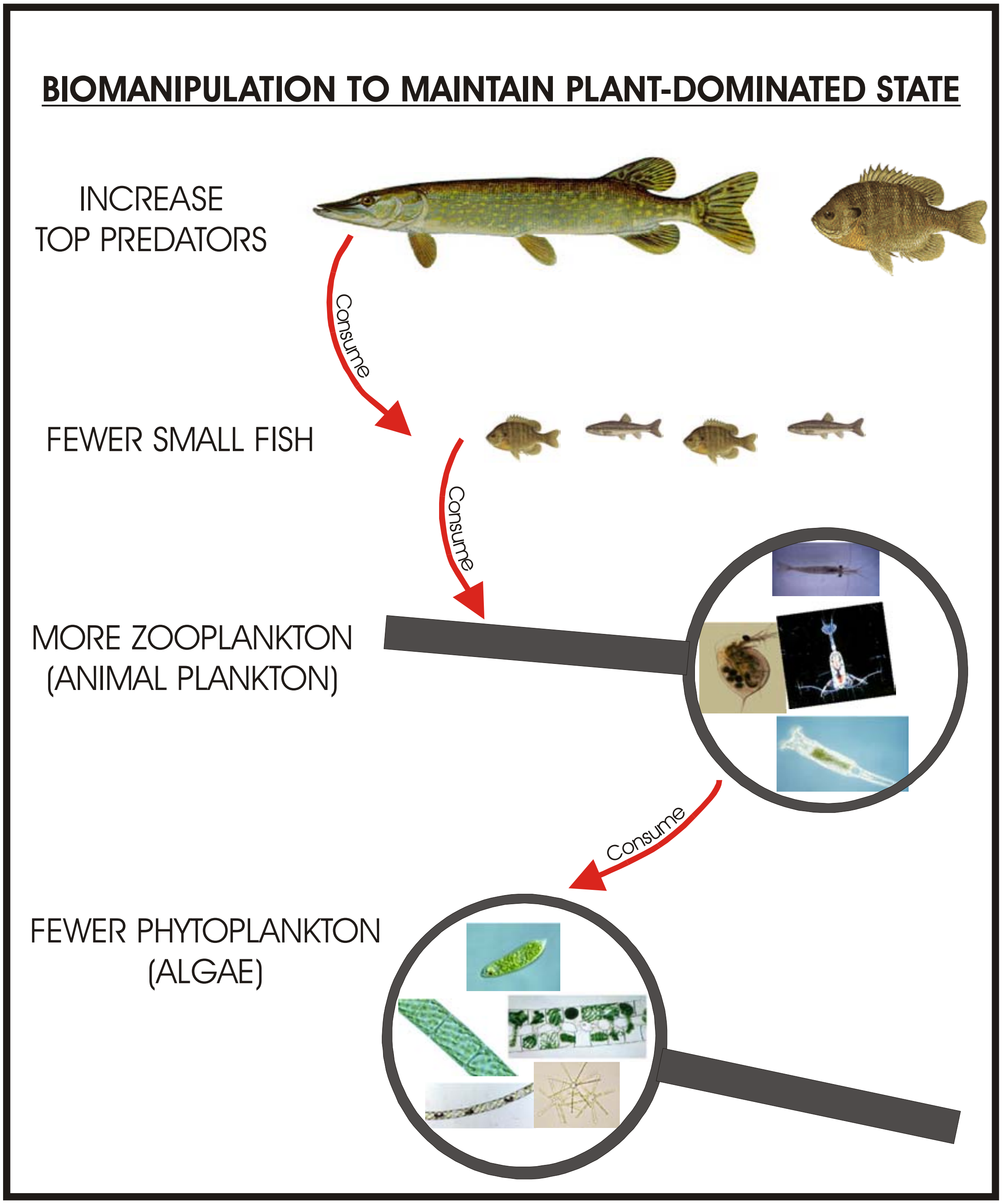


Figure 8: Biomanipulation to Maintain Plant-Dominated State

RESTORATION/REHABILITATION

Moss et al (1996) outline a basic strategy in the restoration of shallow lakes:

- Diagnosis of problem and establishing goals
- Removal of existing or potential forward switches
- Reduction of nutrient loading
- Biomanipulation
- Re-establishment of plants
- Re-establishment of appropriate fish community
- Monitoring of results

Identifying and removing the forward switches that have catalyzed the loss of plants is critical to a restoration project. The past must be reconstructed to identify any water level increases, deliberate management of the plant or fish community, pesticide use, introduced or exotic grazing animals, and plant-destructive human activities.

It is usually difficult to significantly reduce nutrients in a lake. Although it will help sustain the success of a restoration project, a project may proceed without this step, particularly if the Total Phosphorus concentration is below 100-150 *u*g/l (Moss et al, 1996).

Water Level Manipulation

Water level drawdown is a multipurpose management strategy used in shallow lakes. The technique is used to control certain aquatic plants, to manage fish populations, to repair structures such as dams and locks, and to carry out other improvement procedures such as dredging. Drawdowns are used in the management of submergent aquatic macrophytes through their exposure to dry, freezing, or dry, hot conditions for a period long enough to kill the plants (Cooke et al 1993). Minimization of the volume of water in a lake facilitates more economical chemical control of nuisance aquatic plants and fish. Drawdown also can consolidate sediments, reduce internal nutrient loading, and provide opportunities to conduct habitat and shoreline improvement projects.

A lowering of water level can buffer the plant-dominated state or even induce a reverse switch from algal-dominance to a plant-dominated state (Scheffer, 1998). Coops and Hosper (2002) suggest that shallow lake managers consider a combined strategy of restoring natural water level fluctuations and managed manipulations designed for a specific process to occur. An example would be a two-month recession of water to stimulate expansion of submersed vegetation.

Aquatic Plant Response to Drawdown

Aquatic plants do not all respond the same way to drawdown. In lakes with a mixture of species, exposure of the lakebed to a combination of dry and hot or dry and cold conditions may eliminate or curtail one nuisance plant and favor the development of a resistant species (Cooke et al 1993). The effects of a drawdown on Big Muskego Lake aquatic plant community can be seen in Table 3 in Chapter 2, which shows frequency of occurrence of aquatic plants before (1995) and after (1997) the drawdown. Comparison of aerial photography from 1995 to 2000 (Map 6 and Map 7, Chapter 4) graphically shows the response of the emergent plant community (primarily cattails) to the drawdown.

Cattail Response to Water Level Changes

The ability of cattails to grow within various water depths is linked to the conditions in which the plants convert stored carbohydrates to the energy needed for shoot growth (U.S. Fish & Wildlife Service, 1993). Starches stored in the rhizomes (fleshy, root-like stems) can be converted to energy both aerobically (with oxygen) and anaerobically (without oxygen). Passageways called “aerenchyma” located within living or dead cattail leaves supply a means through which the rhizomes can utilize oxygen from above the water. Aerobic starch conversion is much more efficient so stored energy is available to grow roots through greater depths of water. Conversely, if oxygen is not available, shoots emerging from the rhizomes have less energy to grow through the water column. For this reason, cattails are generally found growing in water less than four feet deep.

The process outlined above has implications for the management of cattail coverage in a marsh or lake. Cattail growth can be stimulated through complete exposure of the lakebed, which causes germination of seeds. Lowering water levels without exposing the substrate can also encourage cattail growth from the rhizomes of adjacent plants. In contrast, raising water levels can reduce the growth of cattails. Cutting of shoots and stems below the water necessitates the inefficient conversion of starches within cattail plants and causes a reduction in growth.

Populations of muskrats (*Ondatra zibethicus*) help keep cattails in check. These mammals utilize leaves for building lodges and the shoots and stems for food. Muskrats create open pockets of water that are utilized by nesting waterfowl. Upon careful examination of Map 7 one can see thousands of openings amid the cattails that were created by muskrats. Within each of these clearings is a muskrat lodge.

Chapter 4
HISTORICAL LAKE AND WATERSHED MANAGEMENT

INTRODUCTION

This chapter summarizes manipulations and management activities that have occurred on Big Muskego Lake and Bass Bay. Some of these activities will be referred to in the alternatives and recommendations chapters that follow. Data on the effects of previous management is quite helpful in determining the course of future management. It is important that previous failures are not repeated and those management activities proven successful continue to be considered as options.

HISTORICAL WATER LEVEL MANIPULATION

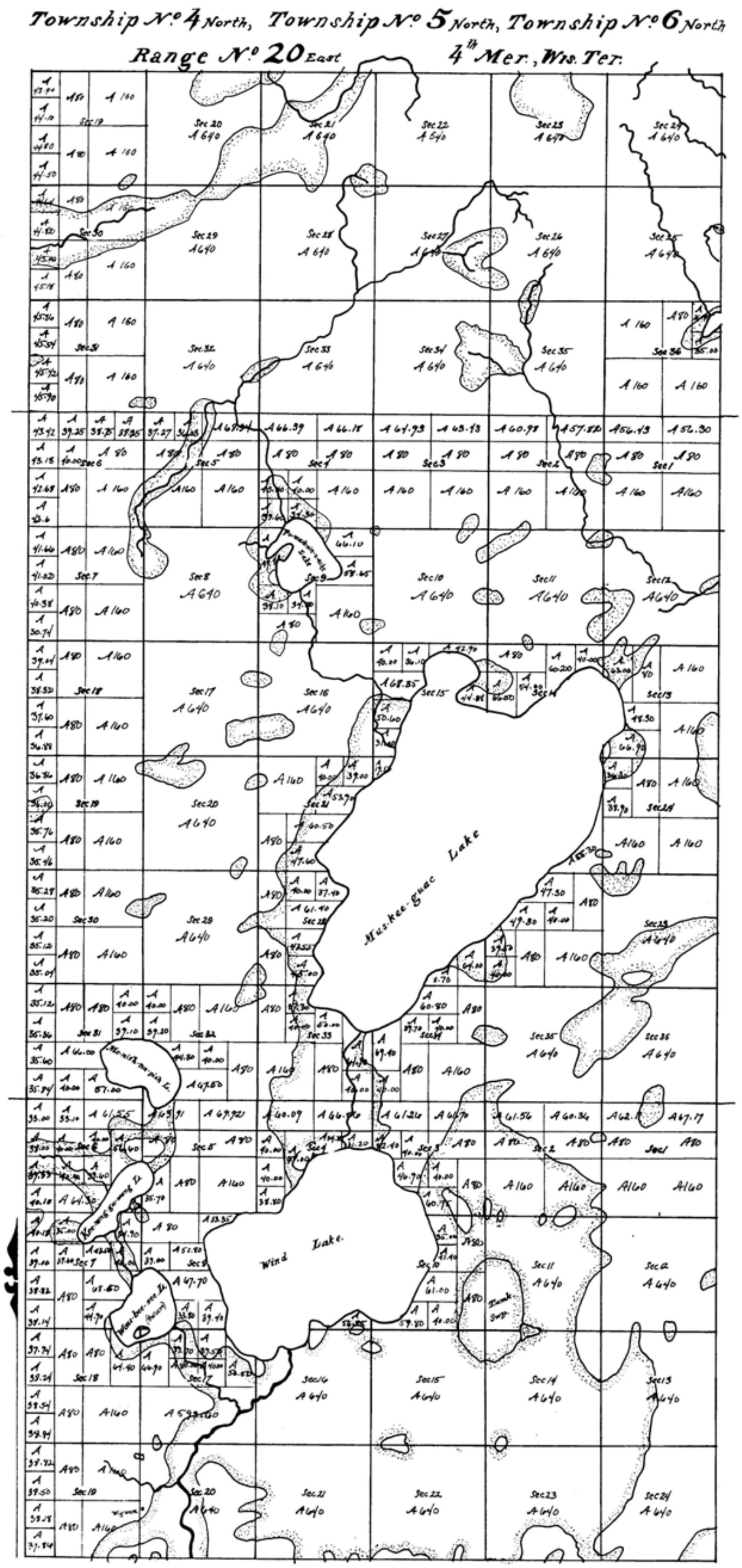
The natural water level on the Big Muskego Lake/Bass Bay system was historically much higher than its present (2004) level. The original lakebed encompassed over 3,200 acres of deep marsh and shallow lake and was known as Mus-kee-guac (Map 5). The area was drained in 1890 leaving distinct basins for Wind Lake, Big Muskego Lake, and Bass Bay. A second drainage was performed between 1892 and 1894 for the purpose of selling the reclaimed land to farming interests. The present water level on the Big Muskego Lake/Bass Bay system was established as a result of the 1896 Wisconsin Supreme Court decision *Priewe vs. Wisconsin State Land & Improvement Company* and is the same as the level established after the first drainage (SEWRPC, 1994). An outlet dam on the south end of Big Muskego Lake currently maintains this water level of approximately 771.5 feet above mean sea level.

POLLUTION SOURCES

Point Source Pollution Abatement

Beginning in 1967, Big Muskego Lake received the treated effluent from a wastewater treatment plant located just northwest of the lake. This facility served homes located roughly in the northwestern quarter of the City and periodically failed to meet effluent standards. Poorly treated effluent likely had a significant impact on nutrient levels within the water and sediments of Big Muskego Lake/Bass Bay. The treatment facility was closed in 1984 and the Milwaukee Metropolitan Sewerage District (MMSD) now manages the wastewater. Wastewater from sewer-serviced areas within Muskego is now treated outside of the watershed and treated effluent is discharged to Lake Michigan.

On-site wastewater disposal systems, when failing or poorly designed, can negatively impact surface water quality. Many homes that had historically been serviced by on-site wastewater disposal systems within the watershed are now also serviced by MMSD. Overall, the potential for nutrient loading to the watercourse from human wastewater sources has been greatly reduced over the last two decades.



Map 5: Reproduction of US Public Land Survey Map for Mus-kee-guac Lake Area: 1836

Nonpoint Source Pollution Abatement

The Wisconsin Department of Natural Resources (DNR) designated the Muskego and Wind Lake drainage area a “priority watershed” in 1991. The *Nonpoint Source Control Plan for the Muskego-Wind Lakes Priority Watershed Project*, completed in 1993, outlines strategies to lower the nonpoint source pollutants entering the surface waters in the watershed. Through this project the City of Muskego was eligible for certain grant funding for projects to abate these pollution sources. Financial assistance from the Wisconsin DNR has been provided to the City for the development of a storm water management plan, a storm water ordinance, an erosion control ordinance, stream and shore protection projects, water quality monitoring, and community information/education projects. In total, over $600,000 in funding was provided to the City through this grant program between 1994 and 2002.

Erosion Control Ordinance

The *Nonpoint Source Control Plan for the Muskego-Wind Lakes Priority Watershed Project* recommended drafting local ordinances controlling construction site and storm water runoff. In December of 1995, under the authority of Wisconsin State Statutes, the City of Muskego adopted an erosion control ordinance. The ordinance created Chapter 29 of the Municipal Code, which established local regulation of land disturbing activities to control erosion and sedimentation. Land disturbing activities in excess of 2,000 square feet require a permit from the City. The permit requires the submittal of plans for construction site “Best Management Practices” (BMPs) to minimize erosion and the transport of eroded material. A permit and BMP plans are also required for land disturbances of any size within 300 feet of a stream or 1,000 feet of a lake.

Storm Water Management Plan/Ordinance

Another recommendation of the nonpoint source control plan was the development of storm water management plans and ordinances. *The City of Muskego Phase 1 Stormwater Management Plan* (RUST, 1995) was developed to manage storm water within three sub-basins of the watershed that included the most intensely developed areas of Muskego. In 1999, *City of Muskego Stormwater Management Plan Phase 2* (Earthtech, 1999) was adopted to address storm water management for the remainder of the Muskego-Wind Lakes watershed that lies within the City. This plan also included management plans for the Lake Denoon watershed. These storm water plans provide recommended nonstructural BMPs such as improved agricultural practices and information/education programs, as well as structural BMPs such as the development of wet detention ponds.

In 1999, the City of Muskego Common Council adopted an ordinance to create Chapter 34 of the Municipal Code, which established local legislation requiring implementation of storm water BMPs. A major provision of the Code requires that new developments manage storm water runoff such that the peak flow generated from a 100-year storm under "post-development" conditions does not exceed the peak flow generated from a 2-year storm under "pre-development" conditions for a 24-hour duration storm event. The Code also requires that storm water management measures are designed to remove on an average annual basis a minimum of 80% of the total suspended solids load from the proposed on-site development when compared to the proposed on-site development without storm water management measures.

1995-1996 RESTORATION/DRAWDOWN PROJECT

Overview

The overall quality of Big Muskego Lake and Bass Bay had deteriorated as of the early 1990s. The lake had diminished water quality, a poor assemblage of emergent and submergent aquatic plants, declining waterfowl habitat, and a fishery dominated by carp. In summarizing the data collected in 1994, the USGS described the water quality of Big Muskego Lake as “poor to very poor” and Bass Bay water quality as “poor.” USGS classified both water bodies as eutrophic and described the phytoplankton population of Big Muskego Lake as dominated by blue-green algae.

The Plan for Rehabilitation

The catalyst to develop a plan and rehabilitate Big Muskego came from downstream Wind Lake. In the 1989, the Wind Lake Management District was successful in obtaining a U.S. EPA Clean Lakes Fund through the Wisconsin Department of Natural Resources (WDNR) to conduct a diagnostic and feasibility study of Wind Lake. The Wind Lake Management District contracted with the Southeast Wisconsin Regional Planning Commission (SEWRPC) to prepare a lake management plan with hydrologic and water quality information collected by the United States Geological Survey (USGS) (SEWRPC, 1991).

Wind Lake residents and DNR staff recognized that the water quality of Wind Lake was likely highly dependent on the suspended sediment and phosphorus load that was discharged from upstream Big Muskego Lake. SEWRPC had the forethought to specifically address the impacts of the discharges from Big Muskego Lake in the diagnostic and feasibility study of Wind Lake. The USGS estimated that 34% of the Wind Lake annual phosphorus load originated from the outlet of Big Muskego. Internal recycling was estimated to contribute another 50% of Wind Lake’s annual phosphorus load. The Wind Lake plan recognized that prior to addressing the internal load through an alum treatment at Wind Lake, the nutrient source at Big Muskego would have to be reduced by at least 75%. Accordingly, the Wind Lake Management Plan also provided recommendations for management alternatives to improve the water quality of Big Muskego.

The Big Muskego Lake/Bass Bay Protection and Rehabilitation District agreed to pursue developing their own recommendations to improve Big Muskego Lake and Bass Bay. Using the Wind Lake management plan as a starting point, volunteers from the Big Muskego/Bass Bay Protection and Rehabilitation District and staff from the WDNR began to meet every two weeks. After about four months of research and planning, this work group developed two alternative restoration plans for Big Muskego. The two plans as well as a “do nothing” alternative were presented to the residents of the District in a newsletter.

In March 1994, the residents of the Big Muskego/Bass Bay Protection and Rehabilitation District supported by a margin of 3:1 to implement a simple, but comprehensive lake restoration plan that included both a 12 month drawdown and a total renovation of the fishery.

The stated objectives of the drawdown project were to:

- Facilitate rough fish eradication
- Oxidize organic material (reduce amount of sediment)
- Increase depth of Big Muskego Lake (average of 1 foot compaction)
- Improve habitat for desirable aquatic plants, fish, and invertebrates
- Improve habitat for wildlife, including endangered and threatened species
- Provide favorable conditions for shoreline improvements
- Provide opportunity for reducing existing cattail stands

By the time the project was completed and the lake refilled in early 1997, the final list of lake management activities included all of the following:

- Implementation of an 18 month drawdown
- Installation of two 26.8 cfs pumps to facilitate drawdown
- Dredging of lake channel leading to outlet
- Deepening of the historical drainage ditch with explosives
- Elimination of the fisheries (Rotenone treatment)
- Burning of cattails to improve habitat
- Detail examination of the pre and post sediment characteristic
- Monitoring of aquatic plants pre and post drawdown
- Reconstruction of the outlet control structure
- Construction of an electric fish barrier at the outlet of Big Muskego Lake
- Construction of a public boating landing on Big Muskego Lake
- Repair of the southern dike structure
- Removal and disposal of carp
- Re-dredging of the channel between Big Muskego Lake and Wind Lake
- Restocking of zooplankton, amphibians and fish
- Adoption of restrictive fishing regulations
- Construction of three nesting islands
- Introduction of osprey and construction of osprey nesting platforms
- Chemical and biological control of Eurasian water milfoil and Purple Loosestrife
- Implementation of watershed nonpoint source controls
- Nutrient inactivation (alum) treatment of Bass Bay
- Designation of a DNR land acquisition zone around Big Muskego Lake

Implementing the Plan

The first management action was to drain Big Muskego Lake and Bass Bay. The 18-month drawdown was planned to consolidate sediments, shift the aquatic plant community and reduce the volume of water that would be treated with rotenone. The drawdown began in September 1995 by opening the 4-foot wide sluice gate at the Big Muskego Lake dam. In order to lower the water level as much as possible, corrugated pipes were hung over the dam as siphons and two pumps, each capable of discharging 26.8 cfs were put in place. In order to obtain the maximum drawdown, the channel in the lake had to be dredged during the winter of 1995 and a historic, in lake drainage channel from 1892 was reopened with the use of explosives.

Throughout the 18-month drawdown, water levels fluctuated in response to rainfall and operation of the pumps. In the end, at least 15 percent of the basin was drawn down for a total of 15 months from December 1995 through March 1997. The maximum drawdown of 3 feet was achieved for a four-month period during July 1996 through October 1996. During the first winter, the Eurasian Water Milfoil root crowns were desiccated and during the summer, emergent bulrushes and arrowhead were established along the near shore. Following the use of rotenone in October 1996, the sluice gate was closed and the lake began to refill reaching full pool in July 1997.

Chemical elimination of the fishery by the use of rotenone was the most significant activity that occurred during the drawdown. The chemical treatment was scheduled for late fall with hopes that treatment would occur before ice but still during cold weather that would slow fish decay and therefore, minimize the odor. Beginning on the first week of October 1996, all direct tributaries to Big Muskego, downstream from Little Muskego, and both lake basins, Big Muskego and Bass Bay, were treated with a target concentration of 0.5 ppm rotenone solution (7.5% active ingredient). Thirteen miles of tributaries were sprayed by the use of backpack sprayers and ATVs; Bass Bay was treated by injecting the rotenone below the water's surface with centrifugal water pumps; and areas of water on Big Muskego Lake were treated with the use of a helicopter. All in all, over 3,219 gallons of rotenone product was applied within the Big Muskego basin during a 4-day period in early October. The treatment was highly effective and within an hour of the treatment fish began to surface and were blown toward shore. The need for fish removal and disposal at the City of Muskego landfill was expected for Bass Bay along areas of shoreline development. The fish carcasses were not removed from Big Muskego Lake, except near the two or three access channels. Unfortunately, it seems that the majority of carp had moved into Bass Bay during the drawdown. By the end of October, WDNR staff, City employees and volunteers had picked up and hauled away 263,400 pounds of carp from Bass Bay and left another 60,000 pounds of carp decompose within drawn down Big Muskego Lake.

The rotenone was allowed to naturally detoxify and by the end of October the lake was ready for restocking. The first stocking efforts were zooplankton and fish from nearby lakes or purchased from private hatcheries. In a three-year period, more than 1.5 million fingerlings and adult fish and 4 million fry were stocked, encompassing over 20 species of forage and game fish. In order to foster some biomanipulation benefits and keep predation rates high, larger fish size limits and lower bag numbers were put in place.

With the application of rotenone in October 1996, the sluice gates were closed to prevent toxic effects to the downstream Wind Lake fishery and to begin the process of refilling Big Muskego and Bass Bay. By April 1997, the basins had reached full pool. That summer, the Army Corps of Engineers (ACOE) continued the aquatic plant and sediment monitoring programs, collecting the data necessary to compare pre- and post-drawdown conditions.

The primary purpose of the sediment monitoring was to document any substantial consolidation and to monitor for a pulse of phosphorus release following lake refill. If there was a substantial nutrient load and corresponding algae bloom as a result of sediment release following lake refill, it would be important to know that for future management actions. Sediment cores were collected pre, during and post drawdown from about 50 sites within the lake. The samples were taken to the ACOE's Eau Galle Aquatic Ecology Laboratory for chemical and physical analysis. As expected, the sediments were consolidated during the drawdown, with increases in mean density and decrease in moisture. Oxidation caused organic matter to decrease from pre-drawdown levels. Although total phosphorus and extractable phosphorus declined after the lake was refilled, there was an increase in soluble reactive phosphorus release during this time (James et al. 2001).

Associated Projects

A number of the accessory management activities were undertaken during the summer of 1996, when Big Muskego Lake was reduced from over 2,000 acres to less than 700 acres. WDNR wildlife managers burned a number of the wetland areas dominated by cattails and with support from Ducks Unlimited, three 1-acre habitat islands were constructed in the southeastern portion of the lake. The outlet control structure at Big Muskego was reconstructed and an electric fish barrier was installed to prevent the foray of carp from downstream Wind Lake from migrating into Big Muskego. With a donation of land from a local sportsman club, the WDNR and City of Muskego re-dredged an old navigation channel and constructed a boat launch along the northern shore of Big Muskego providing the first publicly owned access to the lake.

Osprey Restoration Program

Several partners were involved in a program to establish an osprey population in the vicinity of Big Muskego Lake: The Wisconsin Ornithological Society, Schlitz Audubon Nature Center, Big Muskego Lake/Bass Bay Protection and Rehabilitation District, Wisconsin Electric Power Company (WE Energies), Wisconsin DNR, and GE Medical Systems. GE Medical Systems provided funding to relocate ospreys from nests in northern Wisconsin where the species is more abundant. Approximately six fledgling ospreys have been introduced to Big Muskego Lake/Bass Bay annually since 1998. Volunteers from the Lake District constructed a hack box overlooking the lake in which the young ospreys were housed until they were ready to fly.

The goal of the project was to have ospreys imprint on the area and return to nest, resulting in the restoration of the species locally. After spending the initial summer on Big Muskego Lake, where they learn to fish and feed themselves, the birds migrate to Central or South America. Upon reaching sexual maturity in three to five years, surviving ospreys would likely return to nest at Big Muskego Lake. In 1997, Wisconsin Electric Power Company (now known as WE Energies) erected six nesting platforms along the western shore of Big Muskego Lake to facilitate nesting of returning birds. As of 2003, no ospreys had been observed nesting on any of these platforms, although three non-nesting adults frequented the area that summer.

In 2002, the Wisconsin Ornithological Society received a grant from GE Medical Systems to fit two juvenile ospreys with satellite telemetry transmitters (Figure 9). One female osprey was tracked to Panama in that fall and migrated to the Minneapolis area in 2004. The other is believed to have died, as its signal had never left Muskego and the bird had not been seen. Several adult Ospreys, not confirmed as "stocked" birds, have been observed around Big Muskego Lake in 2003 and 2004 but no successful nesting activity has yet been documented.

Figure 9: Female osprey fitted with a satellite transmitter

Effect of Drawdown on Aquatic Plants

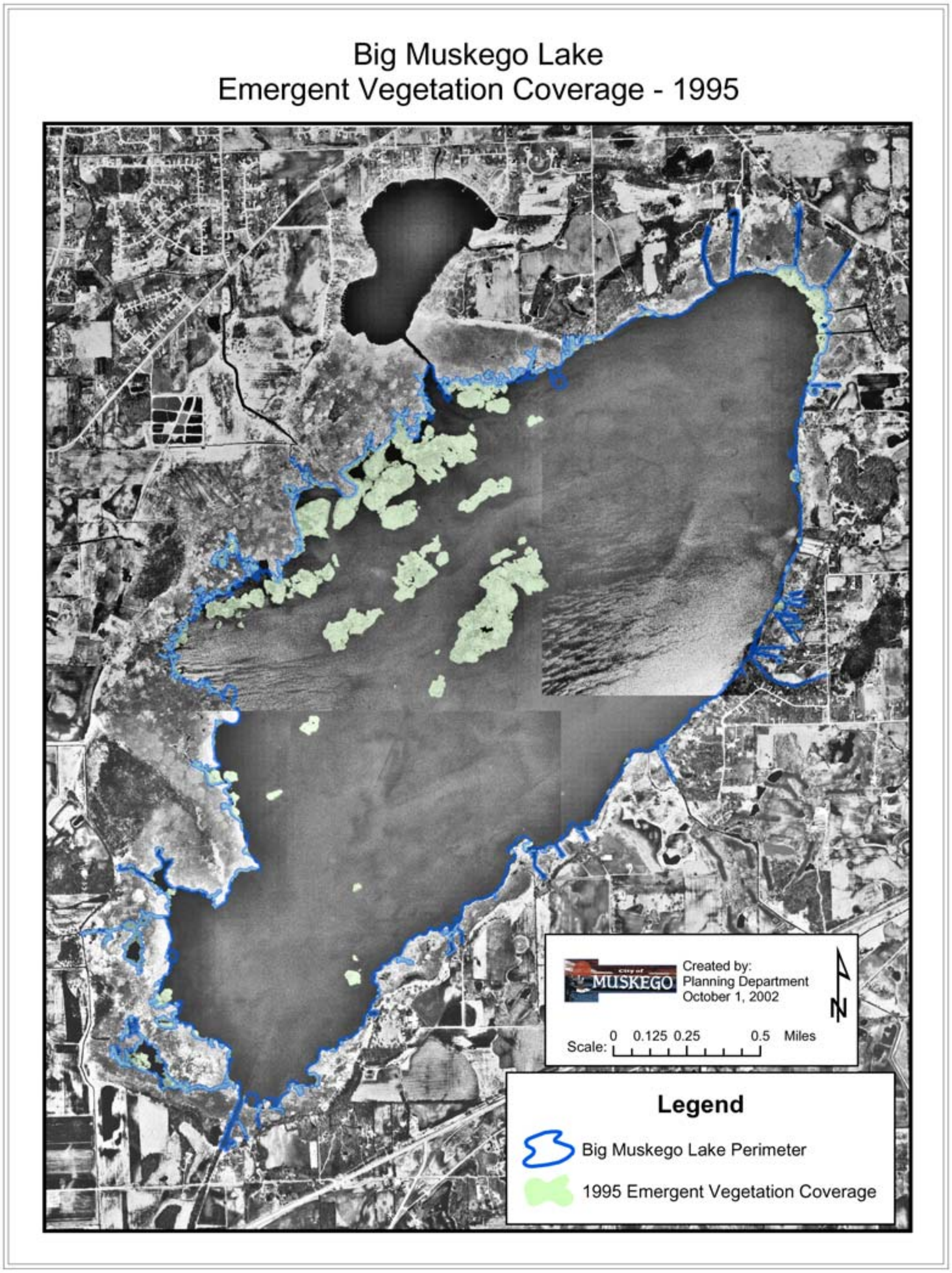
Submergent Aquatic Plants

The rehabilitation project caused a "reverse switch" on Big Muskego Lake to a state of plant-dominance that has remained stable as of 2004. Aquatic plant diversity increased from an average of 1.45 species per site in 1995 to 4.4 species per site in 1997 (Table 4, Chapter 2). Most of the increased diversity was due to native and more desirable species. The Floristic Quality Index increased from 23.8 in 1995 to 29.0 in 1997.

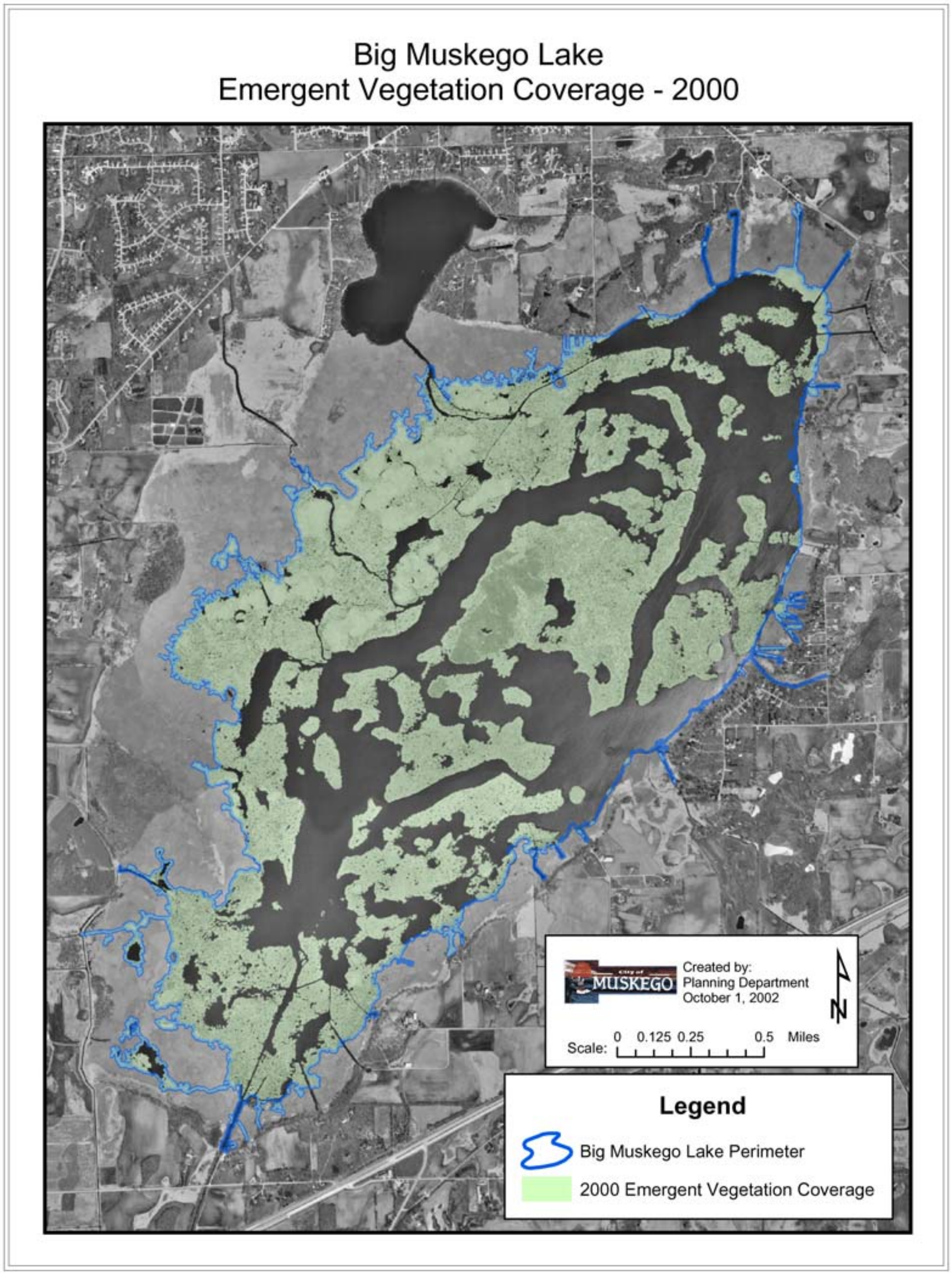
A major objective of the drawdown was to expose the sediments and reduce the viability of rooted nuisance macrophytes (RUST, 1995). Results of the ACOE aquatic plant study showed that EWM dropped from an occurrence frequency of 89.7% of the sampling sites in 1995 to 35.9% of the sampling sites in 1997 (Table 3, Chapter 2).

Emergent Aquatic Plants

The water level drawdown element of the rehabilitation project caused cattails and other emergent aquatic plants to increase in coverage. Prior to the drawdown, the lake had an extensive fetch of open water (Map 6). After refilling, the result was a maze of cattail islands with pockets and channels of open water (Map 7). Emergent vegetation coverage increased from 9% of the surface area in 1995 to 56% in 2000 (Figure 10). Stands of emergent vegetation served to reduce wave action, thereby minimizing sediment re-suspension. This helped promote the growth of submergent aquatic macrophytes.



Map 6: Emergent Plant Coverage Before Drawdown



Map 7: Emergent Plant Coverage Post-Drawdown

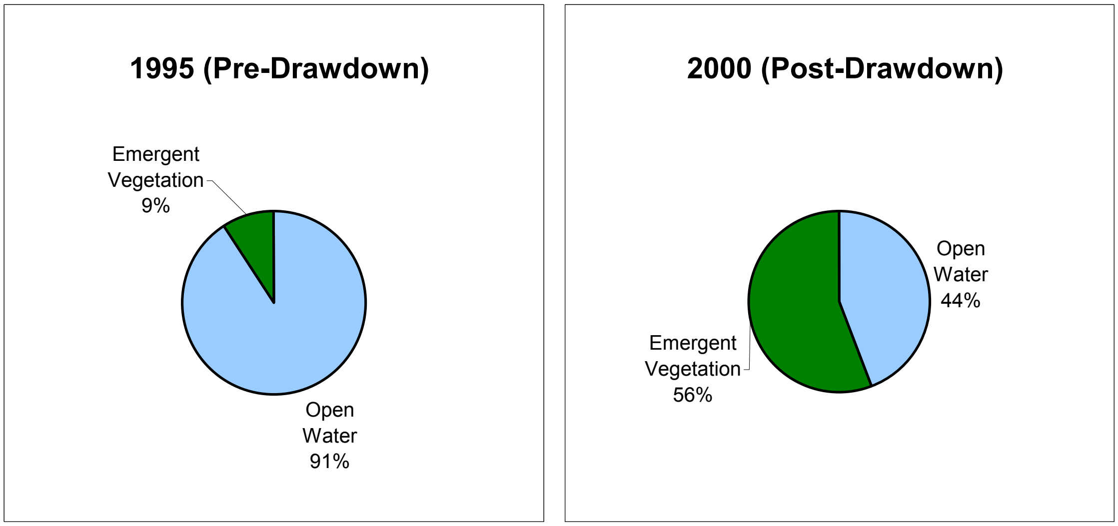


Figure 10: Emergent Plant Coverage on Big Muskego Lake

Effect of Rehabilitation Project on Water Quality

Since the drawdown and alum treatment, some Secchi disk readings and total phosphorus and chlorophyll *a* concentrations of Bass Bay have fallen into the mesotrophic range. In Big Muskego Lake, chlorophyll *a* concentrations measured since the drawdown tend to lie within the mesotrophic range. Total phosphorus concentrations and Secchi disk readings in Big Muskego Lake, while still eutrophic, moved closer to the mesotrophic category (Figure 2 in Chapter 2).

Sediment Response to Restoration Project

The United States Army Corp of Engineers (ACOE) conducted a study to examine the effects of lake drawdown on the physical and chemical characteristics of the lake sediments (James, et al, 2001). Prior to the drawdown, the sediments of Big Muskego Lake had high moisture content, a low sediment density, and a high content of organic matter. Lake drawdown was effective in consolidating sediment (i.e., increasing sediment density) and causing a decrease in organic matter content. These responses in sediment texture and organic matter content have been shown to influence macrophyte growth potential (Barko and Smart, 1986). The prolific growth of rooted aquatic macrophytes after the drawdown project appears to support this concept.

Fishery Response

Fish growth rates and angling success was very good in the years immediately following the drawdown. The Wisconsin DNR conducted a comprehensive fisheries survey on Big Muskego Lake and Bass Bay in spring of 1999 and spring of 2000 to evaluate the success of post-chemical treatment restocking and restrictive size and bag limits on the developing fishery (Appendix B). Following the 1996 chemical eradication of the fishery, 1.5 million fingerling and adult fish were restocked along with 4 million fry. A total of 20 species of fish were stocked in the two waterbodies and their tributaries.

The survey found that the post-treatment stocking was very successful. Thirteen of the 20 species stocked had been recovered, along with 3 species that were not stocked by the DNR. Northern Pike, Largemouth Bass, panfish, and non-game species (minnows, suckers) had established populations and were reproducing. However, the DNR has not seen evidence of Walleye reproduction. Black, Brown and Yellow Bullheads had re-established populations in the lake either by immigration from the watershed or by illegal stocking. Although some Common Carp (*Cyprinus carpio*) had reentered the system, their overall numbers were low and the DNR had not seen evidence of reproduction. As of 2003, Big Muskego Lake carp numbers remained low.

Current management aims to keep a high density of game fish and a population of larger sized panfish in the system to prevent carp from reestablishing their former dominance. This biomanipulation strategy increases predation on small, zooplanktivorous fish. This in turn allows for zooplankton to control algae in the waterway.

Wildlife Response

Wildlife habitat improved dramatically as a result of the restoration project. There was anecdotal evidence that Forsters Terns, Black Terns, and Yellow Headed Blackbirds increased their numbers. Duck nesting activity increased, particularly Redheads (*Aythya americana*). Shorebirds and wading birds such as Great Egrets, Great Blue Herons, and Sandhill Cranes flourished in the restored marsh habitat. Muskrat numbers increased greatly as a result of the prolific cattail growth.

AQUATIC PLANT CONTROL

Chemical Control of Aquatic Plants

The principal target of chemical aquatic plant control efforts in Big Muskego Lake and Bass Bay has been nuisance growths of nonnative Eurasian Water Milfoil (EWM). Recent permit records show the following chemical treatments were made on Big Muskego Lake and Bass Bay. 2,4-D was applied to 4 acres in Big Muskego Lake in 1998, and 21 acres in Bass Bay in 1999 to control EWM. No EWM chemical control treatments occurred in 2000. In 2001, 2,4-D treatments took place in Bass Bay (32 acres) and Big Muskego Lake (3 acres). Approximately 30 acres of EWM were treated with 2,4-D in Big Muskego Lake/Bass Bay in 2002 and 2003.

The 2,4-D treatments were successful, but the effects were generally short-lived, with treatments controlling EWM plants for one season and the majority of these plants re-sprouting the following year. There has been some success on lakes in the area using 2,4-D to decrease the size or density of EWM beds if used for a number of years. Until recently, chemical EWM control activities on Big Muskego Lake and Bass Bay have not followed this consistent management approach.

Filamentous algal blooms have also been a periodic problem, particularly on Bass Bay. Common genera of these primitive plants include *Hydrodictyon*, *Spirogyra*, and *Cladophora*. Filamentous algal growth usually begins on the shallow lake bottom and layers are buoyed to the surface by the oxygen produced. It can then form a mat on the water's surface. This causes a hindrance to swimming, fishing, and boating activities and can produce an offensive odor. A chelated copper compound, called Cutrine Plus, was used to treat areas of nuisance algae in Bass Bay in 2002 and 2003.

Alum Treatment

Bass Bay was treated with alum in 1998. This treatment reduces phosphorus loading from the sediments to the water column. Reducing phosphorus loading, the limiting aquatic nutrient, subsequently reduces phytoplankton (algae) levels. The process uses aluminum sulfate to form an insoluble phosphate, thus preventing it from entering the water column. While this treatment reduces nuisance phytoplankton growths, in some cases it may actually increase macrophyte densities due to increased sunlight penetration into the water column.

Secchi disk readings improved and Chlorophyll *a* concentrations were reduced in Bass Bay for about a year immediately after the alum treatment. Although the Chlorophyll *a* concentration spiked somewhat in the summer of 1999, these parameters have shown general improvement over pre-treatment levels (Figure 1, Chapter 2).

Weevils as a Biological Control of Eurasian Water Milfoil

Weevils (*Euhrychiopsis lecontei*) were stocked into Big Muskego Lake and Bass Bay in 1997 to control EWM. Studies have shown that these tiny native aquatic insects feed heavily upon EWM plants. Adult weevils graze on EWM leaves and stems and the larvae burrow within the stems. Weevils cause tissue damage that makes EWM plants susceptible to bacteria and fungi. Subsequent tissue damage causes plants to lose buoyancy and collapse (Sheldon and Creed, 1995). This causes EWM to lose its competitive advantage of growing a canopy over other aquatic plants.

The 1997 stocking of approximately 35,000 weevils was apparently very effective in controlling EWM. Essentially no nuisance areas of EWM existed in Bass Bay during that summer and there was very little EWM in Big Muskego Lake. However, high frequency and density of EWM returned in Bass Bay during 1998. The initial weevil stocking densities were high and it is hypothesized that the weevils may have outstripped the majority of food stock of EWM in Bass Bay. This may have resulted in poor recruitment the following year. The lack of over-wintering habitat may also have played a role in preventing the milfoil weevils from effecting control of EWM in concurrent years after initial inoculation (Toshner, 2001). A similar pattern was observed in Fish Lake in south-central Wisconsin where EWM returned to pre-treatment densities after an initial pattern of decline (Lille, 2000).

Gallerucella Beetles as a Biological Control of Purple Loosestrife

Two Chrysomelid beetle species (*Galerucella pusilla and G. calmariensis*) have been utilized in North America as biological controls for Purple Loosestrife (Figure 11). These tiny insects, native to Eurasia, feed almost exclusively upon Purple Loosestrife and have not been found to pose a threat to any native plants or cultivated crops. They feed on the leaves and shoots and, if densities are high enough, can keep the plants from flowering and producing seed.

The Wisconsin DNR provides guidelines on how to propagate *Gallerucella* beetles for biological control of Purple Loosestrife. Ten *Gallerucella* are introduced to individually potted Purple Loosestrife plants enclosed within mosquito netting (Figure 12). Beetles are allowed to breed without risk of escape or predation and after about two months, between one thousand and two thousand adult beetles are produced within each netted plant. These beetles are then released to an infested area to begin control (Woods, 2001).

Gallerucella beetles were initially released around Big Muskego Lake and Bass Bay in the summer of 1999 and the project has continued through 2004. As of 2004, an estimated 100,000 to 200,000 adult *Gallerucella* were released around the lake and bay. In the summer of 2004, thriving populations of beetles were observed in most of the release sites of the previous years. Visible damage to Purple Loosestrife plants was evident in most of these areas. In 2003, three intensely stocked areas had damage to the extent that there was almost no flowering and subsequent seed production.

Figure 11: *Gallerucella* beetle

Figure 12: *Gallerucella* Propagation setup

Nuisance Cattail Bogs and Debris

Many of the cattail stands within and around Big Muskego Lake actually grow upon floating mats of organic sediments, or “peat bogs.” At times, portions of these bogs break free during periods of high wind and are carried to other areas within the lake. Often these bog pieces become lodged in front of navigational channels. This was a recurring problem in the years immediately following the lake rehabilitation project, particularly in 1999 and 2000. To address this problem these bogs were cut into more manageable sized pieces and towed away to another part of the lake.

Beginning in the summer of 2000, many of the mid-lake cattail stands began to die off as a response to higher water levels. Pieces of dead cattail plants carried by waves and wind began to pile up on downwind areas of Big Muskego Lake. Accumulated cattail debris caused navigational channels to become blocked. A contractor was hired in 2001 to clear debris using a mechanical harvester. Later that year, Big Muskego Lake/Bass Bay Protection and Rehabilitation District purchased a used aquatic plant harvester from a private party. Deputy Commissioners of the Lake District volunteered their time to use the machine to clear debris from problem areas within the lake. The decay of dead cattail debris was major contributing factor to a partial winter fish kill over the winter of 2000-2001.

OTHER MANAGEMENT ISSUES

Winter Kill Management

With its shallow depth, Big Muskego Lake has historically been susceptible to occasional winter fish kills. This natural phenomenon is common on shallow lakes in years of heavy snow cover. Fish die from low levels of dissolved oxygen in the water. Deep snow blocks sunlight and inhibits the oxygen producing process of photosynthesis. At the same time, oxygen is used up through respiration by fish and plants, and from decomposition of organic matter.

Winter fish kills have ranged in severity, with most causing only a partial kill of the fishery. The deeper basin of Bass Bay is much less susceptible to oxygen depletion than Big Muskego Lake. Therefore, while winter oxygen depletion may occur on Big Muskego Lake, the bay serves as a refuge for fish and a source to restock the lake. Another refuge where fish within Big Muskego Lake can find oxygenated water is in the lake's primary tributary, Pilak Creek.

Big Muskego Lake experienced its most recent winter fish kill during winter of 2000-2001. A deep snow cover blanketed the lake in December, and by the first week of January, dead fish were observed throughout the lake. Deep snow cover had inhibited photosynthetic oxygen production, but the major culprit was the oxygen consumption from decomposition of accumulated organic matter on the lake bottom. Dead cattail debris had accumulated from the prior season's mid-lake cattail die off and was undergoing decomposition.

Aeration can be used to prevent or minimize the effects of a winterkill. During the mid 1970s a hypolimnetic aeration system was installed in Bass Bay. This proved to be ineffective and a severe, but partial winterkill occurred in Bass Bay in 1978-1979. During the Big Muskego Lake winterkill of 2000-2001, two aerators were installed on Bass Bay to assure that the bay would not also winterkill. These aerators kept water in motion at the surface and created a three-acre area of open water. Oxygen levels were monitored in the bay and concentrations remained more than adequate throughout the winter for fish survival

Although a sizable store of fish remained in Bass Bay, the Wisconsin DNR stocked approximately 20,000 Largemouth Bass, and 20,000 Northern Pike, and transferred approximately 5,000 panfish from area lakes.

Dike Maintenance

A dike separates the Big Muskego Lake from an agricultural drainage ditch that was built in the early to mid 1900s. The ditch, located near the southwest end of the lake, diverts runoff to the south and is tributary to Muskego Canal downstream of the Big Muskego Lake outlet dam and electrical carp barrier. In 1998 it was discovered that portions of this dike were breeched, creating a likely source of carp immigration from Wind Lake downstream. In spring of 1999, some carp were observed swimming through breeches in the dike.

Since 1999 Wisconsin DNR Fisheries Management personnel have been patching the dike with fill and sandbags. A plan was developed to significantly increase the width and height of this dike that separates the lake from the ditch. Construction is planned for 2004.

Conservation of Open Space within the Watershed

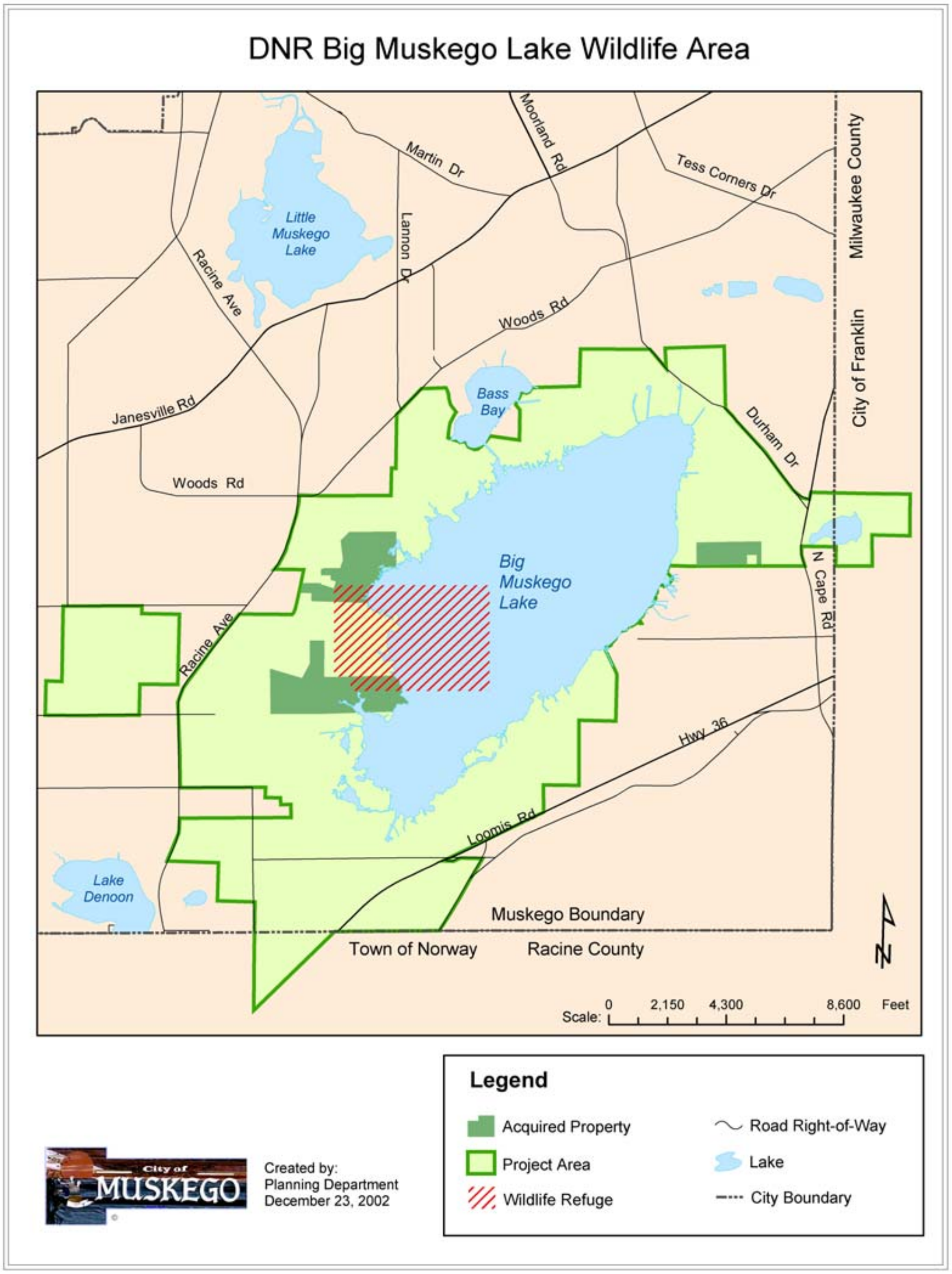
Big Muskego Lake Wildlife Area

In 1999, the State of Wisconsin Department of Natural Resources began the process of purchasing certain available properties within a 3,800-acre project area boundary of the Big Muskego Lake Wildlife Area. The realized size of this area is expected to be smaller as lands will be acquired only from willing sellers. The proposed purpose of the area is to protect, enhance, and manage the aquatic and terrestrial resources of Big Muskego Lake and surrounding lands, as well as to provide public hunting, fishing, and compatible recreational and educational opportunities. The project area boundary is illustrated on Map 8. As of December 2003, 327 acres of land were purchased within the project boundary.

City of Muskego Conservation Plan

In 2001, the City of Muskego adopted a Conservation Plan to protect the community's natural resources and preserve its rural character. This Plan prioritized areas within the community for conservation through acquisition or management. The Plan is a companion to the City's park and open space plan and serves as the ruling document for the purposes of open space acquisition and preservation within the community. In May 2004, the City of Muskego acquired a 140-acre property within the watershed of Big Muskego Lake but outside of the Big Muskego Lake Wildlife Area project boundary.

The Conservation Plan also identifies areas within the City that, if developed, should be done in a manner that preserves important natural resource features. In particular, the development of "conservation subdivisions" is encouraged. These developments allow for residential lots of smaller size than traditional zoning would allow in exchange for the preservation of larger contiguous areas of woodlands and wetlands. Conservation subdivisions may also be required to conduct certain restoration activities such as establishment of prairie vegetation and removal of invasive species. As of June 2004, there was one conservation subdivision developed, two developing, and one planned within the watershed of Big Muskego Lake and Bass Bay.



Map 8: Big Muskego Lake Wildlife Area and Wildlife Refuge

Chapter 5
LAKE MANAGEMENT ALTERNATIVES

INTRODUCTION

Lake management alternatives include both watershed management measures and in-lake rehabilitation techniques. Watershed management, including land use planning and zoning, and nonpoint source pollution control, is employed to maintain or improve the quality of water before it reaches the waterway. In-lake management includes fish regulations and stocking, chemical, mechanical, and biological aquatic plant control, and other measures such as alum treatments, and water level management.

Chapter 2 described the distinct differences in character between Bass Bay and Big Muskego Lake. While many management strategies will benefit both Bass Bay and Big Muskego Lake, some strategies will target an issue in one particular water body. Selection of management alternatives should give consideration to the potential impacts on the non-target water body.

WATERSHED MANAGEMENT ALTERNATIVES

Given the relatively enriched status of both Big Muskego Lake and Bass Bay, water quality can be improved through the reduction of nonpoint source pollutants that enter the system. Best management practices (BMPs) are actions or structures that are designed to reduce nonpoint pollution at construction sites, agricultural lands, and developed areas (residential, commercial, industrial, and transportation). Structural BMPs include creation of detention ponds, streambank buffer strips, and maintenance of storm water conveyance systems. Non-structural BMPs include improved tillage methods, and public information to inform homeowners about how they can reduce their nonpoint source pollution inputs.

Construction site erosion accounts for 63% of all sediment loading (City of Muskego Comprehensive Stormwater Management Plan Phase 2). Because phosphorus compounds attach to soil particles, high sediment loads also tend to produce high phosphorus loads. Construction site BMPs include stabilization and vegetation establishment of disturbed areas, management of overland flow, trapping of sediment, diverting flow, and prevention of tracking soil onto streets. Management alternatives include construction site and structural BMP requirements and enforcement of the City's erosion control ordinance (City of Muskego Municipal Code, Chapter 29).

Strategies for reducing residential nonpoint pollutant loadings involve informing citizens of actions they can take in their everyday lives. Actions include responsible lawn fertilization, proper disposal of pet wastes, and improved maintenance of automobiles. Citizens can be made aware of how to properly dispose of hazardous household chemicals. Residents can also make authorities aware of incidents of illegal or improper dumping of waste.

Conservation of land is another way to maintain the quality of runoff water. Storm water derived from undeveloped land surfaces is cleaner because these areas lack the disturbances of development and impacts of the subsequent urban uses.

IN-LAKE MANAGEMENT ALTERNATIVES

This section outlines activities that may be undertaken within the lake and bay to maintain or improve the quality of the aquatic ecosystem. While some strategies address only one particular aspect, most are holistic. Management activities designed to improve water quality will also serve to improve the fish and wildlife habitat. Humans in turn benefit because of improved aesthetics and recreation opportunities.

Maintaining the Plant-Dominated State

Most of the management alternatives for Big Muskego Lake are designed to either maintain or restore a plant-dominated state over the alternative of algal-dominance. Chapter 3 described the ecological concepts behind how this plant-dominated state produces clearer water, and more favorable fish and wildlife habitat. Depending on the condition of the lake, differing management alternatives may be needed to achieve this end. A decision matrix is best used to describe these conditions and the implementation of various alternatives (Table 6). This matrix identifies conditions in which to implement each strategy, describes benefits and potential drawbacks, and estimates the duration and relative cost of each management option.

The "Do Nothing" Option

In the process of selecting management strategies there is always the option to "do nothing." This is the option that nature should simply be allowed to take its course and the lake will manage itself. The argument against this line of thinking is that human activities have already interfered with natural processes and it may require human actions to mitigate the effects and tip the scale back towards a natural state. Nonetheless, close examination should be given to this alternative, especially when considering longevity of the effects and the cost effectiveness of other management alternatives. A consequence of this however, will be that human uses of the system will likely have to change to adjust to the condition of the waterway.

Biomanipulation as a Management Alternative

Biomanipulation is a management strategy that is employed to maintain the plant-dominated state and could possibly be used to switch a lake from algal- to plant-dominance. For Big Muskego Lake, biomanipulation involves the maintenance of a healthy proportion of top predators. Wisconsin DNR Fisheries Management currently employs this strategy through yearly stocking of 5,000 fingerling Northern Pike. Angling regulations also serve to biomanipulate the lake's ecology. The eight-inch size limit and 15-fish bag limit on panfish (Bluegill, Yellow Perch, etc.) promotes a population size structure with a greater proportion of large individuals. As panfish grow to larger sizes, they begin to feed more upon other small fish and consume fewer zooplankton. With a greater zooplankton component, algal populations are minimized and the plant-dominated, clear water state is buffered. However, this management technique may not be enough to "reverse switch" the lake into plant-dominance if it becomes turbid, and algal-dominated, particularly if carp also dominate the fishery. A more intensive management strategy would likely be required, including lake drawdown and elimination of carp.

Option	Do Nothing	Biomanipulation Only	Partial Drawdown; Continue Biomanipulation	Complete Drawdown w/o Rotenone treatment	Complete Drawdown with Rotenone treatment
Description	Allow the lake to manage itself. No biomanipulation (i.e. no fish stocking). No lake level manipulation	Maintain plant-dominated state through biomanipulation: more top predators & zooplankton	Lower lake approx. 1 foot for an entire growing season. Biomanipulation continued	Completely de-water lake to expose lakebed for an entire growing season. Biomanipulation continued	Completely de-water lake to expose lakebed for an entire growing season. Fishery killed & re-stocked
When Implemented	--	On-going while plant-dominated.	Emergent growth covers less than 20% of lake; Submergent growth not dominated by Eurasian Water Milfoil (EWM).	Emergent growth covers less than 20% of lake; Turbidity, Chlorophyll *a*, and Secchi Depth TSIs increase beyond established thresholds; EWM dominates.	Emergent growth covers less than 20% of lake; Turbidity, Chlorophyll *a*, and Secchi Depth TSI increase beyond established thresholds; EWM and Common Carp dominate.
Expected Result	Lake eventually will turn toward algal-dominated, turbid state; Common Carp dominate.	Will help lake stay in plant-dominated state longer, but may eventually become algal-dominated & turbid.	Emergent Plant growth would increase and buffer plant-dominated state, but lake may still become algal- and Carp-dominated.	50-60% emergent growth would be established. Turbidity & Chlorophyll *a* decrease.	50-60% emergent growth established. Improved water quality, fishery & wildlife habitat.
Drawbacks	Awaiting whims of nature to improve lake	May not be enough to “reverse switch” if lake becomes algal-dominated.	Inconvenience of low water – similar to summer 2002. Some potential for bog/cattail debris problems. Carp unaffected.	No lake use for a season. Potential problems with bogs, cattail debris. Carp unaffected.	Potential problems with bogs, cattail debris after any “excess” cattails die off.
Estimated Duration	--	Unknown	1 to 5 years	5 to 7 years	5 to 15+ years
Relative Cost	No immediate costs; But future restoration costs may be greater	Low	Low	Moderate	High

Table 6: Alternatives for Managing for Plant-Dominated State in Big Muskego Lake

Drawdowns

One of the buffers of the algal-dominated state is the maintenance of open water habitat conducive to wind mixing. Lake drawdowns can be used to induce a switch to a plant-dominated state. Reduced water levels and an exposed lakebed can promote the growth of stands of emergent vegetation, which will reduce wind fetch. Reduced wind mixing subsequently keeps water clearer and promotes the growth of rooted submergent plants. Depending on the goal of management, either a partial or a complete drawdown may be employed. Chemical eradication of the fishery may also accompany a lake drawdown project if the carp population is at a nuisance level.

As stated in the introduction above, certain strategies may be employed to manage a particular issue in one water body. It may seem intuitive that conducting a lake drawdown for emergent plant growth would merely benefit Big Muskego Lake and not help the condition of Bass Bay. However, examination of post-drawdown data from the previous chapter indicates otherwise. The fishery and water quality of Bass Bay improved as a result of Big Muskego Lake's switch to a plant-dominated state.

There is also a scenario where a lake drawdown may be considered even if the lake is in a plant-dominated state. A drawdown may be considered if a nuisance aquatic plant, particularly Eurasian Water Milfoil (EWM), dominates the plant community. EWM has a growth habit of topping out on the water's surface and can preclude boating activity. Excessive EWM can also negatively affect fish populations and effective biomanipulation may not be possible. Chapter 4 describes how the drawdown of 1996 was very effective in reducing the distribution and abundance of EWM. It is reasonable to expect that a future drawdown would produce similar results.

Drawdown and Chemical Fish Eradication

If Common Carp reach a density in which they have a detrimental impact on the fishery and cause excessive turbidity, chemical eradication of the fishery may be warranted. However the decision to chemically eradicate the fishery should be done carefully. Chapter 3 discusses how an algal-dominated state may be induced or buffered by factors other than a carp-dominated fishery. Therefore fish eradication and the costs involved do not necessarily have to accompany a lake drawdown.

Chapter 4 describes how Rotenone was used to chemically eradicate the fishery of Big Muskego Lake and Bass Bay during the 1995-1997 rehabilitation project. The drawdown created a smaller and more economical area of treatment. Although the objective was to remove carp, it was not feasible to selectively remove a single species. Chemical treatment commenced after capturing a good proportion of desirable game fish, panfish, and forage fish in fyke nets and transferring them to other lakes in the area. Following refill, the lake was stocked with appropriate proportions of fish and other aquatic life.

Partial Drawdown

A partial lowering of the lake level can also promote the growth of emergent aquatic plants. Chapter 3 described the response of cattail growth to lake water level. Shallower water levels can allow sprouting of cattails from rhizomes due to increased aerobic conversion of carbohydrates. Therefore, if the management goal is to promote more mid-lake stands of cattails a partial drawdown could be employed.

A partial drawdown actually mimics low lake level from dry natural weather patterns. Dry conditions in the summers of 2002 and 2003 caused the lake level to be considerably lower than normal for much of the growing season. As a result, cattails began re-sprouting in several mid-lake areas where they had died back two years earlier.

Nuisance Aquatic Plant Management Alternatives

Chapter 3 described how it is desirable to manage a shallow lake for a plant-dominated state. However, aquatic plants themselves often can pose as a nuisance. Growths of certain aquatic plants, particularly non-native plants can be invasive and cause negative impacts to fish and wildlife habitat and human recreation. Control measures are needed to minimize the nuisance level.

Chemical Controls

Chemical treatment of aquatic plants in all waters of the state, public or private, requires an approved permit from the Wisconsin DNR. Only chemicals registered for aquatic use with the U.S. Environmental Protection Agency (EPA) and the State of Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) can be used. In many cases, a licensed applicator, certified by DATCP must apply the chemicals.

Aquatic vegetation that is killed with an herbicide/algaecide will decompose. Decomposition utilizes dissolved oxygen and in turn increases the likelihood of a fish kill. When aquatic vegetation has accumulated to the point at which massive amounts are present, the decomposition that occurs after an herbicide/algaecide application could result in oxygen demand so great that there is not enough to sustain fish life, and a fish kill may occur. This problem can be avoided if chemical weed control efforts are carried out before there is a large accumulation of vegetation.

2,4-D

The chemical herbicide 2,4-D (2,4-dichlorophenoxyacetic acid) is selective in killing dicotyledonous or broad leaf plants. It has been found to selectively control infestations of EWM at low concentrations and short exposure times (Killgore, 1984; Miller and Trout, 1985). The goal of treatment is to reduce the distribution and density of EWM and allow native plants to flourish. Chapter 4 describes the recent use of 2,4-D to control EWM on Bass Bay and Big Muskego Lake.

SONAR

Floridone, more commonly known as SONAR, is a slow acting systemic chemical herbicide that must remain in contact with target plants for up to ten weeks. Fluridone is effectively absorbed and translocated by both plant roots and shoots. It will control a broad range of submerged and floating aquatic plants, and some emergent plants but is particularly effective for duckweed and Water Milfoil control. When applied at reduced rates, Sonar can be used to selectively control undesirable, nonnative species. In 30-90 days after application, the target weeds will be controlled and effects can last up to two years. Disadvantages of this control method include its relatively high cost and its effect on non-target plant species.

Alum

Aluminum sulfate or alum is used to reduce internal phosphorus release from the lake bottom. On contact with water, alum forms a fluffy aluminum hydroxide precipitate called "floc." Aluminum hydroxide reacts with phosphorus to form an insoluble aluminum phosphate compound. On the bottom of the lake the floc forms a layer that acts as a phosphorus barrier by combining with phosphorus as it is released from the sediments. Although alum is effective in preventing phosphorus from entering the water column, rooted aquatic plants are still capable of utilizing phosphorus within the sediment. Therefore alum is primarily used as a control of algae, rather than aquatic macrophytes. Previous use of alum on Bass Bay is discussed in Chapter 4.

Glyphosate

The chemical glyphosate formulated for use over water, such as the brand name Rodeo, can be used to control invasive Purple Loosestrife. Foliar formulations will also kill any non-target plants in the zone of spraying because the chemical is a broad-acting vegetation killer. A selective but more labor-intensive method is to cut individual purple loosestrife stems and apply a more concentrated formulation of herbicide to the cut end. This control method is impractical for large areas and is best employed to eliminate small colonizing stands of this invasive plant.

Manual Controls

Manual removal of submergent or emergent aquatic plants by hand pulling or raking is an effective means of controlling nuisances in small areas. NR 109 of the Wisconsin Administrative Code allows riparian owners to remove vegetation in a 30-foot wide area without a permit. The Code also allows for hand removal of non-native aquatic vegetation beyond the 30-foot area, provided the native vegetation is not removed or harmed.

Weed Barriers

Bottom weed barriers require DNR permits. The most commonly used bottom weed barriers are constructed of fiberglass mesh or polyvinyl fabric. The barriers are laid on top of aquatic plants and weighted down with bricks, chain, stakes or other anchoring devices. Plants become crushed and sunlight is blocked. Barriers may require removal and cleaning every 1 to 3 years. Barriers are appropriate management tools for controlling aquatic plants along docks and in deeper swimming areas. Initial cost for the barriers is relatively high, but they can usually be used for 5 or 10 years with proper care and maintenance.

Biological Controls

Biological controls for aquatic plants and algae are in the developing stages and include pathogens (bacteria or fungi) and herbivores (insects, crustaceans or fish). Bacterial treatments are commonly used in small fish-rearing ponds. Presently, fish and crustaceans are not legal control options in the state of Wisconsin. It is illegal to transport or stock grass carp or live crayfish into Wisconsin waters.

Weevils (*Euhrychiopsis lecontei*) are tiny native aquatic insects found to feed heavily upon milfoil species. Adult weevils cause lesions that make the plant more susceptible to bacteria and fungi, while the larval stage burrows into the stems. Subsequent tissue damage causes the plants to lose buoyancy and collapse (Sheldon, 1995). Chapter 4 describes previous EWM control efforts in Bass Bay and Big Muskego Lake using weevils.

Biological controls are also being employed for the control of purple loosestrife. Two Chrysomelid beetles (*Galerucella pusilla and G. calmariensis*), which feed exclusively on purple loosestrife, have been imported from Eurasia. Releases of these insects have been shown to significantly reduce stands of purple loosestrife within a three-year period. An aggressive propagation and release program is underway in Wisconsin to utilize this biological control. The use of *Gallerucella* beetles to control Purple Loosestrife on Big Muskego Lake and Bass Bay is summarized in Chapter 4.

Mechanical Harvesting

Mechanical harvesters are large floating machines that cut plants below the water surface. Harvesting is considered a short-term technique that temporarily removes nuisance plants. To achieve maximum removal of plant material, harvesting is usually performed during summer when submersed and floating-leafed plants have grown to the water's surface. Conventional single-staged harvesters combine cutting, collecting, storing, and transporting vegetation into one piece of machinery. Cutting machines are also available which perform only the cutting function. Maximum cutting depths for harvesters and cutting machines range from 5 to 8 feet with a swath width of 6.5 to 12 feet.

Mechanical harvesting can efficiently remove nuisance aquatic vegetation from large areas and facilitate greater recreational use of a waterway. Mechanically harvesting removes aquatic plants from the system thereby reducing the build-up of organic sediment and removing nutrients that were tied up within the tissue of the plants.

There are some drawbacks to mechanical harvesting however:

- It is generally not possible to operate a mechanical harvester in water depths less than two feet.
- The reduced competition from macrophytes can result in greater algal growth
- Young-of-the-year fishes are often captured along with aquatic plants
- Equipment, maintenance, and staffing are costly.

The Wisconsin DNR regulates mechanical removal of aquatic vegetation through Administrative Code Chapter NR 109. This code requires persons sponsoring or conducting mechanical harvesting of aquatic plants to obtain an aquatic plant management permit. The permit application can require that the sponsor develop an aquatic plant management plan. Should the Big Muskego Lake/Bass Bay Protection and Rehabilitation District decide to employ mechanical harvesting, this document will likely serve as the basis to fulfill that requirement. An addendum would be needed to establish operation parameters and identify specific removal areas.

Burning

Controlled or prescribed burning can be used to control cattails and promote other native plants such as sedges and bulrushes. Cattail burns are most effective when flooding follows as it inhibits cattail re-growth. Wisconsin DNR Wildlife Management personnel have periodically burned cattail stands within and surrounding Big Muskego Lake. The City of Muskego Conservation Plan recommends controlled burns as a management tool to control woody and invasive species in sedge meadow areas around Big Muskego Lake. Controlled burning conducted within navigable waters is regulated under NR 109 and requires a permit.

Chapter 6
RECOMMENDED PLAN

INTRODUCTION

This chapter presents a recommended management plan for Big Muskego Lake and Bass Bay. The Plan is based upon analyses of land use in the watershed, water quality, aquatic plants, fishery, wildlife, and human uses. The Plan builds upon previous experiences, incorporating strategies that have been successfully utilized in the past to manage the waterway. The dynamics of shallow lake ecology are closely considered in tailoring recommended management. An important component of this chapter is to plan for management of public perception of this unique type of water resource.

WATERSHED MANAGEMENT RECOMMENDATIONS

As lands continue to be developed in the watershed it is important that impacts of nonpoint source pollution to Big Muskego Lake and Bass Bay are minimized. Best management practices (BMPs) should be implemented to prevent nutrient enrichment and sedimentation to the waterway. Citizens should become informed on how their activities within the watershed impact lake water quality.

Erosion Control

Chapter 2 described that construction site erosion accounts for the majority of sediment loading in the watershed. This Plan recommends aggressive enforcement of the erosion control regulations set forth in Chapter 29 of the City of Muskego Municipal Code and utilization of the strategies outlined in the Wisconsin Construction Site Best Management Practices Handbook. These strategies include both erosion control and control of sediment transport. The use of filter fabric fences is technically not an erosion control strategy, but rather a sediment transport control strategy. Erosion control prevents soil from becoming dislodged from the ground surface and being carried by water in the first place. The use of ground covers and the timely re-establishment of vegetation are effective erosion control techniques that are often overlooked and should be more extensively applied.

Storm Water Management

This Plan also recommends the continued enforcement of Chapter 34 of the Municipal Code requiring new developments and major redevelopments to treat runoff through the establishment of storm water detention basins. These basins are to be sized such that runoff from a 100-year occurrence interval storm event under “post-development” conditions is released at the rate of a 2-year occurrence interval storm event under “pre-development” conditions. The basins allow for the settling of sediment and the assimilation of nutrients, thus delivering cleaner water to the waterway.

Storm water detention basins should be surveyed periodically to measure accumulated sediments. Should accumulated sediments reduce the volume of a pond such that its ability to capture sediment and assimilate nutrients is significantly affected, the pond should be dredged to its original capacity.

It is further recommended that side slopes of these detention basins be vegetated with tall grasses or prairie vegetation. This vegetation serves not only to prevent erosion and trap sediments, but can reduce proliferation of nuisance Canada Geese. Geese prefer short grass areas near water where they can graze and more easily remain vigilant for potential predators. "Golf course" pond landscapes with mowed turf grass adjacent to the water's edge should be avoided. Fecal matter deposited by large numbers of geese can add a nutrient load to the water that can nullify the nutrient removal function of these ponds.

Public Information and Education

Big Muskego Lake/Bass Bay Protection and Rehabilitation District should become more actively involved in providing information to residents in the watershed. Objectives of the public information and education program should be to raise awareness of lake ecology and develop a sense of stewardship to the waterway.

Newsletter

The Lake District should publish and distribute a newsletter to District residents on a semiannual basis at a minimum. This brief publication should include a summary of current lake projects, as well as information on lake topics such as water quality, aquatic plants, fish, and wildlife. It should provide information on how daily activities can directly or indirectly affect the ecology of the waterway. This includes such topics as near shore landscaping, proper waste disposal, and lawn fertilization.

Community Outreach

It is recommended that the Lake District continue cooperating in educational outreach programs with local schools. Beginning in 1998, students from St. Leonard's School have held a spring field trip at Big Muskego Lake to learn about wildlife and help vegetate waterfowl nesting islands with prairie plants. Consideration should be given to expanding this program to include other school groups. A more structured curriculum could be developed that may also include water quality and fisheries information.

It is recommended that youth groups such as Boy Scouts, Girl Scouts or 4-H become involved in a project to stencil existing storm sewers inlets in the watershed. The stencil depicts a fish and the words "Dump No Waste, Drains to Lake." Developers of new subdivisions should be required to stencil all storm sewer inlets after the final layer of pavement is installed. This stencil reminds citizens that whatever enters the inlet eventually flows into the lake.

Management of Public Expectations

Without a background in lake ecology, the general public often looks upon shallow waters such as Big Muskego Lake as less desirable water resources. The word "lake" conjures an image of a deep, open water body that easily facilitates activities such as swimming and boating. Big Muskego Lake does not match that image. In reality, Big Muskego Lake could very well have been named "Big Muskego Marsh." The waterway has many similarities to Horicon Marsh sixty miles to the north. Whatever it is called, it is an ecosystem that supports a rich diversity of vegetation, fish, and wildlife. Managed for ecological health, this shallow lake/deepwater marsh will maintain high aesthetic, recreational, and economic value.

It is recommended that information be provided within the aforementioned newsletter that helps the public appreciate Big Muskego Lake for the outstanding resource that it is. Articles should expound the merits of this productive shallow water body including its rare and endangered resources. Information should be provided to help the public understand the value of aquatic plants in maintaining water quality and habitat for fish and wildlife.

IN-LAKE MANAGEMENT RECOMMENDATIONS

Management for Plant-Dominated State

It is recommended that Big Muskego Lake and Bass Bay be managed for the plant-dominated over the algal-dominated state. The ecological concepts behind how this plant-dominated state produces clearer water, and more favorable fish and wildlife habitat were described in Chapter 3. The various management alternatives to either maintain or restore a plant-dominated state were summarized in Table 6 in the previous chapter. It is recommended that this decision matrix be used with selection of a particular option dependent on the existing condition of the waterway.

Biomanipulation

This Plan recommends continuation of the biomanipulation strategy that has been employed on Big Muskego Lake and Bass Bay since the 1995-1997 restoration project. In particular, the fishery should be managed to maintain a sizable proportion of top-level predators. Chapter 3 described how top predators could help maintain a plant-dominated state. Detailed fishery management recommendations are presented later in this chapter.

However, as noted in the previous chapter, biomanipulating the fish community may not be enough to “reverse switch” the lake into plant-dominance. Should the lake lose its mid-lake stands of emergent vegetation and become algal-dominated, a more intensive management strategy will be required.

Water Level Manipulations

It is recommended that water level manipulation be used as a tool to either buffer the plant-dominated state or to reverse switch the lake from algal-dominance. Various degrees of water level manipulation may be implemented depending on the goal of management. These include:

- Inducing emergent plant growth
- Inducing submergent plant growth
- Control of nuisance aquatic plants
- Eradication of Common Carp
- Opportunity for maintenance (dredging) of navigational channels

Action Thresholds to Initiate Water Level Manipulation

The decision to implement any plan to manipulate water levels should be based upon the ecological condition of the waterway. The evaluation of the condition should be based upon sound scientific data whenever possible. Values of certain parameters of water quality and the makeup of fish and aquatic plant communities are indicative of the state of the waterway. Fortunately, long-term water quality data have been collected and plant and fish communities have been surveyed. Thresholds can therefore be established that, if exceeded, should initiate management actions that may include manipulation of the water level.

Water quality data, in the form of Trophic State Index (TSI) values, from before and after the 1995-1997 rehabilitation project were compared using box plots (Figures 13, 14, and 15). In these plots, a lower TSI value represents better water quality. The center horizontal line within each box shows the median value for that period of time. The next outer set of horizontal lines (lower and upper hinges) bounds half of the values and are comparable to 25% and 75% inter-quartile ranges. For each parameter there exists a significant difference in the pre- and post-restoration TSI values with almost no overlap. These differences clearly demonstrate that Big Muskego Lake switched from the algal-dominated to plant-dominated state and affirm the alternative stable states model discussed in Chapter 3. A line was drawn horizontally between the boxes establishing a TSI threshold for each parameter.

Table 7 summarizes thresholds for aquatic plants and fish in addition to those for water quality parameters. Exceeding any of these thresholds should warrant serious consideration to manipulate the water level. If multiple thresholds are exceeded, a decision for water manipulation is more imminent.

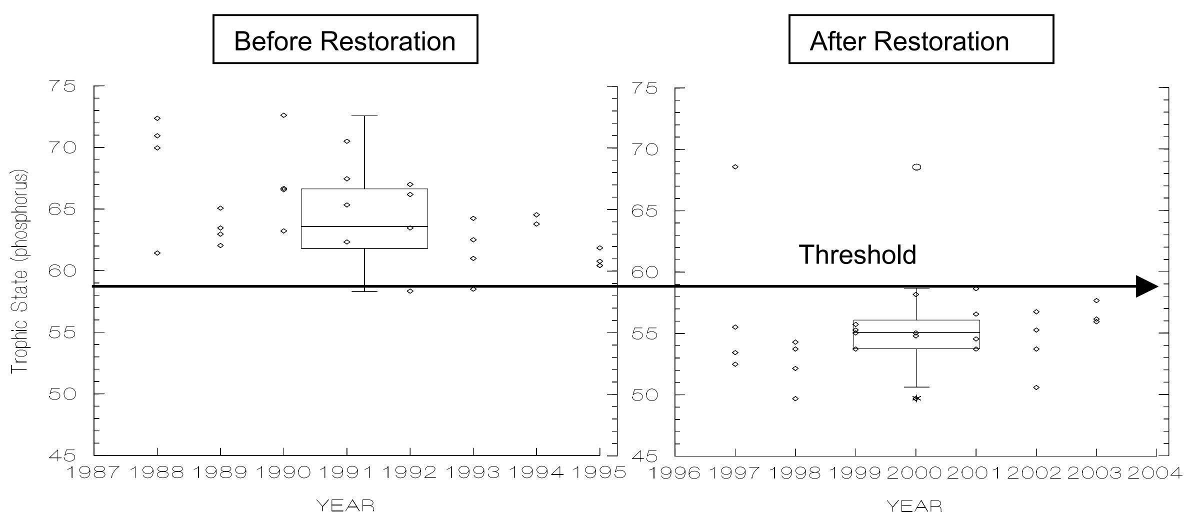


Figure 13: Box Plots for Phosphorus TSI Values Before and After Restoration Project

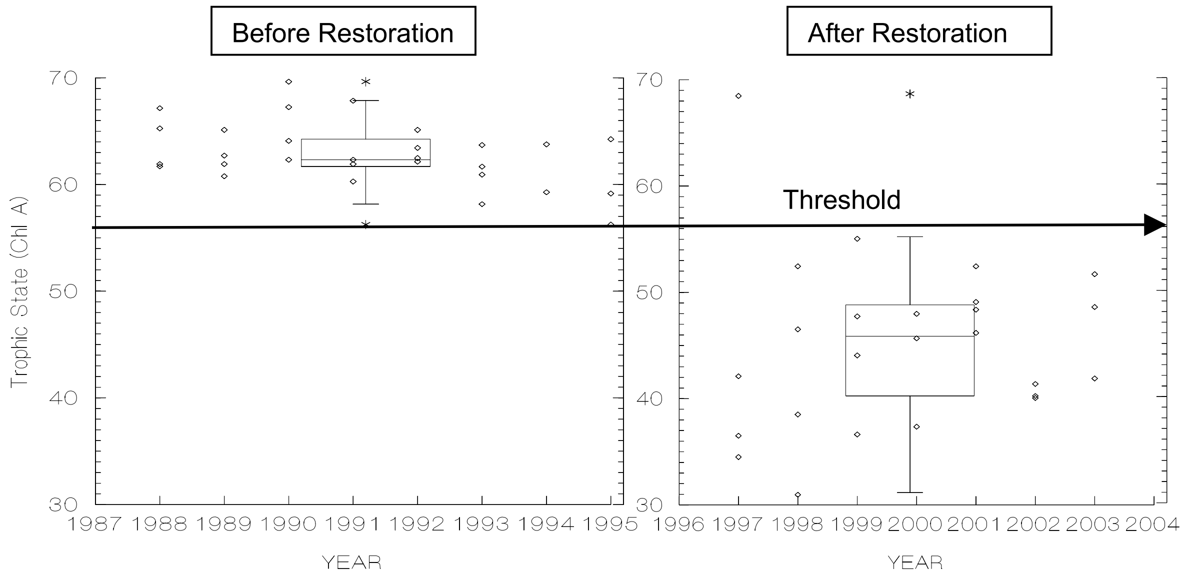


Figure 14: Box Plots for Chlorophyll *a* TSI Values Before and After Restoration Project

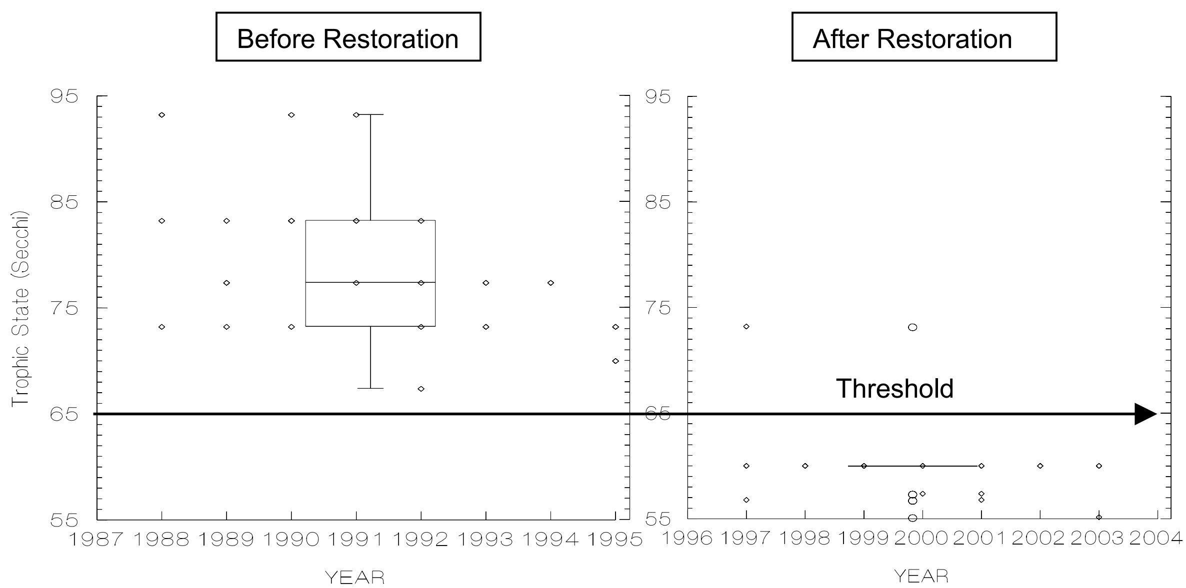


Figure 15: Box Plots for Secchi TSI Values Before and After Restoration Project

Category	Parameter	Management Objectives	Action Threshold
Water Quality	Phosphorus (Total)	TSI: < 50	TSI: > 60
	Chlorophyll *a*	TSI: < 45	TSI: > 56
	Secchi Depth	TSI: < 60	TSI: > 65
Aquatic Plants	Emergent Plant Coverage	35 – 50% lake surface area	< 20% lake surface area
	Eurasian Water Milfoil	< 40% occurrence frequency	60% occurrence frequency
Fish Community	Carp	0 Catch Per Hour Electro fishing (CPH)	> 5 CPH
	Northern Pike	> 10 CPH	< 5 CPH
	Largemouth Bass	> 40 CPH	< 20 CPH
	Bluegill	PSD* 40-70%	PSD* < 20%

Table 7: Management Objectives and Action Thresholds for Various Big Muskego Lake Parameters

* Proportional Stock Density (PSD) is the proportion of fish stock (length > 3”) that is also of quality size (> 6”)

Extent of Water Manipulation

A partial summer drawdown should be implemented if the lake has less than 20% coverage of emergent vegetation and the resultant larger fetch is likely to or has begun to cause increased turbidity from wind-driven waves. A partial drawdown mimics the water level fluctuation caused by a dry weather pattern and will stimulate the growth of emergent plants. The duration of a partial drawdown should be through mid and late summer. In addition to buffering the plant-dominated state, the resulting increase in emergent vegetation will create cover and nesting habitat for wildlife.

A more extensive drawdown should be implemented if Big Muskego Lake and Bass Bay become turbid due to high chlorophyll *a* concentrations or are dominated by carp. A complete drawdown should also be considered as a tool to reduce the extent of Eurasian Water Milfoil (EWM). In this case, the drawdown should extend through winter since EWM root crowns are susceptible to freezing out. Any decision to implement a complete drawdown of Big Muskego Lake and Bass Bay should require the support of the majority of Lake District residents.

Legal Considerations for Water Manipulation/Dam Operation

Partial drawdown can be done under the existing dam order. This order established a normal water elevation of 11.4 feet with a maximum of 11.6 feet (see Chapter 2 for complete order). Lake levels from the last four years were compared in Figure 16 below. This time period shows natural seasonal fluctuations of monthly average water levels deviating approximately one half foot above and below the “ordinary level” of the dam order. Although the dam order does not establish a minimum it is reasonable to assume that intentionally managing the level at an annual average below that of natural seasonal fluctuation (10.9 feet) would qualify as a non-emergency drawdown for habitat and subject to Wisconsin DNR Manual Code 3539.1. Because Big Muskego dam is classified as a small dam according to Ch. 31.19 Statutes, under NR 150 a drawdown for habitat purposes is a type IV action and does not require an Environmental

Assessment (Cunningham, 2003). However, this Plan recommends that an Environmental Assessment be completed in the event of conducting any future "full drawdown" of Big Muskego Lake that requires the use of pumps.

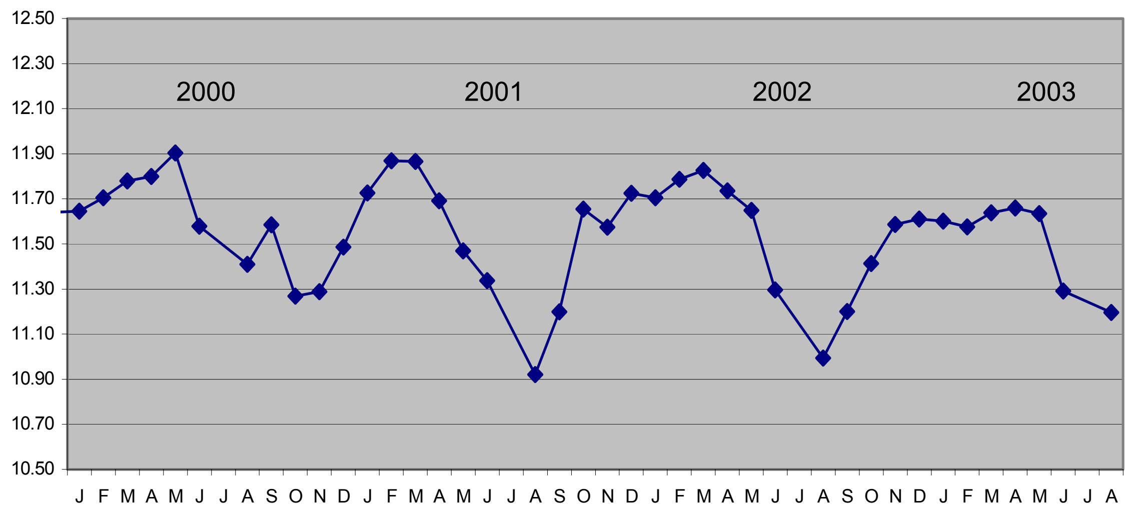


Figure 16: Monthly Mean Lake Levels 2000-2003

Settling Basin for Potential Future Extensive Drawdown

One of the problematic issues of the drawdown of the 1996 restoration project was the periodic pumping of sediment-laden water to Big Muskego Canal. Because gravity alone did not sufficiently drain the lake, pumps were used to augment the drawdown process. When water within the pump area became low, the pumps began to draw soft sediments from the substrate. Wind Lake residents became concerned about excessive sediment loads to that lake. The Big Muskego Lake/Bass Bay Protection and Rehabilitation District contracted to have sediments dredged from Big Muskego Canal.

In the event of a future full drawdown of Big Muskego Lake this Plan presents a contingency to prevent excessive sedimentation to the downstream waterway. Appendix D presents a conceptual design for a settling basin to be located immediately southwest of the Big Muskego dam. Although the land is in private ownership as of the writing of this Plan, the Wisconsin DNR is in negotiations to purchase the property. It is proposed that the construction of a sedimentation basin be a joint project between the Wisconsin DNR and the Big Muskego Lake/Bass Bay Protection and Rehabilitation District. Other financial assistance sources should be sought to meet necessary costs to complete the project.

Management of Aquatic Plants

Goals

The goal of aquatic plant management is to maintain a diversity of native plant species. Appendix A describes the utility of various native plant species for wildlife habitat and food. While this Plan recommends promotion of native species, it is recommended that the growth of nuisance and exotic aquatic plant species be controlled.

Nuisance Submergent Aquatic Plants

This Plan recommends continued use of chemical herbicides to minimize the growth of Eurasian Water Milfoil (EWM) and other submergent aquatic plant nuisances. The Lake District should budget funds sufficient for chemical aquatic plant control of approximately 40 acres each year. The majority of treatment has historically been conducted on Bass Bay. It is recommended that Bass Bay continue to receive most of the treatment since its acreage in comparison to recreational boating and fishing activity makes it cost effective. Because of its overall size, large-scale chemical control on Big Muskego Lake would be cost prohibitive. Only spot control of submergent nuisances should be considered on Big Muskego Lake. Spot treatments should generally be within high traffic areas where boating activity would be hindered or cause plant fragmentation that would lead to spreading of the nuisance.

If dense stands of EWM cover more than 30% of the open water of Big Muskego Lake strong consideration should be given to conducting a full year, large-scale drawdown. Chapter 4 described how the lake drawdown of the restoration project caused a significant decrease in EWM on Big Muskego Lake. Exposing the lake bottom for a winter season serves to desiccate and freeze out EWM root crowns. Remaining areas that do not de-water can then be treated with an herbicide.

Mechanical control of EWM and other submergent nuisances would require a substantial investment. Additional funds would be needed to purchase, operate, maintain, and insure a weed-harvesting machine. This would have a significant effect on Lake District fees. This Plan does not recommend mechanical harvesting of nuisance aquatic plants at this time. If a mechanical harvesting program is considered in the future, it should be implemented only after demonstrating the need, conducting an analysis of costs, and gaining the support of Lake District voters. In this event, the majority of control efforts would be limited to Bass Bay. Due to the shallow nature of Big Muskego Lake, mechanical harvesting would be difficult to conduct and would likely disturb sediments and increase turbidity.

Cattail Nuisance Management

Although this Plan encourages maintenance of a significant amount of emergent plant coverage such as cattails, it is also recognized that cattails can at times be problematic. Cattails tend to encroach upon navigational channels. Recent experience has also shown that when significant amounts of cattails die off, the dead plant material can cause an impediment to navigation and when decomposing, can contribute to oxygen depletion.

This Plan recommends managing cattail coverage at a target of 45% of the lake's surface. At higher levels there is the risk of a large die-off in years of high precipitation and lake levels. It is also recommended that cattails encroaching upon navigation channels be controlled. Specifically, cattail stalks should be cut below the water level to discourage their growth. The Lake District should maintain channels leading to public access sites and private riparian owners should be allowed to maintain existing channels leading to their residences.

Cattail coverage will undoubtedly fluctuate with long-term water levels. It is recommended that nuisance accumulations of dead, floating cattail debris resulting from periodic cattail die-offs are collected and removed using the Lake District's harvesting machine. This will serve to alleviate hindrances to navigation and reduce the buildup of loosely consolidated organic sediment.

Purple Loosestrife

It is recommended that the Lake District remain active in the program to biologically control purple loosestrife through the propagation and stocking of *Gallerucella* beetles. Volunteers should be sought to maintain and expand upon the current program.

Monitoring the Aquatic Plant Community

This Plan recommends monitoring of the aquatic plant community to ascertain if goals are being met. Coverage of emergent plants should be determined as well as the diversity and coverage of submergent aquatic plants. Because the makeup of the plant community is continually changing it is recommended that plants be monitored on a yearly basis.

Aerial photographs should be utilized to determine the extent of emergent plant coverage. If digital orthophotographs are not available for a particular year, non-rectified aerial photographs should be obtained from the United States Department of Agriculture Farm Services Agency and used to estimate the extent of the emergent plant coverage.

A frequency of occurrence survey of aquatic plants should be conducted biannually during the month of August in a cooperative effort between City of Muskego and Wisconsin DNR staff. The 40 sites from the 2002 aquatic plant survey should be located using global positioning system (GPS) technology and surveyed for species occurrence within a one meter sampling transect. If staffing or time does not allow the monitoring of all 40 sites, a random sub sample of these sites should be surveyed.

Fisheries Management

This Plan recommends continuation of biomanipulation strategies designed to promote top predators and reduce the number of zooplanktivorous fish. Specifically the eighteen-inch size limit and one fish bag limit for largemouth bass should remain in effect. It is further recommended that the eight-inch size limit and 15-fish daily bag limit on panfish (Bluegill, Yellow Perch, etc.) be continued. Consideration should be given to increasing the size limit on Northern Pike.

It is recommended that the Wisconsin DNR maintain populations of Northern Pike and Largemouth Bass such that electro-fishing surveys catch more than 10 Northern Pike per hour and more than 40 Largemouth Bass per hour. If existing populations cannot sustain this level through natural reproduction, sufficient numbers of fingerlings should be stocked to maintain these population levels. Electro-fishing surveys should be completed on at least a biannual basis to monitor the fishery.

Should carp abundance approach the critical action level described in Table 7 it may be feasible to significantly reduce carp abundance by targeting spawning carp congregations rather than conducting a full drawdown and whole lake treatment. It is recommended that rotenone treatments or carp removal in spawning congregation areas be considered as management options to reduce the carp population.

This Plan further supports the project to repair and maintain the dike located on the southwestern shore of Big Muskego Lake to prevent carp immigration.

Winterkill Management

As noted in Chapter 4, shallow lakes such as Big Muskego are vulnerable to occasional winter fish kills due to oxygen depletion. It is recommended that dissolved oxygen concentrations be periodically measured throughout the winter on Big Muskego Lake and Bass Bay. Aeration equipment should be deployed on Bass Bay if dissolved oxygen concentrations in the bay become dangerously low for fish survival. Keeping Bass Bay adequately oxygenated will create a refuge for fish survival and preserve a population to repopulate Big Muskego Lake.

Traditionally the aeration of shallow water bodies like Big Muskego Lake has often caused greater harm than good due to the suspension of sediments. If economically feasible, innovative aeration equipment that does not suspend bottom sediments should be considered for use on Big Muskego Lake to reduce the occurrence of winterkill.

Wildlife Management

It is recommended that wildlife resources be managed to optimize populations of both game and non-game species. The recommendations regarding management for a plant-dominated state should serve to accomplish this. A “hemi marsh” system with open water between areas of emergent vegetation creates more wildlife cover and nesting habitat. A diversified plant community provides a greater variety of food for wildlife.

It is further recommended that wild rice be reestablished within Big Muskego Lake. Wild rice seed derived from a local source should be utilized, as it will more closely match the genetics of the wild rice that historically grew on Big Muskego Lake.

Water Quality Monitoring

It is recommended that the City of Muskego continue to monitor all of the water quality parameters outlined in Chapter 2. Essentially, this monitoring replicates the USGS water quality monitoring conducted between 1988 and 2002. It is recommended that a second Secchi depth reading be taken on Big Muskego Lake within the deep hole adjacent to the northernmost wildlife habitat island. Because of the shallow depth at the historic monitoring site, Secchi depth readings have often been on the lake bottom. This additional site will allow a better measure of water transparency.

It is also recommended that stage and rainfall data continue to be collected at the gauging station located at the Big Muskego Lake outlet. These data are fundamental in the management of water levels and aquatic plant growth.

BIBLIOGRAPHY

Barko, J. W., and Smart, R. M. 1986. Sediment –related mechanisms of growth limitation in submersed macrophytes. Ecology, 67: 1328-1340.

Beklioglu, M. and B. Moss. 1996. Mesocosm experiments on the interaction of sediment influence, fish predation and aquatic plants with the structure of phytoplankton and zooplankton communities. Freshwater Biology, 36: 315-325.

Brooks, J.L. and S.I. Dodson. 1965. Predation, body size and composition of plankton. Science, 150: 28-35.

Caird, J.M. 1945. Algal growth greatly reduced after stocking pond with fish. Wat. Works Eng. 98:240.

Cooke, G.D., E.B. Welch, S.A. Peterson and P.R. Newroth. 1993. Restoration and Management of Lakes and Reservoirs. Lewis Publishers, Ann Arbor, Michigan.

Cunningham, Paul, Fisheries Ecologist, Wisconsin DNR, Personal communication, September 18, 2003.

Earthtech, 1999 *City of Muskego Stormwater Management Plan Phase 2*

Forsberg, C., S. Kleiven and T. Willen. 1990. Absence of allelopathic effects of Chara on phytoplankton in situ. Aquatic Botany, 38: 289-294.

Helsel, Dan and Zagar, Thomas. 2003. Big Muskego Story, Rehabilitating a Large Shallow Lake. Lakeline, 23:1 Spring 2003 pp 21-28.

Hrbacek, J., K. Bvorakova, V. Korinek and L. Prochazkova. 1961. Demonstration of the effect of the fish stock on the species composition of the zooplankton and the intensity of metabolism of the whole plankton association. Verh. Int. Verein. Theoret. Angew. Limnol., 14: 192-195.

Hurlbert, S.H., J. Zedler and D. Fairbanks. 1971. Ecosystem alteration by mosquitofish (*Gambusia affinis*) predation. Science 175:639-641.

James, W.F., H.L. Eakin, and J.W. Barko. 2001. Rehabilitation of a shallow lake (Big Muskego Lake, Wisconsin) via drawdown: Sediment response. APCRP Technical Notes Collection (Aquatic Plant Control Technical Note PD-12), U.S. Army Engineer Research and Development Center, Vicksburg, MS. www.wes.army.mil/el/aqua

Killgore. J. 1984. Use of herbicide/adjuvant formulations for the control of *Myriophyllum spicatum L.* Miscellaneous Paper A-84-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 36 pp.

Lillie, R.A., Graham, S., and Rasmussen, P., 1993, Trophic State Index equations and regional predictive equations for Wisconsin lakes: Wisconsin Department of Natural Resources Technical Bulletin No. 138, 116p.

Lillie, R.A. 2000. Temporal and Spatial Changes in Milfoil Distribution and Biomass Associated with Weevils in Fish Lake, WI, Wisconsin Department of Natural Resources.Journal of Aquatic Plant Management (2000) 38(2): 98-104

Madsen, J.D. and J.W. Barko. 1997. Aquatic Vegetation of Big Muskego Lake: 1995 Survey. Eau Galle Aquatic Ecology Laboratory, U.S. Army Engineer Waterways Experiment Station. Letter Report.

Miller, G.L. and M.A. Trout. 1985. Changes in the aquatic plant community following treatment with the herbicide 2,4-D in Cayuga Lake, New York. In: Proc. First Int. Symp. on Water Milfoil *(Myriophyllum spicatum)* and related Haloragaceae species. Aquatic Plant Management Society, Inc. pp.126-138.

Moss, B., J.H. Stansfield, K. Irvine, M. R. Perrow, and G.L. Phillips. 1996. Progressive restoration of a shallow lake – a twelve-year experiment in isolation, sediment removal and biomanipulation. J. appl. Ecol. 33: 71-86.

Moss, B., J. Madgwick and G. Phillips. 1996. A guide to the restoration of nutrient-enriched shallow lakes. W W Hawes, UK.

Moss, B. 1998. Ecology of Freshwaters, Third edition, Man and Medium, Past to Future. Blackwell Science, Oxford.

Moss, B. 1998. Shallow Lakes Biomanipulation and Eutrophication. Scope Newsletter, Number Twenty-Nine.

Perrow, M., M. Meijer, P. Dawidowicz and H. Coops. 1997. Biomanipulation in shallow lakes: state of the art. Hydrobiologia. 342/343: 355-365.
RUST, 1995 *The City of Muskego Phase 1 Stormwater Management Plan*

Scheffer, M. 1990. Multiplicity of stable states in freshwater systems. Hydrobiologia. 200/201: 475-486.

Scheffer, M. 1998. Ecology of Shallow Lakes. Chapman and Hall, London.

Sheldon, S.P. and R.P. Creed, Jr. 1995. Use of a native insect as a biological control for an introduced weed. Ecological Applications. 5(4): 1122-1132.

Sondergaard, M., E. Jeppesen, and S. Berg. 1996. Pike (*Esox lucius* L.) stocking as a biomanipulation tool 2. Effects on lower trophic levels in Lake Lyng, Denmark. Hydrobiologia, 342/343: 319-325.

Stansfield, J., B. Moss and K. Irvine. 1989. The loss of submerged plants with eutrophication III Potential role of organochlorine pesticides: a palaeoecological study. Freshwater Biology, 22: 109-132.

Toshner, Scott, WDNR Water Resources Specialist, Personal communication, February 15, 2001.

USGS. 2001. Water-Quality and Lake-Stage Data for Wisconsin Lakes, Water Year 2001. U.S. Geological Survey Open-File Report 02-135.

U.S. Fish & Wildlife Service, 1993, Waterfowl Management Handbook Leaflet 13.4.13

Woods, et al 2001. Biological Control of Purple Loosestrife: A guide to Rearing *Gallerucella* spp. (A re-write of document by Loos, Alyson, and Ragsdale, David).

Appendix A

AQUATIC PLANTS

OF

BIG MUSKEGO LAKE AND BASS BAY

AQUATIC PLANTS OF BIG MUSKEGO LAKE/BASS BAY

Sedge (*Carex spp.*)

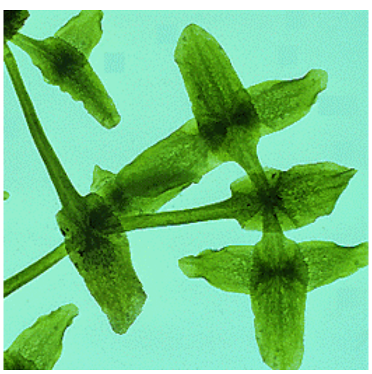
Sedges are emergent, grass-like plants found in littoral areas, wetlands and adjacent uplands. A major identifying characteristic of this plant is that in cross section, sedges have a distinct triangular stem. They are found over a broad range of alkalinity and moderate pH and conductivity ranges. Sedges are good indicators of environmental conditions. They help in capturing and filtering stormwater runoff. Sedges are important in providing food and habitat for wildlife.

Coontail (*Ceratophyllum demersum*)

Coontail, also known as a hornwort, is one of the most common plants in Wisconsin lakes. It is a submersed aquatic plant that resembles a raccoon's tail. This plant does not produce true roots, but modified leaves will attach themselves to the bottom sediment if growing near the bottom of the lake. It is usually found in soft substrates and is turbidity tolerant. Coontail is useful as fish cover, and reduces phosphates in the water. Many types of waterfowl utilize coontail for food. It is closely related to *Ceratophyllum echinatum*, or otherwise known as smooth coontail or spiny hornwort. *C. echinatum* has been listed a Species of Special Concern in Wisconsin. These two types of coontail can be distinguished from eachother by the number of leaf forks: *C. demersum* has 1-2 serrated leaf forks, while *C. echinatum* has 3-4 unserrated leaf forks.

Chara (*Chara spp.*)

Although often confused for an aquatic plant, chara is actually a submersed alga. It is also known as muskgrass due to its distinct musky odor. Besides its smell, another identifying characteristic of chara is its rough, grainy texture due to calcium carbonate deposits on its surface. Chara is beneficial in its ability to slow the movement and suspension of sediments. It is a valuable food source for many species of ducks and provides cover for fish.

	**Elodea (*Elodea Canadensis*)** This is a common, submersed perennial plant in Wisconsin waters. Its green leaves grow in whorls of three. It is usually found in soft substrate, and is turbidity tolerant. Elodea provides cover for fish, as well as larvae and small crustaceans. Muskrats and waterfowl feed on the plant or the invertebrates that live on the plant.
	**Lesser Duckweed (*Lemna minor*)** Duckweed is a very small aquatic plant that is found floating on the surface of the calm waters of lakes and ponds. This plant has no distinct leaves or stems, but has a leaf-like structure called a frond. A lone root protrudes into the water below the frond. Duckweed is beneficial in removing large amounts of nutrients from the water. It is also a very valuable food source for ducks, muskrats, beaver, and some species of fish.
	**Star Duckweed (*Lemna trisulca*)** This species of duckweed usually lives just beneath the waters surface. Star duckweed has elliptical, very thin, pale green leaves, and forms three branches. This plant has "stalks" that come off of the leaf, which can attach to the stalks of other plants, and form clusters. It found in calm lakes and ponds, in habitats similar to lesser duckweed. This plant provides food for ducks.

Purple Loosestrife (*Lythrum salicaria*)

Purple loosestrife is a very invasive plant native to Europe and Asia. This plant is a very hardy perennial with a square, woody stem that produces purple flowers throughout the summer. This plant outcompetes native plants that are depended upon for food and wildlife habitat. It can also choke waterways, which causes problems for recreation. Purple Loosestrife is considered a nuisance species in Wisconsin, and it is illegal to sell, distribute, plant, or cultivate the plants or seeds.

Northern Watermilfoil (*Myriophyllum sibiricum*)

This is a native species of watermilfoil in Wisconsin. It can be found growing in lakes and ponds, in shallow to deep water. It prefers soft substrate, and is not turbidity tolerant. The leaves are feather-like and soft, and arranged in whorls of four around the stem. Northern watermilfoil looks very similar to the non-native, invasive, Eurasian watermilfoil, and it is difficult to distinguish between the two. One way to differentiate the two is the native milfoil has fewer pairs of leaflets (7-11) than the Eurasian species (9-11).

Eurasian Watermilfoil (*Myriophyllum spicatum*)

Eurasian watermilfoil is a very invasive, non-native aquatic plant. This submersed plant has a stem that is reddish-brown to whitish-pink. This branching plant can grow very tall, and its leaves are feather-like and soft, arranged in whorls of four around the stem. Eurasian watermilfoil prefers slower moving lakes and ponds, but can also grow in faster moving water. This exotic plant, when in abundance, inhibits recreational use, clogs water intakes, and promotes algal blooms, which deteriorate water quality. Decaying mats of this plant decrease the oxygen level in the water. Eurasian watermilfoil grows very rapidly and shades out other native plants that waterfowl and fish and invertebrates rely on for food and cover. In late summer and fall, this weed becomes brittle and fragments break off and float away. These fragments can disperse over a great distance, sink, re-root , and start new plants. Eurasian watermilfoil is often dispersed to new locations through transport on boat trailers.

	**Northern Naiad (*Najas flexilis*)** Northern naiad, also known as slender naiad or bushy pondweed, is abundant statewide. This plant acts as a pioneer species by invading open or disturbed areas, with a preference for hard substrates. Waterfowl feed on its stems, leaves, and seeds. It is also valued by fish for food and cover.
	**Spiny Naiad (*Najas marina*)** This native aquatic plant has distinct spiny leaves. Spiny naiad prefers soft substrate and typically grows in lakes and ponds with high alkalinity, high pH, and high conductivity. Waterfowl, marsh birds, and muskrats eat the stems, leaves, and seeds of spiny naiad. It also provides fish and invertebrate habitat.
	**Yellow Pond Lily (*Nuphar luteum*)** The leaves of this plant float on the surface of the water and are large and heart shaped. This plant produces yellow flowers in summer and fall. It prefers a mucky or silt bottom in stagnant, shallow areas and grows an underground rhizome system. Yellow pond lilies provide great cover for wildlife. Beavers and muskrats eat the rhizomes, and beavers also eat the leaves. Waterfowl eat the seeds of the lily.

	**White Water Lily (*Nymphaea alba*)** This aquatic plant is found in quiet, clear waters. The leaves of this plant float on the surface of the water and are mostly round, with a purplish-red underside. It prefers a mucky or silt bottom in stagnant, shallow areas. This plant has a thick rhizome system that lies buried in the mud. White water lilies offer habitat for invertebrates and other organisms. Deer, muskrat, beavers, and others will feed on the rhizomes and the leaves of this plant. Ducks feed on the seeds of these lilies.
	**Large-leaf Pondweed (*Potamogeton amplifolius*)** This aquatic perennial herb is usually found in softer substrates in depths less than 9 feet. This pondweed has two types of leaves. The mature submerged leaves have a characteristic quarter moon shape, while the floating leaves are greener, and more oblong. This plant is in flower from July to September. Wideleaf pondweed provides cover for fish and its seeds provide food for waterfowl.
	**Curlyleaf Pondweed (*Potamogeton crispus*)** Curlyleaf pondweed is a non-native submersed aquatic plant that has distinctive wavy or “curly” leaves. It is an invasive plant that was introduced from Eurasia in the early 1900’s. In the spring, curlyleaf pondweed can become very thick. It dies back around July, and starts up again when the water begins to cool. This pondweed produces winter foliage - even under the ice. Curlyleaf pondweed forms surface mats that interfere with water recreation. It can usually be found in soft substrates, and is turbidity tolerant. Its seeds and tubers are poor waterfowl food.

Leafy Pondweed (*Potamogeton foliosus*)

This pondweed has a slender stem that, along with its leaves, is completely submerged. This plant can form dense stands. Leafy pondweed is turbidity tolerant, and can be found in shallow waters and in soft substrate. Leafy pondweed provides good fish habitat as well as food for waterfowl.

Illinois Pondweed (*Potamogeton illinoensis*)

This common submersed plant grows well in fast or slow moving waters. It has two primary leaf shapes: elliptical, floating leaves or lance-shaped submersed leaves with pointed tips and bases. This plant can be found over a broad alkalinity range, a moderate to high pH range, and moderate conductivity, but is not turbidity tolerant. Illinois pondweed is an important food for many waterfowl and some small mammals. It also provides habitat for fish and invertebrates.

American Pondweed (*Potamogeton nodosus*)

This pondweed is one of the most common and widespread pondweed species in the U.S. It can be identified from other pondweeds by its long petioles on its submersed leaves. American pondweed is found in shallow water, has no substrate preference, and is turbidity tolerant. Besides providing valuable fish cover, it is also a valuable food source for waterfowl.

	**Sago Pondweed (*Potamogeton pectinatus*)** Sago Pondweed is a submersed aquatic plant that can be recognized by its thin, small leaves and bushy appearance. It can tolerate high salinity, pH, and alkalinity. This plant is often found in monotypic stands. It can be found in areas with poor water quality conditions. Sago Pondweed provides food or shelter for many organisms, and is a very valuable food source for waterfowl.
	**Narrowleaf Pondweed (*Potamogeton pusillus*)** Narrowleaf Pondweed is a thin, branching plant with a flattened stem. It is a submersed plant, common in slow flowing waters, and is widespread in the Northern Hemisphere. This plant is an excellent source of food for waterfowl, and provides habitat for fish and wildlife.
	**Water Crowfoot (*Ranunculus longirostris*)** Water Crowfoot is also known as white water crowfoot and is in the buttercup family. This aquatic plant has white flowers that appear in early summer. This plant floats on the surface of the water. It usually grows in slow, calcareous water, and can be found over a moderate range of alkalinity, pH, and conductivity. It shows no turbidity preference. Water Crowfoot provides a good habitat for invertebrates, as well as a good food source for waterfowl.

	**Arrowhead (*Sagittaria latifolia*)** Arrowhead, also known as duck potato, is recognizable by its distinctive arrow shaped leaves and conspicuous flowers. The flowers are white and blossom from July to September. This emergent plant grows in shallow water, where most of the plant is above water. It can be found over a broad range of pH and alkalinity, and a moderate conductivity range. Arrowhead can absorb large amounts of heavy metals from its surrounding environment. Waterfowl eat the seeds of Arrowhead. Ducks, geese, otters, and muskrats eat the tubers.
	**Bulrush (*Scirpus spp.*)** Bulrushes are emergent plants, often seen as tall leafless stems growing in groups. The leaves of some bulrushes are reduced to sheaths. This plant can grow up to 6 feet tall in some areas. Bulrushes provide wave breaks to help slow down erosion. They also provide food and cover for ducks and other wildlife.
	**Cattail (*Typha latifolia*)** Cattails are easily identified by their size along with their distinct cigar-like flower spike. This plant often grows in dense stands due to extensive spreading by rhizomes and can become monotypic – decreasing the diversity of wetlands. Cattails can also form dense, floating mats. Besides providing habitat, cattails are an excellent source of food for many organisms. Muskrats and geese feed on the shoots and rhizomes, and fish use the submersed stalks for shelter and spawning habitat. Many parts of the cattail can be utilized by humans as well.

<table>
<tr><td></td><td>Common Bladderwort (Utricularia vulgaris)

Bladderwort is a rootless, free floating aquatic plant that has tiny bladder-like structures on their branched underwater leaves. The bladders are small vacuum traps that catch tiny aquatic animals. The bladderworts are the only predatory aquatic plants in the U.S. In spring and summer, they send up shoots of small, yellow, snapdragon-like flowers. This plant is usually found in shallow waters, and can tolerate nutrient poor, somewhat acidic, boggy conditions. Muskrats, ducks and other waterfowl, occasionally eat bladderwort, but it is not a preferred food.</td></tr>
<tr><td></td><td>Wild Rice (Zizania aquatica)

Wild Rice is a large native grass that produces edible grains. It prefers soft substrate and shallow waters. This annual does not handle competition well. This plant was a staple food of the Native Americans. It is a valuable food source for humans as well as wildlife. Wild Rice also provides excellent brood cover for many types of water birds.</td></tr>
<tr><td></td><td>Water Stargrass (Zosterella dubia)

This submersed plant can be found in a range of water depths, from shallow to several meters deep. It has yellow flowers that bloom at the waters surface in summer and fall. This plant is often confused for a pondweed, but can be easily separated from the group by its lack of a prominent midvein. The leaves of water stargrass are eaten by waterfowl, and offer good cover for fish.</td></tr>
</table>

Appendix B

FISHERIES MANAGEMENT SURVEY

BIG MUSKEGO LAKE AND BASS BAY

CORRESPONDENCE/MEMORANDUM

DATE: July 26, 2000 FILE REF: 3600

TO: Randy Schumacher

FROM: Sue Beyler and Steve Gospodarek

SUBJECT: Comprehensive survey of Big Muskego Lake (WBIC 0762400) and Bass Bay (WBIC 0763200) – 1999 and 2000.

ABSTRACT

A comprehensive fisheries survey was conducted on Big Muskego Lake and Bass Bay in spring 1999 and 2000 to evaluate the success of post-chemical treatment restocking and restrictive size and bag limits on the developing fishery. Since the 1996 chemical treatment, 1.5 million fingerling and adult fish were restocked along with 4 million fry. A total of 20 species of fish were stocked in the two lakes and their tributaries.

The stocking was very successful. Thirteen of the 20 species stocked have been recovered, along with 3 species that were not stocked by the department. Northern pike, bass, panfish and non-game species (minnows, suckers) have established populations and are reproducing. However, we have not seen evidence of walleye reproduction. Black, brown and yellow bullheads have reestablished themselves in the lake either by immigration from the watershed or by illegal stocking.

Northern pike showed a 25 percent drop in density in a one-year period, from spring 1999 to spring 2000. The 1999-2000 angling season was the first in which a substantial number of northerns were over the 26-inch minimum size limit. Anglers reported a high rate of success, especially during the winter tip-up season. Mortality rates of 81 to 88 percent on male and female northerns illustrate the impact that even one year of excellent angling can have on a population.

Largemouth bass are just reaching the special 18-inch minimum size limit imposed to provide a higher density of predators to control carp. Despite this, bass show a 51 percent mortality rate for fish still under the size limit. Although natural mortality and emigration over the Muskego Lake dam account for some of this, hooking mortality and harvest below the special size limit may also be involved. Bass PSD, at 43 percent, is just within the target range of 40 to 70 percent recommended by Anderson (1980). RSD-15, at only 4 percent, is still below the recommended range of 10 to 15 percent. Adult bass (8-inch and longer) density is only 3.2 per acre, which may not be high enough to adequately control carp.

Bluegill size structure and growth rate are very good. PSD ranged from 62 to 74 percent. Anderson recommends a target range of 20 to 60 percent. RSD-8 was an outstanding 43 percent in 1999, but dropped to only 11 percent in 2000. Seventy-five percent fewer bluegills were available for harvest in 2000 than in 1999. Bluegill harvest was also reported to be excellent during the previous season. The special 8-inch length limit and reduced bag limit of 15 for panfish was also designed to preserve a high

level of carp predation. Despite these restrictions, anglers targeted the big bluegills and severely reduced their numbers.

Carp have reentered the system via a breech in the dike at the southwest end of Big Muskego. So far, we have seen no evidence of reproduction. The carp that were observed in the fyke nets and electrofishing were all large individuals. Maintenance and repair of the dike is an ongoing project. The electrical and physical barrier at the Big Muskego Lake dam is in place and functions well. As insurance against failure of the barrier, we have awarded a rough fish contract for removal of carp that congregate below the barrier. Sixteen thousand pounds of carp were removed in one day in June 2000.

In summary, the restocking of Big Muskego Lake and Bass Bay was very successful. A high-density gamefish population is needed to prey on carp eggs, fry and fingerlings to prevent carp from reestablishing dominance. Restrictive size and bag limits were imposed to meet this end. However, some gamefish species (northerns, bass and bluegills) are showing the impact of high angler harvest.

We recommend continuing to stock 10,000 northern pike fingerlings annually, and stocking 10,000 walleye fingerlings biennially to maintain high predator density and supplement natural reproduction. Bass, bluegills and other panfish should be monitored, and more restrictive harvest regulations should be considered if their populations decline. Otherwise, maintain the existing protective size and bag limits on bass and panfish. Maintain the electrical barrier, and the Muskego Lake dike to prevent carp immigration. Continue the rough fish contract for removal of carp below the barrier. Discuss periodic lake drawdowns with the City of Muskego and Big Muskego Lake Management District to enhance emergent vegetation and protect water clarity.

METHODS

Fyke nets were set on Big Muskego and Bass Bay beginning March 19, 1999. Up to 12 nets were fished each day through April 2. Northern pike were measured to the nearest tenth-inch in length and given a differential finclip (males – left pectoral, females – right pectoral, immature – upper caudal) to identify recaptures. Northern pike population was estimated by continuous mark and recapture using the modified Schnabel formula $N = \frac{\Sigma(CtMt)}{R+1}$, where Ct is the number of fish captured on a given day, Mt is the number of marked fish at large on each day, and R is the total number of recaptured fish during the sampling period. Other gamefish and panfish were identified and measured to the nearest tenth-inch in length to obtain catch per unit effort, mean length and length distribution.

Fyke nets were again set on March 7, 2000 and were fished continuously through March 29. Up to 12 nets were fished each day. As in 1999, northern pike were measured, weighed to the nearest ounce, and given the same differential finclip. Care was given to differentiating between new clips and regenerated clips from 1999. Northern pike population was again estimated using continuous mark and recapture and the modified Schnabel formula. Scales for aging were collected from 10 northern pike per inch group, by sex. Panfish and other gamefish were identified and measured to the nearest tenth-inch.

Electrofishing was conducted in late April and early May to assess bass and panfish populations. Bass and bluegills were marked for the first 6 nights, followed by 2 nights spent looking for recaptured fish.

Bass and bluegills from the entire survey route were measured to the nearest tenth-inch. Bass over 8 inches in length and bluegills over 6 inches in length were given an upper caudal finclip during the marking runs. Scales for aging were collected from 10 bass and 20 bluegills per inch group. Other fish captured in the timed run stations were identified and measured to the nearest tenth-inch.

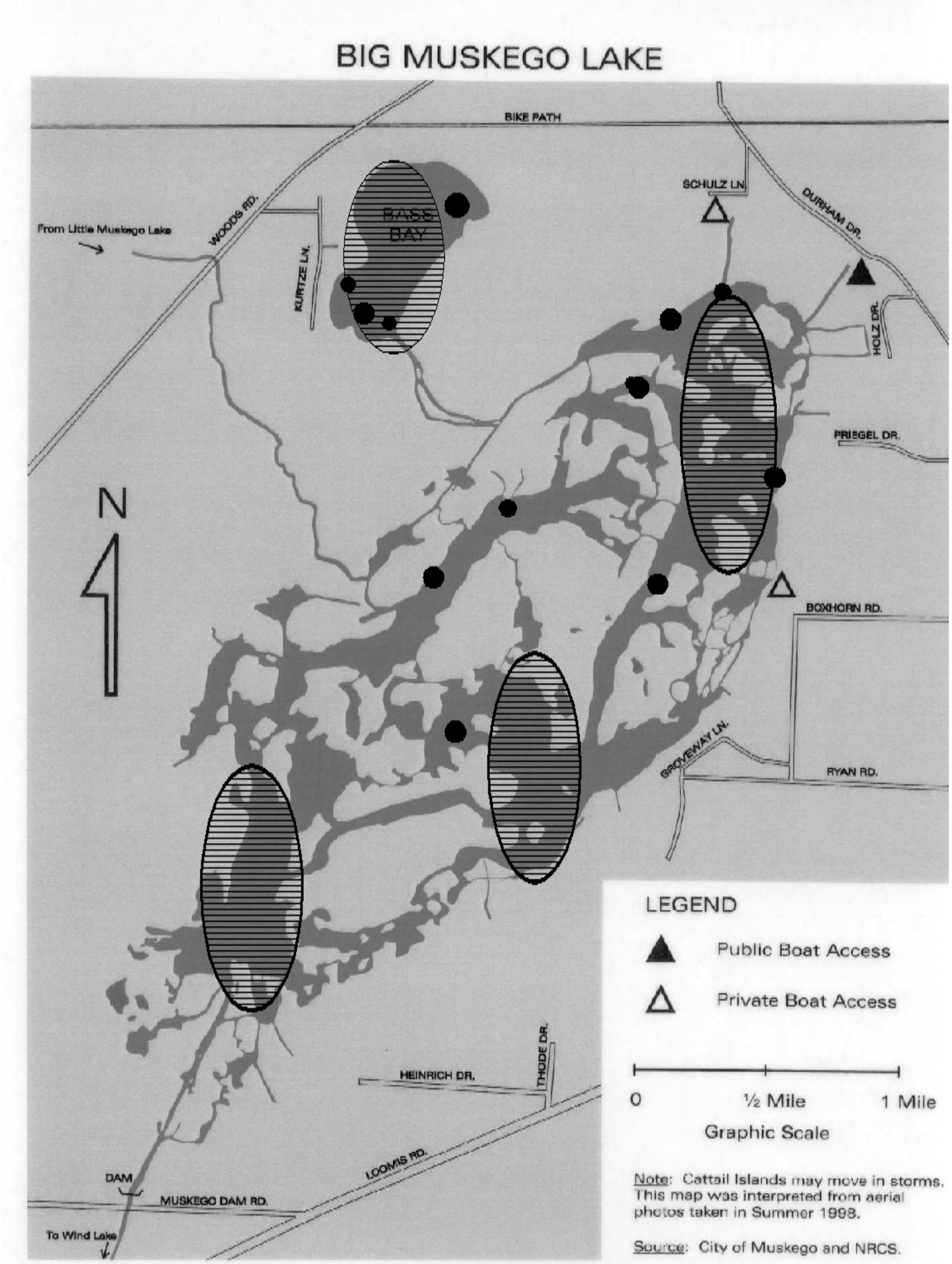


Figure 1. Survey map of Big Muskego Lake and Bass Bay showing electrofishing areas and fyke net locations.

RESULTS

Northern Pike

We captured 1,810 northern pike in fyke nets in 1999 (Table 1). Females slightly outnumbered males. Mean length was 17.8 inches for males, 20.6 inches for females, and 20.1 inches for sex unknown northerns.

Table 1. Northern pike captured by fyke net from Big Muskego Lake and Bass Bay, spring, 1999. Total effort = 173 net nights.

Sex	Number	Catch/Net Night	Mean Length	Std. Dev.
Male	758	4.4	17.8	2.23
Female	802	4.6	20.6	2.75
Unknown	250	1.5	20.1	3.17
Total	1,810	10.5		

The length frequency mode for male northerns was at 17 inches (Figure 2). For females, the length mode was at 19 inches (Figure 3). Male northerns up to 29 inches long were captured. Females up to 31 inches were seen in the sample. The mean length, length range and length mode of the sex unknown northerns in the sample were nearly identical to that for females. Many of these unknown fish were probably immature or spawned-out females.

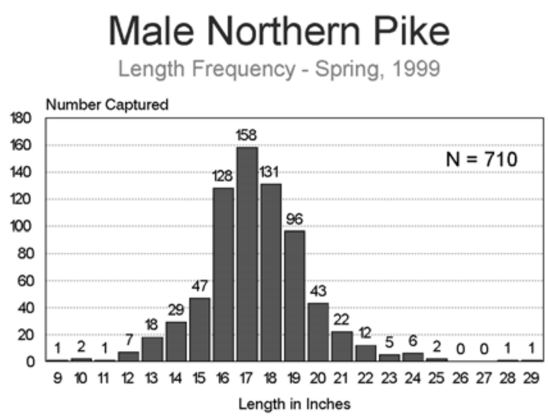


Figure 2. Length frequency for male northern pike captured by fyke net, 1999.

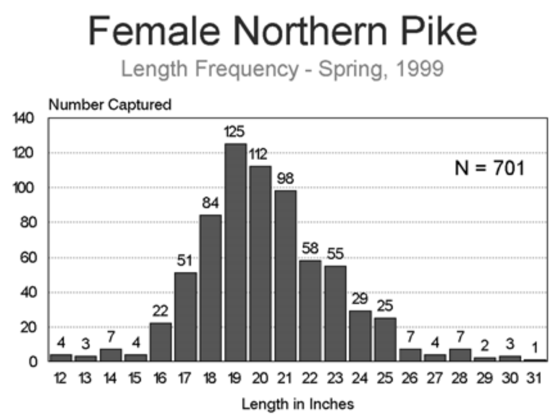


Figure 3. Length frequency for female northern pike captured by fyke net, 1999.

The 1999 northern pike population estimates were obtained through continuous mark and recapture using the modified Schnabel formula. The total population estimate was 19,106 (8.5 per acre), consisting of 8,243 males (95% confidence range 5,925 to 11,826), 7,941 females (95% confidence range 5,821 to 11,140), and 2,922 sex unknown (95% confidence range 1,565 to 5,976).

In spring, 2000 we captured 1,199 northern pike in fyke nets from Big Muskego Lake and Bass Bay (Table 2). Contrary to what we saw in 1999, male northerns in the fyke net sample outnumbered females by over 50 percent. Only 2 sex unknown northerns were caught this year. Mean length of the males and females increased by 1 to 2 inches since 1999.

Table 2. Northern pike captured by fyke net from Big Muskego Lake and Bass Bay, spring, 2000. Total effort = 240 net nights.						
Sex	**Number**	**Catch/Net Night**	**Mean Length**	**Std. Dev.**	**Mean Weight**	**Std. Dev.**
Male	736	3.1	18.9	2.03	1.85	0.66
Female	461	1.9	22.4	3.45	3.13	1.78
Unknown	2	0.008	14.6	2.12		
Total	1199	5.0				

The length frequency mode for male northern pike increased from 17 to 18 inches since 1999. No males over 26 inches long were captured in 2000 (Figure 4). Female northern pike have length modes at 20, 22 and 24 inches. Females up to 34 inches long were captured (Figure 5).

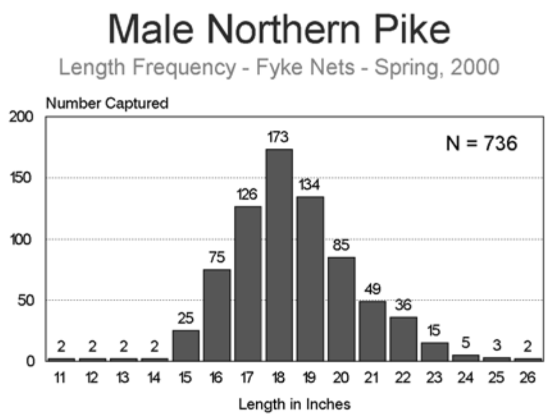


Figure 4. Length frequency of male northern pike captured by fyke net in spring, 2000.

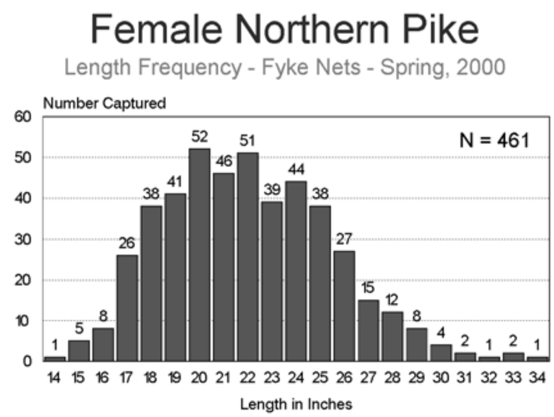
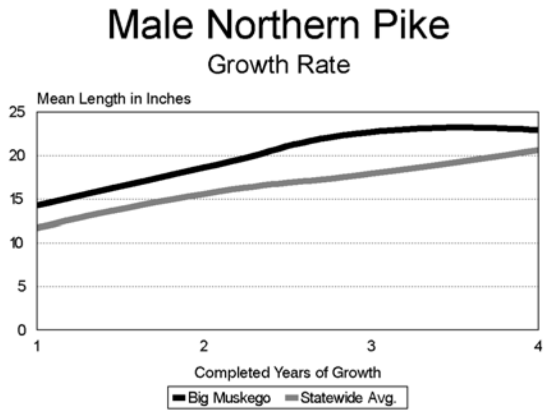


Figure 5. Length frequency of female northern pike captured by fyke net spring, 2000.

Our 2000 population estimate was also obtained by continuous mark and recapture, using the modified Schnabel formula. Total population was estimated at 14,449, or 6.4 per acre. We estimated 5,956 males (95% confidence range 4,431 to 8,182), and 8,493 females (95% confidence range 4,923 to 15,924). Too few sex unknowns were captured in 2000 to estimate their numbers. Again, it is likely that most of the northerns identified as sex unknown in 1999 were actually immature or spent females which are now included in the female population.

Male and female northerns were aged using scales. The mean length of each year class was calculated. The resulting growth rate was plotted against mean length at age for other Wisconsin lakes. As is typically seen in chemically treated lakes, growth rates for both male and female northerns is excellent; well above the statewide average (Figures 6 and 7).



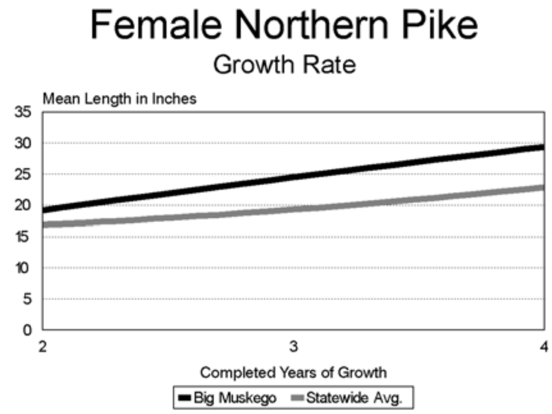
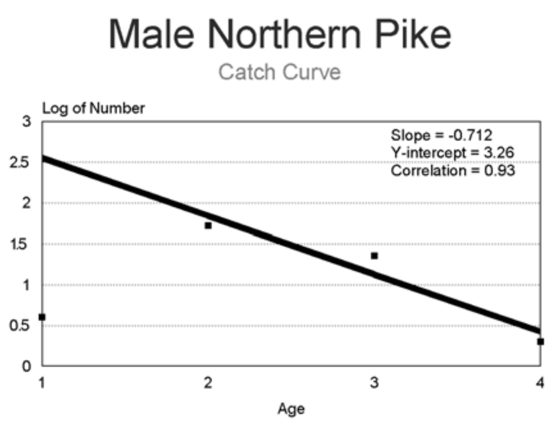


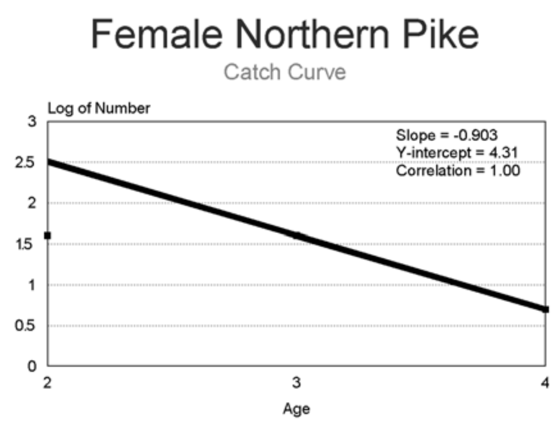
Figure 6. Growth rate of male northern pike from Big Muskego Lake compared to statewide average.

Figure 7. Growth rate of female northern pike from Big Muskego Lake compared to statewide average.

Catch curves for male and female northerns were constructed (Figures 8 and 9). Total mortality rates calculated from these catch curves are based on only 2 or 3 year classes and may be skewed due to the limited sample size but still give us insight into how quickly northern pike are being removed.

Mortality rate for male northerns age 2 to 4 is 81 percent. For females age 3 to 4 mortality is 88 percent. Most mortality among these young-adult northerns is likely due to angler exploitation. At this age, northerns are just reaching the 26-inch minimum size limit. Observations and angler anecdotes support the evidence of high angling mortality, as does the 25 percent drop in the estimated adult population.





. Figure 8. Catch curve for male northern pike.

Figure 9. Catch curve for female northern pike.

Largemouth Bass

In May, 2000, Big Muskego Lake and Bass Bay were electrofished to capture largemouth bass and panfish. Data was tallied separately for the two lakes. The catch rate, mean length and mean weight for bass from both lakes were nearly identical (Tables 3 and 4).

Table 3. Largemouth bass captured by electrofishing from Bass Bay in May, 2000. Total effort = 7.7 hours.					
Number	**Catch/Hour**	**Mean Length**	**Std. Dev.**	**Mean Weight**	**Std. Dev.**
251	32.6	11.7	2.00	1.07	0.68

Table 4. Largemouth bass captured by electrofishing from Big Muskego Lake in May, 2000. Total effort = 15.18 hours.					
Number	**Catch/Hour**	**Mean Length**	**Std. Dev.**	**Mean Weight**	**Std. Dev.**
557	36.7	11.9	1.23	1.16	0.71

Length frequency for the combined largemouth sample has a very strong modal length at 11 inches (Figure 10). One bass over 18 inches long (the minimum size limit) was captured. Bass proportional stock density (PSD) using a stock length of 8 inches and a quality length of 12 inches is 43 percent. Relative stock density using a quality length of 15 inches (RSD-15) is 4 percent. Anderson (1980) recommends PSD between 40 and 70 percent, and RSD-15 between 10 and 25 percent.

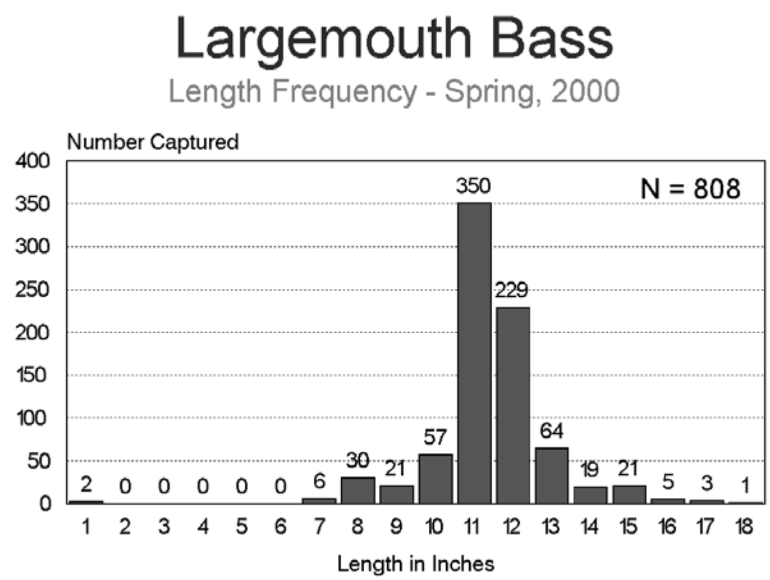


Figure 10. Length frequency for largemouth bass captured from Big Muskego Lake and Bass Bay in May, 2000.

Largemouth bass measuring 8 inches or longer were marked with a caudal finclip during the first 6 days of electrofishing. Marked fish were counted during the subsequent recapture run. We marked 560 largemouth during the marking run and found 19 marked bass out of 259 caught in the recapture run. The resulting population estimate using the Peterson formula is 7,293 with a 95 percent confidence range of 4,767 to 11,669. This gives us a density of 3.2 8-inch or larger bass per acre.

Largemouth bass were aged using scales. The resulting mean length for each age group was plotted against mean length at age for bass from other lakes in southeast Wisconsin. Growth rate of Big

Muskego largemouth bass is slightly above average compared to other southeast Wisconsin lakes (Figure 11).

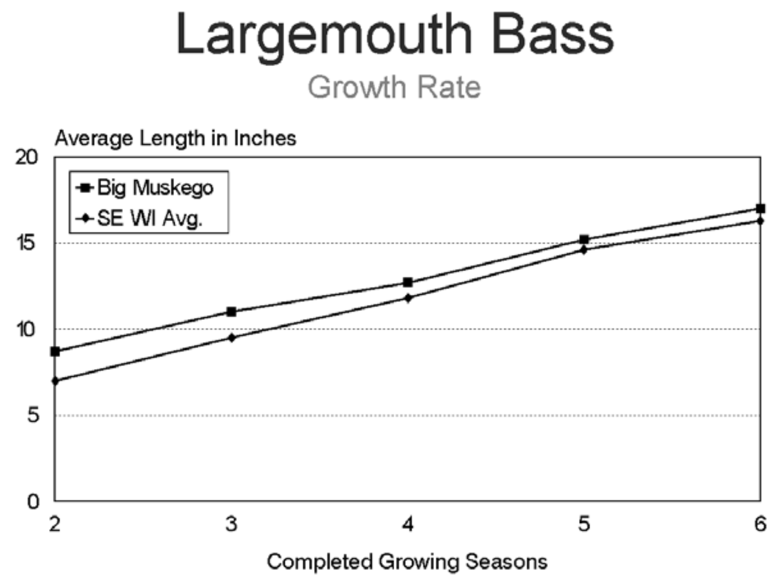


Figure 11. Growth rate of largemouth bass from Big Muskego Lake compared to other southeast Wisconsin lakes

A catch curve was constructed for largemouth bass (Figure 12). The resultant mortality rate for age 4 to 6 bass is 51 percent. Bass in this age range are still below the 18-inch minimum size limit, so this mortality should be due to a combination of hooking injury, and natural causes such as predation.

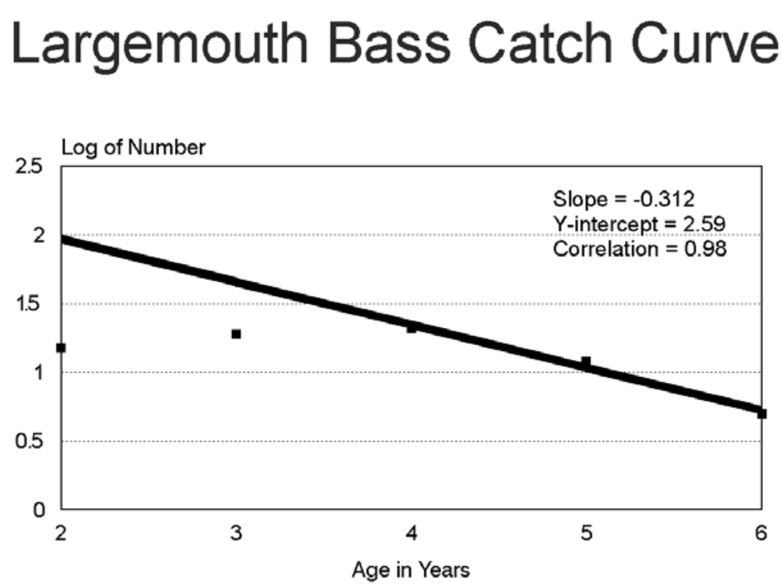


Figure 12. Catch curve for largemouth bass from Big Muskego Lake and Bass Bay, 2000.

Bluegills

Bluegills were captured by fyke net in Big Muskego and Bass Bay in 1999. Mean length of this early spring sample was an outstanding 6.8 inches (Table 5).

Table 5. Bluegills captured by fyke net from Big Muskego Lake and Bass Bay in April, 1999. Total effort = 173 net nights.			
Number Captured	**Catch per Net Night**	**Mean Length**	**Std. Dev.**
3233	18.7	6.8	1.75

Bluegills from 2 to over 9 inches long were captured. The length mode of the measured sample was at 8 inches (Figure 13), which is the minimum legal limit. Bluegill PSD, using a stock length of 3 inches and a quality length of 6 inches is 64 percent, slightly above Anderson's recommended range of 20 to 60 percent. RSD-8 is and outstanding 43 percent.

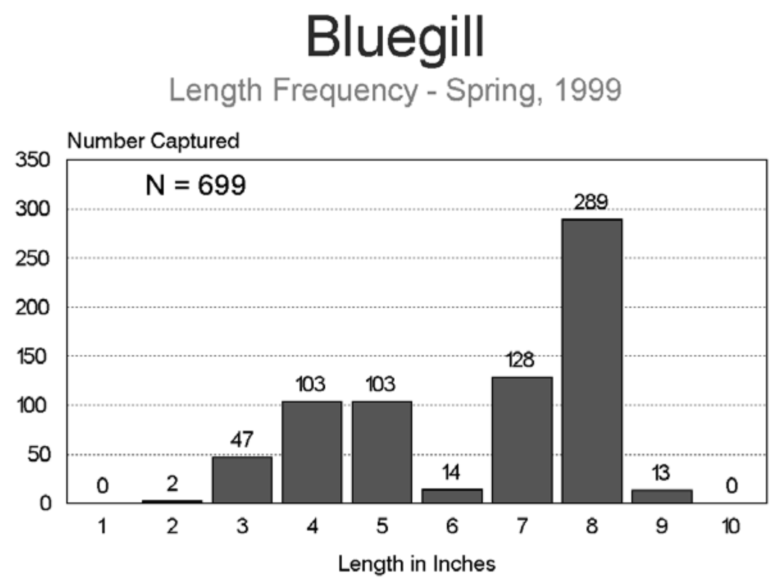


Figure 13. Bluegills captured by fyke net from Big Muskego Lake and Bass Bay in April, 1999

Bluegills captured by fyke net in 2000 averaged only 5.2 inches in length (Table 6).

Table 6. Bluegills captured by fyke net from Big Muskego Lake and Bass Bay in spring 2000. Total effort = 240 net nights			
Number Captured	**Catch per Net Night**	**Mean Length**	**Std. Dev.**
2323	9.7	5.5	2.13

The peak in the length mode for this 2000 fyke net sample is at 7 inches (Figure 14). The number of bluegills drops off sharply at 8 inches in length, the minimum legal length limit for bluegills and other panfish. At 62 percent, PSD for the 2000 bluegill sample is still above the target range. But RSD-8 drops to only 10 percent.

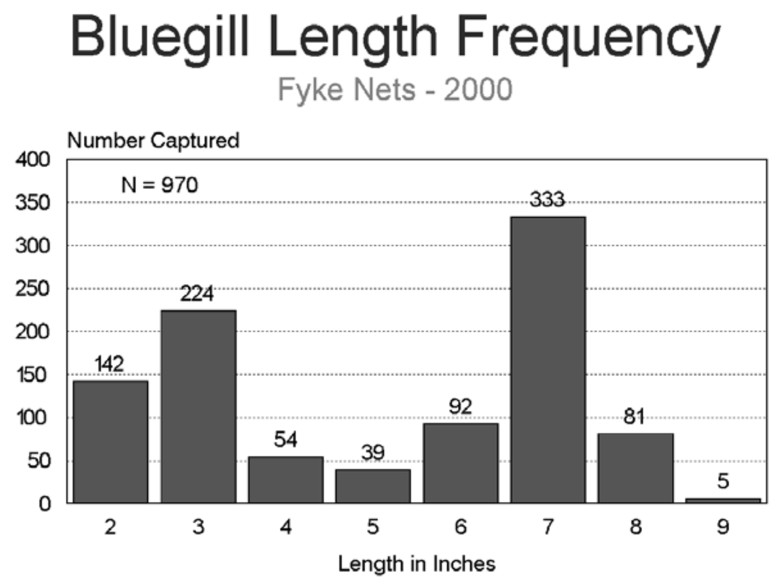


Figure 14. Length frequency for bluegills captured by fyke net from Big Muskego Lake and Bass Bay in spring, 2000.

We also sampled bluegills through May electrofishing in 2000. Catch rate of bluegills was slightly higher in Bass Bay than in Big Muskego (Tables 7 and 8). Mean lengths of the 2000 Bass Bay and Big Muskego samples are nearly equal, and are equivalent to that seen in 1999. Both are higher than the 2000 fyke net sample.

Table 7. Bluegills captured by electrofishing from Bass Bay in May, 2000. Total effort = 7.7 hours.

Number	Catch/Hour	Mean Length	Std. Dev.
275	35.7	6.7	1.63

Table 8. Bluegills captured by electrofishing from Big Muskego Lake in May, 2000. Total effort = 15.18 hours.

Number	Catch/Hour	Mean Length	Std. Dev.
413	27.2	7.0	1.29

Length mode of the 2000 electrofishing sample from Bass Bay and Big Muskego combined is also at 7 inches (Figure 15). PSD of bluegills caught in May by electrofishing is 74 percent. RSD-8 is still only 11 percent.

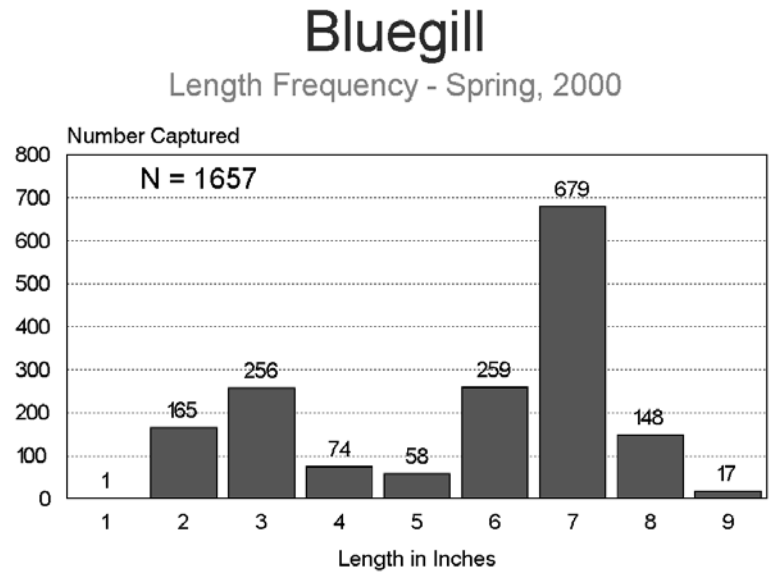


Figure 15. Length frequency for bluegills captured from Big Muskego Lake and Bass Bay in spring, 2000.

Bluegills measuring 6 inches or longer were marked in the first 6 days of May electrofishing. We marked 403 bluegills and found only 1 marked bluegill out of 191 caught in the recapture run. Using the Peterson formula gives us a population estimate of 38,784 bluegills with a 95 percent confidence range of 11,753 to 70,516. The resultant density is 17.2 6-inch or larger bluegills per acre.

Bluegills measuring 6 inches and longer were aged using scales to produce a catch curve of adults (Figure 16). The resultant mortality rate for bluegills aged 4 to 6 years is 44 percent. These fish are at, or just below, the 8 inch minimum size limit. Four-year-old bluegills in Big Muskego averaged 7.4 inches in length, while 5-year-olds averaged 7.6 and 6-year-olds averaged 7.3 inches in length.

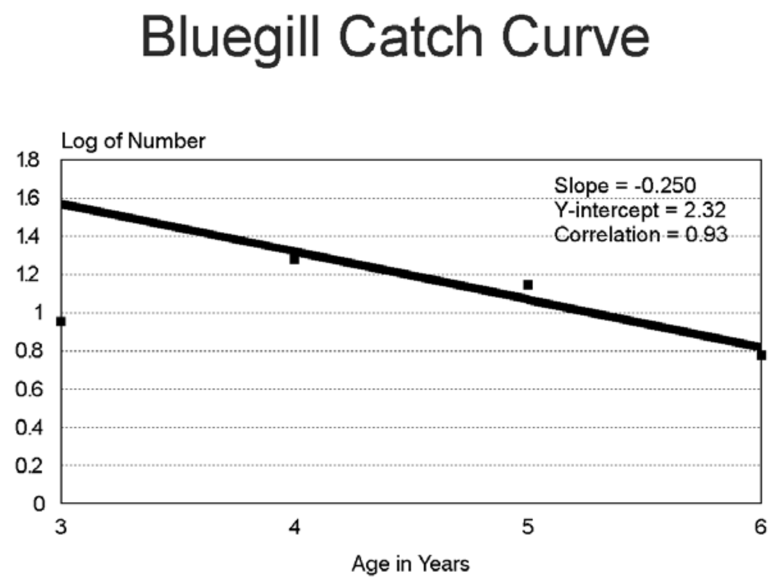


Figure 16. Catch curve for bluegills from Big Muskego Lake and Bass Bay, 2000

Other Species

Yellow perch dominated the fyke net catch in 1999, surpassing even bluegills in number (Table 9). Yellow perch averaged 8.1 inches, just over the legal minimum length of 8 inches.

Twenty-seven walleyes were captured. These two-year-old fish, from a single year class stocked in 1997, were just reaching the 15-inch minimum length limit and would be vulnerable to angling in the 1999/2000 season. Other common species were black crappie, pumpkinseed, lake chubsucker and white sucker.

Table 9. Fish captured by fyke net from Big Muskego Lake and Bass Bay, 1999. Total effort = 173 net nights.

Species	Number Captured	Catch/Net Night	Mean Length	Std. Dev.
Walleye	27	0.2	14.9	1.49
Yellow Perch	4,750	27.5	8.1	1.12
Black Crappie	145	0.8	8.0	2.53
Pumpkinseed	187	1.1	5.0	1.11
Green Sunfish	5	0.03	8.3	0.33
Rockbass	1	0.01	6.0	-
Lake Chubsucker	79	0.5	7.7	0.71
White Sucker	333	1.9	16.0	0.87
Golden Shiner	5	0.03	8.3	0.33
Yellow Bullhead	2	0.01	123	0.071
Brown Bullhead	1	0.01	8.5	-
Black Bullhead	14	0.1	9.0	1.39
Carp	5	0.03	17.4	1.43

In 2000, yellow perch catch rate dropped to just a fraction of what it had been in 1999 (Table 10). Mean length dropped slightly. Perch fishing over the previous year was reported to be excellent. Fewer walleyes were captured in 2000 than in 1999. Mean length of walleyes increased by 3 inches.

Table 10. Fish captured by fyke net from Big Muskego Lake and Bass Bay, 2000. Total effort = 240 net nights.				
Species	**Number Captured**	**Catch/Net Night**	**Mean Length**	**Std. Dev.**
Walleye	17	0.07	17.9	1.20
Yellow Perch	505	2.1	7.9	1.80
Black Crappie	173	0.7	7.0	2.93
Pumpkinseed	420	1.8	6.4	1.21
Green Sunfish	4	0.02	4.0	-
Warmouth	7	0.03	5.4	0.87
Black Bullhead	101	0.4	-	-
Yellow Bullhead	6	0.03	-	-
Brown Bullhead	1	0.004	-	-
Rockbass	2	0.01	-	-
Lake Chubsucker	84	0.4	-	-
White Sucker	38	0.2	-	-
Golden Shiner	9	0.04	-	-
Central Mudminnow	3	0.01	-	-

Few panfish were captured in the May electrofishing timed-runs (Tables 11 and 12). By May, the chara and rooted aquatic plants have grown close to the surface and netting fish becomes extremely difficult. Catch rates of most species are higher in Bass Bay than in Big Muskego Lake. Big Muskego lacks a distinct shoreline, which also makes electrofishing more difficult.

Table 11. Fish captured by electrofishing from Bass Bay, 2000. Total effort = 7.7 hours				
Species	**Number Captured**	**Catch per Hour**	**Mean Length**	**Std. Dev.**
Yellow Perch	32	4.2	5.4	2.05
Black Crappie	12	1.6	10.2	2.56
Pumpkinseed	27	3.5	6.5	0.63
Green Sunfish	1	0.1	5.1	-
Lake Chubsucker	18	2.3	4.5	1.86
Golden Shiner	1	0.1	3.9	-
White Sucker	12	1.6	17.2	0.79
Yellow Bullhead	1	0.1	11.5	-
Black Bullhead	1	0.1	11.8	-

Table 12. Fish captured by electrofishing from Big Muskego Lake, 2000. Total effort = 15.18 hours.				
Species	**Number Captured**	**Catch per Hour**	**Mean Length**	**Std. Dev.**
Musky	1	0.1	16.2	-
Yellow Perch	3	0.2	7.6	2.69
Black Crappie	10	0.7	7.3	1.93
Pumpkinseed	32	2.1	6.3	0.91
Warmouth	1	0.1	3.8	-
Lake Chubsucker	15	1.0	3.9	1.78
Golden Shiner	3	0.2	5.2	0.61
White Sucker	1	0.1	16.3	-
Yellow Bullhead	1	0.1	11.1	-
Black Bullhead	5	0.3	10.1	0.94

DISCUSSION

The 25 percent decline in the adult northern pike population illustrates the impact that a single good year of fishing can have on a gamefish population. Female northerns, in particular, were harvested in great numbers. Females feed voraciously and grow quickly; both of which make them especially vulnerable to angling. Despite its large size, parts of Big Muskego Lake become anoxic during the winter months, and northern pike and other fish concentrate in deeper holes and channels where they are easily targeted by anglers. The 1999/2000 season was the first since the 1996 chemical rehabilitation in which substantial numbers of northern pike were over the 26-inch legal length limit.

At this time, few largemouth bass have reached the minimum 18-inch size limit. This special regulation is intended to provide higher densities of largemouth to prey on carp that may reenter the system. Despite this, mortality rate for largemouth from age 4 to 6 is 51 percent. Even with slightly above average growth rate, these age 6 largemouth are still below the minimum size limit. Hooking mortality and predation undoubtedly account for some loss, but harvest below the special 18-inch size limit may also be occurring.

Bluegills showed a drop in both catch rate (from spring fyke nets) and mean length. Bluegills available for harvest (over the 8-inch minimum size limit) fell more than 75 percent after the 1999/2000 fishing season. High growth rates in these early stocked year classes produced a bumper crop of large bluegills. Once anglers got word of good bluegill fishing on Big Muskego, harvest of bluegills skyrocketed. Even the reduced bag limit of 15 panfish in aggregate was not enough to adequately protect large bluegills.

The yellow perch population appears to have suffered even more. The catch rate of yellow perch in spring 2000 fyke nets dropped to just a fraction of that seen in 1999. Few perch were picked up in the random sample electrofishing runs, but schools of small perch were observed in other areas of Big Muskego and Bass Bay. Like northerns, perch tend to congregate in a few areas of the big lake and in Bass Bay, and are easily targeted by anglers.

Species diversity remains very good. Fourteen species of fish were captured in 1999 and 16 species were identified in the 2000 survey. Twenty species of fish had been stocked in Big Muskego, Bass Bay and their tributaries after the 1996 chemical treatment. Three species of fish (black, brown and yellow bullheads) were not stocked by the Department, but have established populations.

Carp have reentered the system. Portions of the dike separating Big Muskego Lake from the Wind Lake inlet channel have been inundated during high water and carp were able to swim from the channel into the lake. Efforts to reinforce the dike have reduced, but not eliminated, carp migration into Big Muskego. At this time, carp numbers are still low. We have seen no evidence of carp reproduction in the lakes. It is hoped that keeping a high density of gamefish and panfish in the lakes will prevent carp from reestablishing their former dominance.

The electrical barrier on the Big Muskego dam has been effective in preventing carp from entering the lake via this route. Cooperation between the City of Muskego, the Lake Association and the Department has been excellent. The three agencies working together have monitored and maintained the barrier, coordinated opening the bypass gate and turning the barrier on, and responded to security alarms.

A rough fish contract has been awarded to a local resident to remove carp from below the barrier. Removing these carp reduces the chance that failure of the barrier would allow a large number of carp into Big Muskego Lake. The Wind Lake Management District has paid the contractor for each pound of carp removed, since these carp originate in Wind Lake and would otherwise return to Wind Lake when stopped by the barrier. So far, 16,000 lbs. of carp have been removed.

In summary, the post-chemical treatment restocking of Big Muskego Lake and Bass was a success. Sixteen species of fish have reestablished populations in the lakes. Although carp have reentered the system, they have not yet established a secure, reproducing population.

Anglers have taken advantage of the excellent fishing that typically follows the chemical rehabilitation and restocking of a lake. Continued stocking of northern pike is necessary to supplement natural reproduction in the face of high angler exploitation. Stocking walleyes, in Bass Bay, would help reduce the pressure on northern pike and provide additional angling opportunities. The single year class of walleyes stocked has done well and anglers have requested that we continue to stock them. Bass, centrarchid panfish and perch are all well established and are reproducing on their own.

Now that the lake level is being held at its more “normal” stage, we have seen a reduction in the size of cattail islands. While not the best habitat, these cattail islands stabilize bottom sediments and reduce wind fetch. Loss of these islands will allow more wind-driven turbidity, and reduce the growth of high-quality rooted macrophytes. Poor water clarity also favors rough fish, such as carp, over sight-feeding gamefish species. Periodic lake drawdowns would enhance the growth of cattails and other shallow-water emergents.

Future management recommendations include:

- Stock 10,000 small fingerling northern pike annually to supplement natural reproduction and satisfy angler demand. These fish need to remain at high density to control carp.

- Stock 10,000 small fingerling walleye biennially into Bass Bay to reestablish the population that existed prior to chemical treatment.

- Monitor the bass, bluegill and perch populations through spring electrofishing. Assess population levels through catch-rate and size structure. Resume stocking, if needed. Evaluate the need for more restrictive bag limit, if the populations show evidence of continued decline. These fish also needed at high density for carp control.

- Retain protective size and bag limits on bass and panfish to maintain high-density populations.

- Operate and maintain the electrical barrier and Muskego Lake dam to prevent carp from entering Big Muskego Lake.

- Maintain rough fish contract to reduce the threat of carp entering Big Muskego from Wind Lake.

- Discuss the feasibility of periodic lake drawdowns with the City and Lake Association to help protect emergent vegetation stands, such as cattail, which stabilize the bottom sediments and contribute to lake clarity by reducing the effects of wind. This would also benefit wildlife.

- Maintain the Big Muskego Lake dike to prevent carp from entering during periods of high water levels. Major dike repairs need to be undertaken in the near future.

Appendix C

SURVEY

OF

BIG MUSKEGO LAKE/BASS BAY

PROTECTION AND REHABILITATION DISTRICT

Report to the City of Muskego
Big Muskego Lake/Bass Bay – Lake District Survey

Executive Summary

Late in the summer of 2002, the City of Muskego, in conjunction with the University of Wisconsin-Whitewater conducted a survey. The target of this survey was the resident of the Big Muskego Lake/Bass Bay Lake District. The attached report provides the details regarding this survey.

The essential component of the Lake District Survey is the creation of defined goals and attributes of the various homeowners surrounding the water. Their interests vary according to age, tenure, and location. Although tempting, the reader should be cautioned from aggregating these characteristics in order to create a composite resident. For example, if was find that young people like pizza more than older persons and that young people like cola more than older people, it is not correct to extrapolate that younger people like coke and pizza more than older people. This is an unproven assumption.

In the same fashion, although it is found that Bass Bay respondents were significantly more likely to list Motorized Boating as a priority use and Entertaining as a priority use, it is incorrect to assume that they entertain while boating. The significance tests used are independent of each answer.

As a result of the demographic questions, it is found that the respondents distributed among the various Lake District locations.

32.2% Big Muskego Lake (plus or minus 3%)
28.7% Bass Bay (plus or minus 3%)
39.1% Off-Lake Resident of Lake District (plus or minus 3.5%)

Further demographic question find that the resident tend toward longer-term residents (over 10 years).

16.5% 0-3 years (plus or minus 2%)
30.1% 4-10 years (plus or minus 3.1%)
53.4% over 10 years (plus or minus 3.7%)

The final demographic question finds that the Lake District respondents are primarily between 35 and 64.

10.4% 18-34 years old (plus or minus 1.4%)
43.4% 35-49 (plus or minus 6.4%)
30.1% 50-64 (plus or minus 3.1%)
16.2% over 64 (plus or minus 2%)

When these demographic questions are matched up against the utilization priorities, it is found that location contributed to different priorities. This is not surprising; hedonic housing patterns would suggest that individuals move to specific locations to take advantage of the unique circumstances offered. Economic studies employing hedonic questions find that families are often attracted to locations based on the quality of the local schools. In the Muskego Lake district survey, it is observed that:

1—Big Muskego and Off-Lake respondents were more likely to list FISHING as a priority use.
2—Big Muskego respondents were more likely to list OBSERVING WILDLIFE as a priority use.
3—Bass Bay respondents were more likely to list MOTORIZED BOATING as a priority use.
4—Big Muskego respondents were more likely to list HUNTING as a priority use.
5—Bass Bay respondents were more likely to list ENTERTAINING as a priority use.

The relationship between Tenure and priority use is less dramatic. There is no area in which long-term residents have a significantly different use for the water than shorter-term residents. This is not surprising since the attraction of the lake covers multiple generations. A similar result is found for Age and priority uses. Once again, it is location that determines the priorities, not age. Citizens of various ages use the lake for similar reasons.

This process is repeated in terms of Lake Management questions and location. It is found that:

1—Big Muskego and Bass Bay respondents were more likely to list NUISANCE MANAGEMENT as a priority management issue.
2—Bass Bay respondents were more likely to list STORMWATER MANAGEMENT as a priority management issue.

Each lake presents its own unique management problems: one is a shallow lake with historic management problem, while the other is on the edge of the developing city. As a result these results are not surprising. However, once again, there are very limited relationships between tenure and management priorities (see report) and age and management priorities (see report). The issues of management are contained within the original determination of location.

The results of this survey provide the community with a rich database upon which it can craft solutions that fit the needs of the specific location. As with many issues, one size does not fit all. One locations priority may be another lake irrelevancy.

Russ Kashian, PhD
Assistant Professor
University of Wisconsin-Whitewater
December 2002

Big Muskego Lake/Bass Bay - Lake District Survey

Please take a few minutes to give us your opinions to help in the development of a lake management plan for Big Muskego Lake/Bass Bay. Remember, there are no right or wrong answers and everyone's opinion counts! If you do not have an opinion, please indicate that by circling the appropriate letter. Your responses are strictly confidential and will be compiled by an independent researcher. Please return the completed survey to City Hall in the stamped envelope provided by **October 11, 2002**. Thank you!

1. Where do you live?
   a. Big Muskego Lake   b. Bass Bay   c. Off-Lake Resident of Lake District

2. How long have you been a Big Muskego Lake/Bass Bay District resident?
   a. 0 to 3 years   b. 4 to 10 years   c. over 10 years

3. What is your age?
   a. 18-34   b. 35-49   c. 50-64   d. 65+

4. Rank, in order of importance, the **three (3)** primary reasons you use Big Muskego Lake/Bass Bay.

   _____ Entertaining friends/relatives
   _____ Observing Wildlife
   _____ Enjoying the View
   _____ Water Skiing
   _____ Non-Motorized Boating
   _____ Jet Skiing/PWC's
   _____ Swimming/Snorkeling
   _____ Motorized Boating
   _____ Hunting
   _____ Fishing
   _____ Snowmobiling
   _____ Other ________________________

5. How often do you engage in each of the following activities on Big Muskego Lake/Bass Bay? (Circle one level for each activity and estimate number of times per year)

		Never		Occasionally		Daily	Estimate no./year
a.	Swimming/Snorkeling	1	2	3	4	5	_______
b.	Canoe/Row/Paddleboat	1	2	3	4	5	_______
c.	Powerboating/Skiing	1	2	3	4	5	_______
d.	Jet Ski/PWC	1	2	3	4	5	_______
e.	Pontooning	1	2	3	4	5	_______
f.	Snowmobiling/ATV's	1	2	3	4	5	_______
g.	Fishing	1	2	3	4	5	_______
h.	Hunting	1	2	3	4	5	_______
i.	Scenic Viewing	1	2	3	4	5	_______
j.	Other ________________	1	2	3	4	5	_______

6. How would you rate the condition of Big Muskego Lake/Bass Bay for the following activities? (Circle one level for each activity)

		Poor	Fair	Good	Excellent	Don't know/ No opinion
a.	Swimming/Snorkeling	1	2	3	4	5
b.	Canoe/Row/Paddleboat	1	2	3	4	5
c.	Powerboating/Skiing	1	2	3	4	5
d.	Jet Ski/PWC	1	2	3	4	5
e.	Pontooning	1	2	3	4	5
f.	Snowmobiling/ATV's	1	2	3	4	5
g.	Fishing	1	2	3	4	5
h.	Hunting	1	2	3	4	5
i.	Scenic Viewing	1	2	3	4	5
j.	Other _________________	1	2	3	4	5

7. For Bass Bay ONLY, please rate the following statements regarding aquatic plants over the past year:

		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Opinion
a.	Aquatic plant growth is excessive and a nuisance.	1	2	3	4	5	6
b.	Aquatic plant growth is at sufficient level to provide fish/wildlife habitat	1	2	3	4	5	6
c.	Current management of aquatic plants is adequate	1	2	3	4	5	6

8. For Big Muskego Lake ONLY (Not Including Bass Bay), please rate the following statements:

		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Opinion
a.	Aquatic plant growth (including cattails) is excessive and a nuisance.	1	2	3	4	5	6
b.	Aquatic plant growth (including cattails) is at sufficient level to provide fish/wildlife habitat	1	2	3	4	5	6
c.	Current management of aquatic plants is adequate	1	2	3	4	5	6

9. How do you rate the effectiveness of the Rehabilitation/Drawdown Project of 1995-1997 for the following?

	Very Effective		Neutral		Not Effective	No Opinion
a. Wildlife	1	2	3	4	5	6
b. Fish	1	2	3	4	5	6
c. Human Use	1	2	3	4	5	6
d. Other _______________	1	2	3	4	5	6

10. Rank **three (3)** lake-related management activities in order of importance to you.

____ Fish/Wildlife Management
____ Stormwater Management
____ Natural Vegetation Management
____ Open Space Preservation
____ Boating Law Enforcement
____ Nuisance Aquatic Plant/Algae Management
____ No Action Required
____ Other _____________________

11. Overall, what is your opinion of the current condition of BASS BAY?
a. Poor b. Fair c. Good d. Excellent e. No Opinion

12. Overall, what is your opinion of the current condition of BIG MUSKEGO LAKE?
a. Poor b. Fair c. Good d. Excellent e. No Opinion

13. What improvements would you like to see on Big Muskego Lake/Bass Bay?

____
____

____
____

14. Are there any other concerns or issues regarding Big Muskego Lake/Bass Bay you feel should be addressed?

____
____

____
____

THANK YOU!

Report to the City of Muskego

Big Muskego Lake/Bass Bay – Lake District Survey

December 2002

In late summer 2002, a survey was sent out to 362 families in the Big Muskego Lake/Bass Bay Lake District. 177 surveys were returned. The following report is a summary and analysis of the responses to the survey. One initial comment regarding the responses is the interest and cooperation was noteworthy: the respondents were knowledgeable in their comments and made extensive written notes that should be reviewed individually.

In reviewing the report on the Lake District Survey, several issues need to be addressed. First, the Lake District is a large expanse of land (occupying over two square miles and several waterways). As a result, the questions are reviewed in reference to the relationship between the respondent and the question. For example, while questions regarding the quality of Bass Bay are asked to all respondents, the answers provided by the residents of Bass Bay are of note. In effect, they are the on-site citizen reporters of the Bay.

Part One

This portion of the report is designed to develop a picture of the Lake District respondent. The residents of the district differ in age, tenure, and location. In order to serve this need, a number of demographic questions were presented.

Question #1

Where do you live?

56 (32.2%)	Big Muskego Lake
50 (28.7%)	Bass Bay
68 (39.1%)	Off-Lake Resident of Lake District

Question #2

How long have been a Big Muskego Lake/Bass Bay District resident?

29 (16.5%)	0-3 years
53 (30.1%)	4-10 years
94 (53.4%)	over 10 years

Question #3

What is your age?

18 (10.4%)	18-34 years old
75 (43.4%)	35-49
52 (30.1%)	50-64
28 (16.2%)	over 64

Part Two

This section reviews the needs of the participants. According to Hedonic theory, the monetary value of housing is based on the amenities offered to the homeowner. As a result, it is important for the community to recognize those attributes valued by lake residents. If possible, the Lake District may attempt to maximize these amenities to the benefits of the residents. In addition, the differing locations within the community may elicit different responses. The lake residents are asked, first, their location. These are then tabulated in relation to location and lake-specific responses. Following this, a chi-square test is conducted to ascertain any significant difference in response between locations. In order to assess the needs of the participants, these questions attempted to find the lake-related activities that interested the residents.

Question #4

The Primary reasons you use Big Muskego Lake/Bass Bay

1—Fishing (96 votes—63 surveys cited this as their primary reason)
2—Enjoying the View (83 votes—47 surveys cited this as their primary reason)
3—Observing Wildlife (82 votes—40 surveys cited this as their primary reason)
4—Motorized Boating (45 votes—25 surveys cited this as their primary reason)
4—Hunting (45 votes—31 surveys cited this as their primary reason)
6—Entertaining Friends/Relatives (39 votes—14 surveys cited this as their primary reason)

Note, when cross tabulation was calculated between respondent location (for example Where do I live—Bass Bay) and primary reasons. This study employs a chi-square significance test to determine significant differences in responses. However, due to a lack of response on certain questions, only the top six primary reasons are reviewed.

The basic format is such: Holding all other issues constant, are residents of Big Muskego Lake more or less likely to rank "Fishing" as one of their top three activities than residents of Bass Bay or Off-Lake residents of the Lake District?

a. Considering the issue of Fishing, respondents from Big Muskego and the "Off-Lake" residents are significantly more likely to have placed Fishing as one of their top three activities.

   21 of 50 respondents from Bass Bay listed Fishing
   36 of 56 respondents from Big Muskego Lake listed Fishing
   38 of 68 respondents from "Off-Lake" listed Fishing

   Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

   Chi-Square = 5.367 (thus reject the null hypothesis that there is no difference in ranking priorities between location of respondent)

In order to clarify the chi-square test, this question will serve as a basis for explanation. Consider this situation. While only 42% (21 out of 50) of the Bass Bay respondents selected Fishing, 64% (36 of 56) of the Big Muskego Lake respondents selected fishing. This difference between the two groups is significant at the 5% level.

b. Considering the issue of "Enjoying the View", there is no significant difference in this top three-activity answer.

28 of 50 respondents from Bass Bay listed Enjoying…
26 of 56 respondents from Big Muskego Lake listed Enjoying…
27 of 68 respondents from "Off-Lake" listed Enjoying…

Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

Chi-Square = 3.075 (thus fail to reject the null hypothesis)

c. Considering the issue of Observing Wildlife, respondents from Big Muskego Lake respondents are more likely (and respondents from Bass Bay are less likely) to have placed Observing Wildlife as one of their top three activities.

16 of 50 respondents from Bass Bay listed Observing…
37 of 56 respondents from Big Muskego Lake listed Observing…
27 of 68 respondents from "Off-Lake" listed Observing…

Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

Chi-Square = 14.113 (thus reject the null hypothesis that there is no difference in ranking priorities between location of respondent)

d. Considering the issue of Motorized Boating, respondents from Bass Bay are significantly more likely (and "Off-Lake respondents are less likely) to have placed Motorized Boating as one of their top three activities.

20 of 50 respondents from Bass Bay listed Motorized …
16 of 56 respondents from Big Muskego Lake listed Motorized …
8 of 68 respondents from "Off-Lake" listed Motorized …

Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

Chi-Square = 12.630 (thus reject the null hypothesis)

e. Considering the issue of Hunting, respondents from Big Muskego Lake are more likely and (respondents from Bass Bay are significantly less likely) to have placed Hunting as one of their top three activities.

3 of 50 respondents from Bass Bay listed Hunting
22 of 56 respondents from Big Muskego Lake listed Hunting
20 of 68 respondents from "Off-Lake" listed Hunting

Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

Chi-Square = 15.997 (thus reject the null hypothesis that there is no difference in ranking priorities between location of respondent)

f. Considering the issue of Entertaining, respondents from Bass Bay are significantly more likely (and "Off-Lake" respondents are less likely) to have placed Entertaining as one of their top three activities.

20 of 50 respondents from Bass Bay listed Entertaining
10 of 56 respondents from Big Muskego Lake listed Entertaining
9 of 68 respondents from "Off-Lake" listed Entertaining

Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

Chi-Square = 12.855 (thus fail to reject the null hypothesis)

For comparison purposes, it is worth mentioning that some activities are significantly more important to respondents from one region as opposed to another. The following list reviews the areas where respondent location resulted in significantly different utilization priorities.

Big Muskego and Off-Lake respondents were more likely to list FISHING as a priority use.
Big Muskego respondents were more likely to list OBSERVING WILDLIFE as a priority use.
Bass Bay respondents were more likely to list MOTORIZED BOATING as a priority use.
Big Muskego respondents were more likely to list HUNTING as a priority use.
Bass Bay respondents were more likely to list ENTERTAINING as a priority use.

Question #5

Note, for Likert Scale questions, a chi-square test is inappropriate. This would require the bundling of answers to create a binary response (Yes-No or Poor-Excellent). This would require that, for example, in question #6, we bundle the Poor and Fair as one answer and the Good and Excellent as another. This would create the omission of the Don't Know/No Opinion category. This attempt at creative statistics is fundamentally flawed, especially if there is a Neutral category (see questions #7 and #8). The responses should simply be reviewed according to the information provided.

How often do you engage in the following activities on Big Muskego Lake/Bass Bay?

	Never=1		Occasionally=3		Daily=5
Swimming/Snorkel (N=155)	**66.5%**	7.7%	14.8%	9.0%	1.9%
Canoe/Row/Paddl (N=154)	**49.4%**	18.8%	20.8%	10.4%	0.6%
Powerboat/Skiing (N=149)	**67.1%**	6.0%	10.1%	15.4%	1.3%
Jet Ski/PWC (N=145)	**88.3%**	2.8%	2.8%	5.5%	0.7%
Snowmobile/ATV (N=148)	**70.9%**	6.1%	6.8%	13.5%	2.7%
Pontooning (N=151)	**71.5%**	6.6%	13.9%	6.6%	1.3%
Fishing (N=161)	24.2%	10.6%	28.6%	**31.1%**	5.6%
Hunting (N=152)	**63.2%**	5.9%	13.8%	12.5%	4.6%
Scenic Viewing (N=162)	13.6%	11.7%	14.8%	16.0%	**43.8%**
Other (N=29)	**69.0%**	3.4%	6.9%	13.8%	6.9%

Question #6

How would you rate the condition of Big Muskego Lake/Bass Bay for the following activities?

Likert Scale

	Poor=1	Fair=2	Good=3	Excellent=4	DK=5
Swimming/Snorkl (N=166)	**44.6%**	16.9%	12.0%	1.2%	25.3%

Canoe/Row/Paddl (N=165)	8.5%	13.9%	**37.0%**	15.8%	24.8%
Powerboat/Skiing (N=163)	**33.1%**	17.8%	13.5%	4.9%	30.7%
Jet Ski/PWC (N=158)	29.7%	13.3%	8.2%	2.5%	**46.2%**
Snowmobile/ATV (N=162)	16.0%	19.8%	20.4%	9.9%	**34.0%**
Pontooning (N=156)	5.1%	8.3%	26.9%	15.4%	**44.2%**
Fishing (N=167)	6.0%	17.4%	**37.1%**	18.0%	21.6%
Hunting (N=162)	3.7%	11.1%	22.2%	15.4%	**47.5%**
Scenic Viewing (N=166)	3.6%	10.8%	**34.3%**	37.3%	13.9%
Other (N=147)	26.7%	10.0%	6.7%	3.3%	**43.3%**

Question #7

For Bass Bay ONLY, please rate the following statements regarding aquatic plants over the past year?

a. Aquatic plant growth is excessive and a nuisance (N=127)

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Opinion
40.9%	19.7%	9.4%	7.9%	0.8%	21.3%

b. Aquatic plant growth is at a sufficient level to provide fish/wildlife habitat (N=123)

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Opinion
5.7%	22.8%	20.3%	11.4%	8.9%	**30.9%**

c. Current management of aquatic plants is adequate (N=124)

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Opinion

4.8%	12.1%	13.7%	16.1%	**29.8%**	23.4%

Question #8

For Big Muskego Lake ONLY, please rate the following statements

a. Aquatic plant growth (including cattails) is excessive and a nuisance (N=140)

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Opinion
30.7%	**22.1%**	15.0%	5.0%	10.0%	17.1%

b. Aquatic plant growth (including cattails) is at a sufficient level to provide fish/wildlife habitat (N=133)

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Opinion
9.0%	**26.3%**	23.3%	12.8%	8.3%	20.3%

c Current management of aquatic plants is adequate (N=124)

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Opinion
3.0%	14.9%	17.2%	19.4%	**23.9%**	21.6%

Question #9

How do you rate the effectiveness of the Rehahilitation/Drawdown Project of 1995-1997 for the following?

	Very Effective 1	2	Neutral 3	4	Not Effective 5	No Opinion 6
Wildlife (N=164)	22.6%	**28.0%**	16.5%	4.9%	6.7%	21.3%

Fish (N=164)	**29.3%**	26.8%	14.0%	3.0%	6.7%	20.1%
Human Use (N=161)	10.6%	20.5%	16.8%	5.6%	**26.7%**	19.9%
Other (N=46)	8.7%	4.3%	0.0%	0.0%	10.9%	**69.6%**

Question #10

Rank three lake-related management activities in importance to you?

1— Fish/Wildlife Management (118 votes)
2— Nuisance Aquatic Plant/Algae Management (113 votes)
3— Natural Vegetation Management (77 votes)
4— Open Space Preservation (72 Votes)
5— Stormwater Management (45 votes)
6— Boating Law Enforcement (28 votes)

Employing a chi-square significance test, a specific series of questions are asked.

The basic format is such: holding all other issues constant, are residents of Big Muskego Lake more or less likely to rank “Boating Enforcement” as one of their top three management priorities than residents of Bass Bay or Off-Lake residents of the Lake District?

a. Considering the issue of Fish/Wildlife Management, there is no significant difference in listing this as a top three priority based on the respondents location.

30 of 50 respondents from Bass Bay listed Fish/Wildlife.
43 of 56 respondents from Big Muskego Lake listed Fish/Wildlife.
44 of 68 respondents from “Off-Lake” listed Fish/Wildlife.

Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

Chi-Square = 3.705 (thus we fail to reject the null hypothesis that there is no difference in ranking priorities between location of respondent)

b. Considering the issue of Nuisance Management, Lake residents (Bass Bay and Big Muskego Lake) are more significantly more likely to have listed this area as a top three lake-related management priority.

40 of 50 respondents from Bass Bay listed Nuisance Management.

38 of 56 respondents from Big Muskego Lake listed Nuisance Management.

34 of 68 respondents from "Off-Lake" listed Nuisance Management

Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

Chi-Square = 11.745 (thus we reject the null hypothesis that there is no difference in ranking priorities between location of respondent)

c. Considering the issue of Natural Vegetation Management, there is no significant difference in listing this as a top three priority based on the respondents location.

18 of 50 respondents from Bass Bay listed Vegetation.

28 of 56 respondents from Big Muskego Lake listed Vegetation .

31 of 68 respondents from "Off-Lake" listed Vegetation.

Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

Chi-Square = 2.179 (thus we fail to reject the null hypothesis that there is no difference in ranking priorities between location of respondent)

d. Considering the issue of Open Space Preservation, there is no significant difference in listing this as a top three priority based on the respondents location.

17 of 50 respondents from Bass Bay listed Open Space.

25 of 56 respondents from Big Muskego Lake listed Open Space.

29 of 68 respondents from "Off-Lake" listed Open Space.

Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

Chi-Square = 1.396 (thus we fail to reject the null hypothesis that there is no difference in ranking priorities between location of respondent)

e. Considering the issue of Stormwater Management, Bass Bay Respondents are more significantly more likely to have listed this area as a top three lake-related management priority.

22 of 50 respondents from Bass Bay listed Stormwater Management.

14 of 56 respondents from Big Muskego Lake listed Stormwater Management.

8 of 68 respondents from "Off-Lake" listed Stormwater Management.

Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

Chi-Square = 15.851 (thus we fail to reject the null hypothesis that there is no difference in ranking priorities between location of respondent)

f. Considering the issue of Boating Law Enforcement, there is no significant difference in listing this as a top three priority based on the respondents location.

8 of 50 respondents from Bass Bay listed Boating Law Enforcement.

8 of 56 respondents from Big Muskego Lake listed Boating Law Enforcement .

10 of 68 respondents from "Off-Lake" listed Boating Law Enforcement

Using df = 1, a chi-square result of greater that 3.841 is required to reject the null hypothesis that all lake residents have equivalent priorities.

Chi-Square = 0.066 (thus we fail to reject the null hypothesis that there is no difference in ranking priorities between location of respondent)

To review the results of the comparison, there were several areas where respondent location resulted in significantly different management priorities.

Big Muskego and Bass Bay respondents were more likely to list NUISANCE MANAGEMENT as a priority management issue.

Bass Bay respondents were more likely to list STORMWATER MANAGEMENT as a priority management issue.

Question #11

Overall, what is your opinion of the current condition of Bass Bay? (N=158)

Poor	Fair	Good	Excellent	No Opinion
1	2	3	4	5
9.5%	29.7%	**32.9%**	4.4%	23.4%

Question #12

Overall, what is your opinion of the current condition of Big Muskego Lake? (N=162)

Poor	Fair	Good	Excellent	No Opinion
1	2	3	4	5
19.8%	**34.0%**	27.8%	4.9%	13.6%

Part Three

This section supplements the chi-square analysis. In the first analysis, the respondents were separated according to location. These responses were then reviewed according to the three primary uses of the lake in question #4. Differences between the location of the respondent and their uses were analyzed for significant differences.

a. Tenure Analysis

This section repeats the process by looking at the uses by tenure in the lake district (Question #2 and #4). As a result, a chi-square test will be used to test the relationship between (for example) fishing and the tenure of the respondent Once this process is repeated according to tenure and Question #10 (important management activities), it is found that in no area is there a significant difference in use between tenure. This is a logical consideration since persons residing on a lake will consistently use it for similar purposes if we assume a homogeneous population.

Once again, the process is repeated by looking at question #2 (tenure) and Question #10 (Management activity priority). In the singular area of Boating Law Enforcement there is a significant difference between the tenure of the respondent and their priority. Persons living on the lake fewer than four (4) years list this as a significantly lower priority than other residents. This may be a reflection of a knowledge or frustration.

b. Age Analysis

This section repeats the process by looking at the uses by age of the respondent and their utilization priorities (Question #3 and #4). Due to the sample size, the categories were compressed for the chi-square analysis (from four categories to two) This resulted in an under 50 category and a 50 plus category. This process is then repeated according to age and Question #10 (important management activities). In reference to age and utilization, it is found that in no area is there a significant difference between age groups. This is a logical consideration since persons residing on a lake will consistently use it for similar purposes if we assume a homogeneous population.

Once again, the process is repeated by looking at question #3 (age) and Question #10 (management activity priority). In the singular area of Natural Vegetation Management there is a significant difference between the tenure of the respondent and their priority. Persons living in the lake district 50 years and older list this as a significantly higher priority than other residents.

Appendix D

SETTLING BASIN DESIGN

FOR FUTURE DRAWDOWN OF

BIG MUSKEGO LAKE

July 28, 2003

City of Muskego
W182 S8200 Racine Avenue
Muskego, WI 53150

Attn: Mr. Tom Zagar
Conservation Coordinator

Re: Big Muskego Lake – Lake Management Plan
City of Muskego
Project No. 03215

Dear Mr. Zagar:

We have completed our evaluation of the potential configuration, outlet arrangement and anticipated sediment removal rates with the future installation of a proposed settling basin for use during draw down operations for Big Muskego Lake. It is our understanding past draw down events have resulted in large increases of sediment loadings down stream of the dam. In an effort to reduce future sediment loading during these events, the City of Muskego retained Crispell-Snyder, Inc. to provide recommendations for a proposed settling basin to treat the pumped lake water prior to entering the channel down stream of the Big Muskego Lake dam. The recommendations provided herein will be included in the Lake Management Plan for Big Muskego Lake, currently being prepared by the City.

Existing Site

The Big Muskego Lake Dam is located in the southeast one quarter of the northeast one quarter of Section 33, Town 5 North, Range 20 East, as shown on Figure 1. The proposed location for the proposed settling basin is located west of the Muskego Canal and north of Muskego Dam Road. The site is typified by a wooded berm to the east along the bank of the canal, a wetland located in the center of the site, an existing farm complex located to the west and a gravel access road to the north.

Soils within the site are composed of Montgomery silty clay loams, Houghton muck and Wallkill silt loams. These soils are typified by slow to moderately rapid permeability rates and high groundwater tables.

As depicted on Figure 1, the entire site lies within a mapped floodplain. The approximate floodplain elevation for the 100 year recurrence interval storm event is 774'.

Alternative Basin Configuration

The draw down process followed by City staff has two primary stages. First, the lake level is lowered through manipulation of the gates on the lake dam. Once the lake level drops below the dam gates, the remaining lake water is pumped over the dam using two, 26.8 cubic feet per second pumps (approximately 12,030 gallons per minute per pump). Depending on the water level within the lake one or both pumps may be operating. It is toward the end of this process where the majority of the sediment has been discharged to the canal. Consequently, the proposed settling basin was designed based on either one or both pumps operating.

Design of the temporary settling basin was based on Type 1, or discrete, sedimentation. Type 1 sedimentation assumes that suspended solids within the water column settle unhindered and do not interact with one another. Consequently, settling is solely a function of the fluids properties and the individual particle characteristics. Based on Type 1 sedimentation, the smallest size particle to be removed by the settling basin is dependent on the flow rate of the influent and the surface area of the basin. Thus, knowing the flow rate of the influent and the discrete settling velocity of a range of particle sizes, two alternative basin configurations were designed that would provide for the estimated particulate removal rates.

Figure 2 shows the first alternative configuration for the temporary settling basin. This facility would have an operating surface area of approximately 1.5 acres and a total volume of approximately 5.5 acre-feet. The basin is composed of four distinct zones; the inlet zone, the settling zone, the sediment storage zone and the outlet zone. The inlet zone is located on the northwest side of the basin where the pump discharge will enter into the facility and is approximately 50 feet in length. No particulate settling will occur in either the inlet or outlet zones. The settling zone provided under this configuration is approximately 580 feet in length and 0.5 feet in depth. The sediment storage zone exists below the settling zone. This zone provides for the accumulation and storage of sediments between cleanings. The sediment storage zone is approximately 2.6 feet in depth and has an estimated storage volume of 3.3 acre-feet. The outlet zone is located in the northeast portion of the facility and is approximately 50 feet in length. Figure 2 depicts three 36” diameter stand pipe outlet structures under this configuration. This arrangement is based on a flow rate through the facility equal to 26.8 cfs or one pump running. For a flow rate of 53.6 cfs, the outlet structure arrangement would consist of four 48” diameter stand pipe outlet structures.

By providing a horizontal velocity of 2.5 fps through the proposed facility, the smallest particle removed is approximately 20 microns in diameter. Based on research conducted by R. Pitt, Table 1, it can be estimated that approximately 62 percent of the suspended solids discharged to this facility will be removed.

Initial goals during the preliminary design process were to provide for approximately an 80 to 90 percent removal rate. This was determined to be impractical as the surface area required to settle a 5 micron particle, at a flow rate of 26.8 cfs, was approximately 4.7 acres or roughly three times larger than Alternative 1.

Alternative 2 is shown in Figure 3 and encompasses many of the same design aspects as Alternative 1. The operating surface area provided is approximately 1.3 acres and a total storage volume of 4.7 acre-feet. Under this configuration, lake water will be pumped into the northeastern portion of the facility and travel approximately 665 feet through the settling zone prior to reaching the outlet zone in the southern portion of the facility. The settling zone is provided has a depth of 0.5 feet while the sediment storage zone has a depth of approximately

2.6 feet and a storage volume of 2.8 acre-feet. Similar to Alternative 1, the outlet zone will be composed of either three 36" diameter stand pipes or four 48" diameter stand pipes depending on the required flow rate through the facility.

Based on a horizontal velocity of 2.5 fps through the proposed facility, the smallest particle removed is approximately 20 microns. Again, as in Alternative 1, this relates to an estimated removal of 62 percent of the suspended solids delivered to the proposed basin.

Evaluation of Alternatives

Each of the alternatives presented provide the same level of service in terms of the percentage of suspended sediment captured and quality of effluent discharged to the Muskego Canal. Additionally, each alternative impacts the gravel maintenance road along with northern portion of the site. Consequently, relocation of this road will be required for each alternative.

The most significant difference between the two alternatives is the anticipated impacts to the existing wetland located in the middle of the site.

Alternative 1 is sited such that the northern one third to one half of the existing wetland would be sacrificed for the construction of the settling basin. The Wisconsin Department of Natural Resources may not allow the construction of this facility without mitigation of the lost wetland. Conversely, Alternative 2 was designed to avoid the wetland while maintaining the same level of service as Alternative 1. However, Chapter 30 permits will still be required under this alternative for grading in excess of 10,000 square feet and for the construction of an ultimately connected pond.

Additionally, the WDNR will need to review either configuration for impacts upon the mapped floodplain. The placement of fill material within the limits of the mapped floodplain is regulated under Chapter NR116 of the Wisconsin Administrative Code and local zoning ordinances. Prior to the construction of either settling basin configuration, a floodplain analysis will need to be prepared to evaluate any potential impacts upon the mapped floodplain.

It is possible that Alternative 2 could result in a potential increase in the flood stages due to the extension of the berm along the southwest portion of the Muskego Canal. However, given the flood stage is approximately 2.1 feet above the berm, the potential increase may be minimal.

Alternative 1 is not anticipated to affect the 100 year recurrence interval flood stages due to its location west of the existing berm and a berm height below that of the 100 year flood plain.

The estimated capital cost to construct Alternative 1 is approximately $118,500 and is shown in Table 2. While the sedimentation basin is actively in use, the annual operation and maintenance costs are anticipated to be approximately 25% of the capitol costs or $29,625 per year (based on SEWRPC Technical Report 31, "Costs of Non-point Source Water Pollution Control Measures".) If the facility is to be drained and remain in place in between draw down events, the annual operation and maintenance costs are anticipated to be approximately 6% of the capital costs or $7,110 per year.

Operation and maintenance of the basin while in use will consist of inspections and repairs to the berm, outlet structures, riprap; removal and disposal of the sediments contained in the sediment storage zone; draining the facility once lake draw down operations have been completed; and reseeding the bed and side slopes. Operation and maintenance during periods when the facility is dormant will include semi-annual mowing, reseeding as necessary, inspection of the outlet control devices and berm, and performing any repairs necessary.

The estimated capital cost to construct Alternative 2 is approximately $126,400 and is shown in Table 3. Like Alternative 1, Alternative 2 is planned to be actively used infrequently while remaining dormant the majority of the time. During draw down operations, the annual operation and maintenance costs are anticipated to be approximately 25% of the capital costs or $31,600. During those periods when the facility will remain dormant, the annual operation and maintenance costs are anticipated to be approximately 6% of the capital costs or $7,584.

Based upon the aforementioned costs and permitting issues, the recommended alternative would be Alternative 2. Although Alternative 2 represents a capital cost increase of approximately 7%, Alternative 2 will be more acceptable to the Wisconsin Department of Natural Resources as disturbance of the existing wetland is minimized. Floodplain impacts of Alternative 2 are anticipated to be minimal as the top of the extended berm is approximately 2.1 feet below the 100 year recurrence interval water surface elevation.

Installation and Restoration Recommendations

Construction of the proposed settling basin should begin with the installation of erosion control practices in order to prevent the migration of suspended solids into the canal or the existing wetland. Temporary erosion control measures appropriate to the initial phases of construction would be silt fence placed downstream of all disturbed slopes and tracking pads installed at points of ingress and egress to the site. Upon completion of grading operations and the installation of the outlet structures, the basin side slopes and bermed areas should be restored with seed and erosion mat. Influent discharge lines into the facility and the outlet structure outfalls should be directed to a riprap apron to dissipate energy and prevent scouring.

Upon completion of draw down operations, the stored sediments will need to be removed and the facility drained. Water tolerant, fast germinating grasses should be planted on the basin bottom and side slopes. Once the area has been restored, the temporary erosion control measures can be removed.

Should you have any questions or comments regarding this matter, do not hesitate to contact me at our Lake Geneva office.

Sincerely,

CRISPELL-SNYDER, INC.

Richard J. Wirtz, P.E.
Senior Project Engineer

RJW/ld

cc: Sean McMillen, City of Muskego
Todd Weik, Crispell-Snyder, Inc.
Dan Snyder, Crispell-Snyder, Inc.

TABLE 1
Corrections For Needed Surface Areas For Particle Size Controls Other Than 5 Microns

Particle Size (microns)	Typical Percentage of Particles Larger than Particle	Particle Settling Rate (cm/sec)	Required Area Multiplier Compared to 5 micron
1	100	1.5×10^{-4}	27
2	94	6×10^{-4}	6.7
5	88	4×10^{-3}	1.0
10	78	1.5×10^{-2}	0.27
20	62	6×10^{-2}	0.067
40	47	2×10^{-1}	0.02
100	28	8×10^{-1}	0.005

Wet Detention Ponds, R.Pitt., November 2, 1993.

TABLE 2
Alternative 1 – Estimated Capitol Costs

Item	Units	Quantity	Cost Per Unit	Total
Excavation	CY	4,700	$ 12.00	$ 56,400
Riprap	CY	90	$ 50.00	$ 4,500
Filter Fabric	SY	280	$ 3.00	$ 840
Erosion Mat	SY	1,490	$ 5.00	$ 7,450
36” CMP Standpipe	EA	3	$ 300.00	$ 900
24” CMP Discharge Pipe	LF	180	$ 50.00	$ 9,000
Clearing and Grubbing	SY	1,370	$ 2.00	$ 2,740
Restoration	SY	2,950	$ 4.00	$ 11,800
Silt Fence	LF	250	$ 2.00	$ 500
Tracking Pad	EA	1	$1,650.00	$ 1,650
Gravel Road Reconstruction	TON	270	$ 11.00	$ 2,970
			Subtotal	$ 98,750
			20% Contingencies	$ 19,750
			Total Estimated Cost	$118,500

*Estimated cost increase for four 48” CMP standpipes and four 24” CMP discharge pipes is approximately $4,920.

TABLE 3 **Alternative 2 – Estimated Capital Costs**				
Item	Units	Quantity	Cost Per Unit	Total
Excavation	CY	4,430	$ 12.00	$ 53,160
Riprap	CY	90	$ 50.00	$ 4,500
Filter Fabric	CY	280	$ 3.00	$ 840
Erosion Mat	SY	4,250	$ 5.00	$ 21,250
36" CMP Standpipe	EA	3	$ 300.00	$ 900
24" CMP Discharge Pipe	LF	120	$ 50.00	$ 6,000
Clearing and Grubbing	SY	1,150	$ 2.00	$ 2,300
Restoration	SY	2,450	$ 4.00	$ 9,800
Silt Fence	LF	980	$ 2.00	$ 1,960
Tracking Pad	EA	1	$1,650.00	$ 1,650
Gravel Road Reconstruction	TON	270	$ 11.00	$ 2,970
		Subtotal		$105,330
		20% Contingencies		$ 21,066
		Total Estimated Cost		$126,396

*Estimated cost increase for four 48" CMP standpipes and four 24" CMP discharge pipes is approximately $3,720.

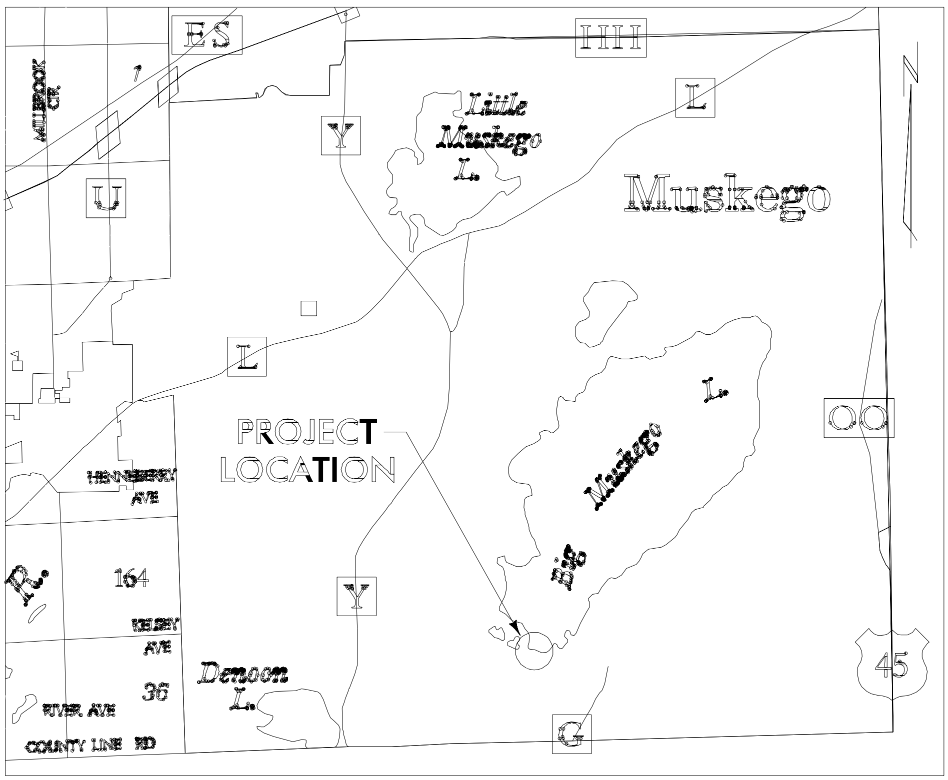
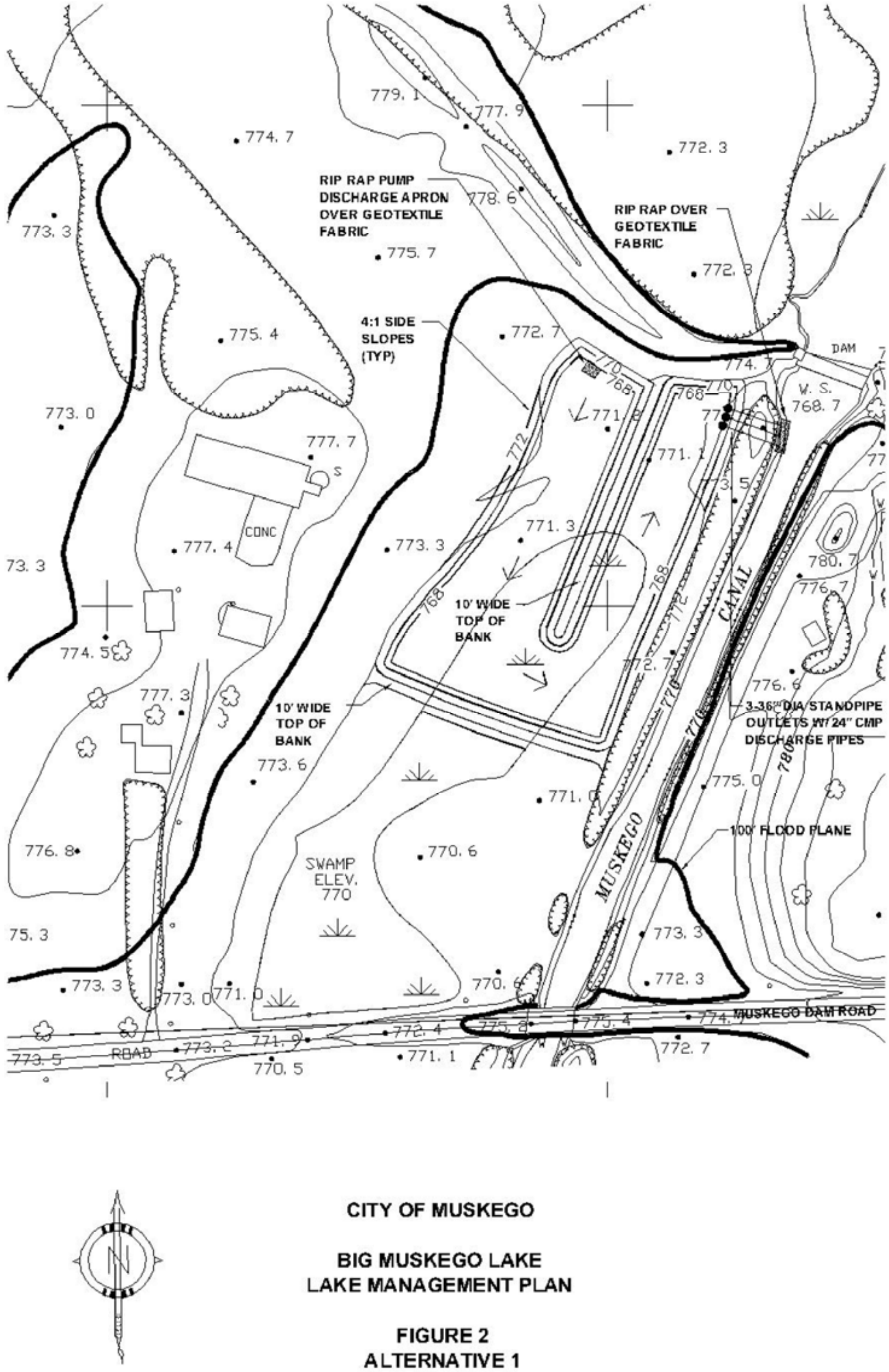


FIGURE 1

LOCATION MAP

BIG MUSKEGO LAKE – LAKE MANAGEMENT PLAN	03215

CRISPELL-SNYDER, INC.
CONSULTING ENGINEERS

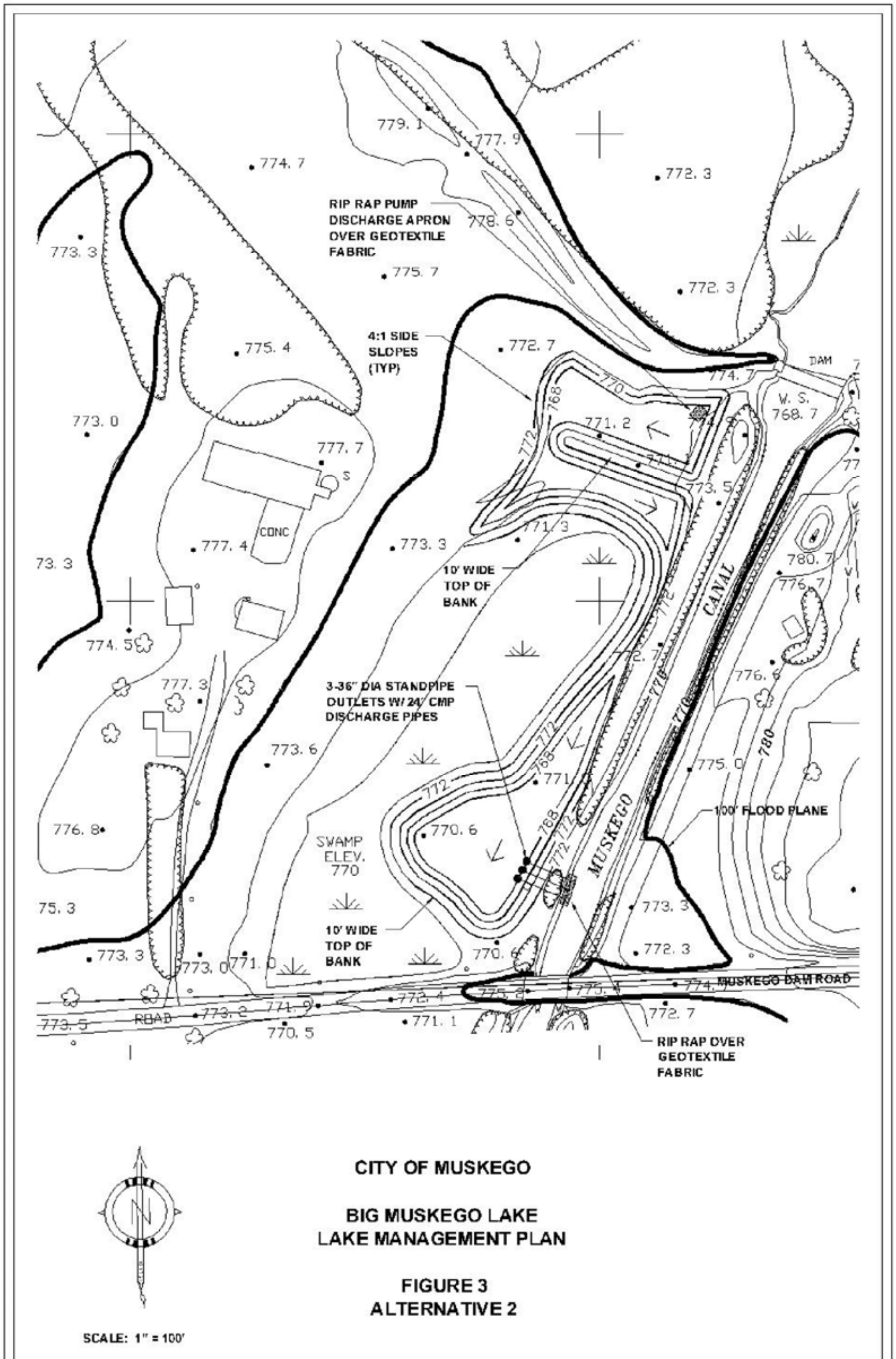


CITY OF MUSKEGO

BIG MUSKEGO LAKE
LAKE MANAGEMENT PLAN

FIGURE 2
ALTERNATIVE 1

SCALE: 1" = 100'



CITY OF MUSKEGO

BIG MUSKEGO LAKE
LAKE MANAGEMENT PLAN

FIGURE 3
ALTERNATIVE 2

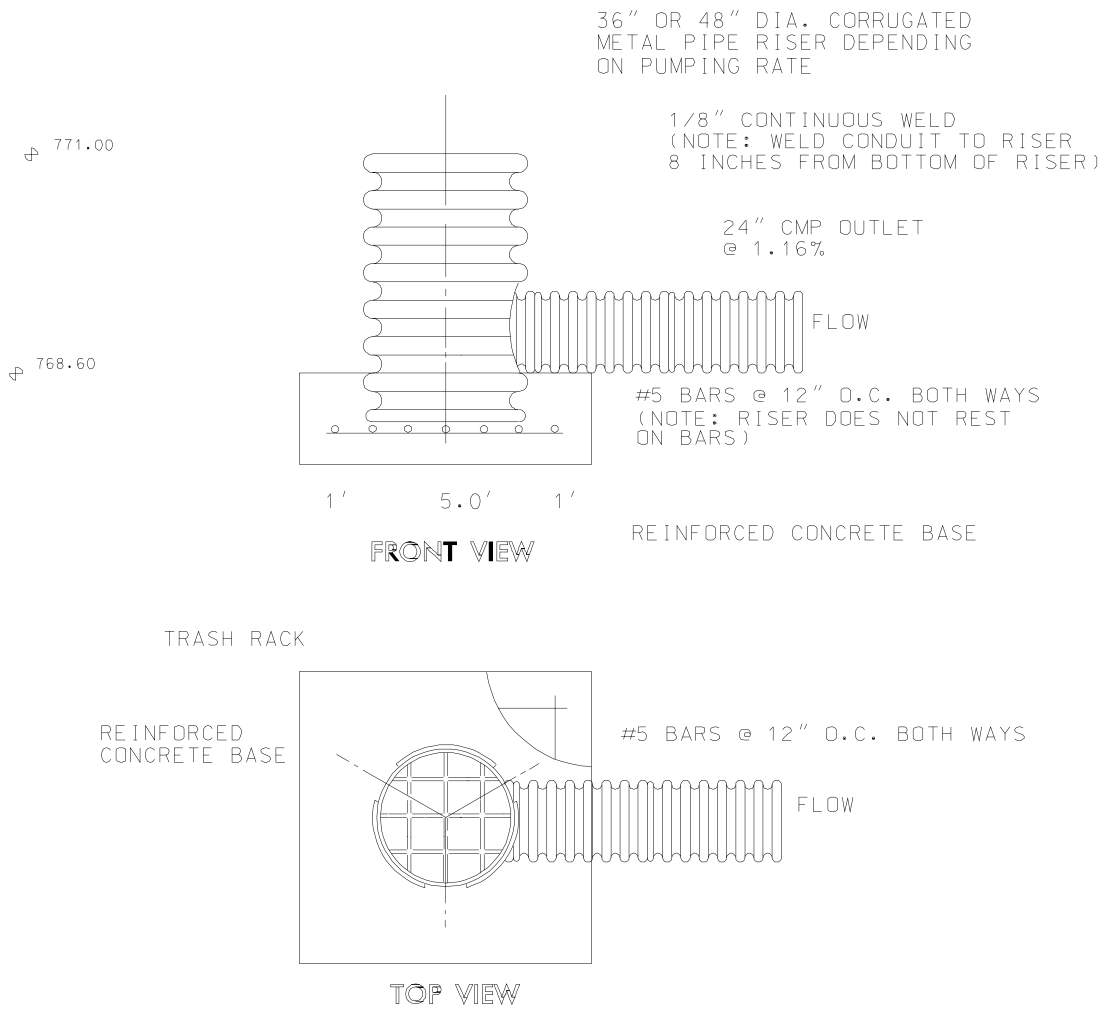


FIGURE 4

STAND PIPE OUTLET DETAIL

(NOT TO SCALE)

REVISION/PLOT DATE

BIG MUSKEGO LAKE – LAKE MANAGEMENT PLAN	03215
CRISPELL-SNYDER, INC. CONSULTING ENGINEERS Lake Geneva, WI (262)348-5600 Racine, WI (262)554-8530 Germantown, WI (262)250-8000	LOCATION: CITY OF MUSKEGO WAUKESHA COUNTY SCALE: NONE DATE: JULY, 2003 DRAWN BY: B. FOLLENSBEE